[1979]

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1979 - The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats. Rocky Mountain Forest and Range Experiment Station General Technical Report. RM-65.

Potential Use of Hydroelectric Facilities for Manipulating the Fertility of Lake Mead[1]

Larry J. Paulson[2]

John R. Baker[3]

James E. Deacon[4]

Abstract.--Analysis of historical nutrient data for Lake Mead indicates that the fertility of the reservoir has decreased which may be the cause for a corresponding decline in the largemouth bass population. However, it appears that fertility can be manipulated by altering the operation of the dam. The depletion of nutrients in the euphotic zone by phytoplankton and subsequent accumulation in the hypolimnion during summer and fall provide a natural nutrient gradient from which water of varying fertility can be drawn for discharge. This combined with alterations in the depth or seasonal pattern of discharge can possibly be used to enhance fertility and bass production in Lake Mead.

INTRODUCTION

Reservoirs are usually highly productive aquatic systems during initial impoundment since nutrients derived from the basin provide adequate fertility for phytoplankton growth (Neel 1967). However, in deep-discharge reservoirs, nutrients that accumulate in the hypolimnion during thermal stratification are removed via the discharge. This progressive loss of nutrients tends to reduce the fertility of the reservoir and may explain why the productivity of deep reservoirs often decreases with time (Wright, 1967).

Analysis of historical nutrient data for Lake Mead, Arizona-Nevada indicates that the fertility of this large reservoir has decreased since 1956. Over this same period, the largemouth bass (Micropterus salmoides) population has undergone a significant decline (Espinosa, Deacon and Simmons 1970, Allan and Romero 1975), possibly due to this decrease in fertility. In this paper, we evaluate the relationship between fertility of Lake Mead and the operation of Hoover Dam, and suggest some mechanisms whereby the fertility could possibly be manipulated to enhance productivity in the reservoir.

DESCRIPTION OF LAKE MEAD

Due to limitations imposed on length of papers for this symposium, the reader is referred to Hoffman and Jonez (1973) for a detailed description of Lake Mead. However, pertinent morphometric characteristics of the reservoir are given in Table 1.

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[1]Paper presented at The Mitigation Symposium, Colorado State University, Fort Collins, Colorado, July 16-20, 1979.

[2]Director, Lake Mead Limnological Research Center, University of Nevada, Las Vegas.

[3]Research Associate, Department of Biological Sciences, University of Nevada, Las Vegas.

[4]Chairman, Department of Biological Sciences, University of Nevada, Las Vegas.

Table 1.--Morphometric characteristics of Lake Mead (derived from Lara and Sanders (1970), Hoffman and Jonez (1973))

Parameter	Lake Mead
Maximum operating level (m)	374.0
Maximum depth (m)	180.0
Mean depth (m)	55.0
Surface area (km^2)	660.0
Volume ($m^3 \times 10^9$)	36.0
Maximum length (km)	183.0
Maximum width (km)	28.0
Shoreline development	9.7
Discharge depth (m)	83.0
Annual discharge (1977) ($m^3 \times 10^9$)	9.3
Storage ratio at maximum operating level (years)	3.9

DATA SOURCES

Nitrate data collected at the Hoover Dam intake towers were obtained from the U.S. Geological Survey "Quality of Surface Waters in the U.S.," Water Supply Papers 1946-1963 and from "Water Resources Data for Arizona" or "Water Resources Data for Nevada," Water Quality Records 1964-1976 prepared jointly by the U.S. Geological Survey and state agencies. Recent nitrate and phosphate data were also obtained from the Lake Mead Monitoring Program.[5]

HISTORICAL CHANGES IN FERTILITY OF LAKE MEAD

The average nitrate concentration in the epilimnion and hypolimnion during thermal stratification (May to October) was computed from monthly measurements made at the Hoover Dam intake towers. Nitrate concentration in the epilimnion ranged from 200 - 350 $\mu g \cdot l^{-1}$ during 1946-1952 but increased to 600 $\mu g \cdot l^{-1}$ in the mid-1950's. (Fig. 1). Nitrate then decreased sharply in 1957 but increased again around 1960. After Lake Powell was formed in 1963, nitrate concentration in the epilimnion increased slightly but decreased again after 1969. The increase in nitrate concentration in the mid-1950's and early 1960's was caused by increased runoff and high nitrate loading from the Colorado River (Paulson and Baker 1979). Nitrate loading also increased during 1965-1969, but this was caused by loss from Lake Powell rather than flooding from the Colorado River (Paulson and Baker 1979). Subsequent to each increase in loading from the Colorado River, the nitrate concentration in Lake Mead had decreased within a few years. We are currently investigating the cause(s) for the decline in nitrate, but available data indicate that it is most related to the hypolimnion discharge at Hoover Dam.

[5] J.E. Deacon unpublished data.

The average nitrate concentration in the hypolimnion during thermal stratification always exceeds that in the epilimnion (Fig. 1).

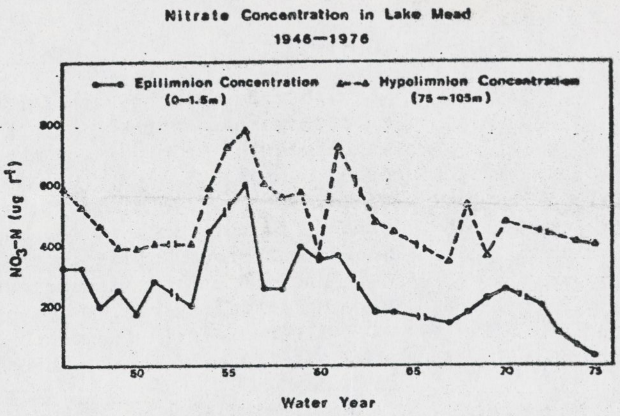

Figure 1.--Average nitrate concentration in the epilimnion and hypolimnion at the Hoover Dam intake towers during thermal stratification (May-October) 1946-1975. (USGS data).

This reflects the degree of nitrate accumulation that occurs either due to hypolimnion loading from the Colorado River or decomposition of morbid phytoplankton cells settling from the epilimnion. Periodic increases in hypolimnetic nitrate concentration (e.g. 1962, 1967) are apparently caused by hypolimnion loading. However, displacement of nitrogen from the epilimnion to the hypolimnion via sinking phytoplankton cells seems to be the principal mechanism of nitrate accumulation in the hypolimnion.

The concentrations of nitrate and phosphate in Boulder Basin of Lake Mead are essentially uniform with depth during the winter (Fig. 2). Epilimnetic nitrate, and to a lesser degree, phosphate, become depleted during the spring and early summer following periods of high phytoplankton productivity. By summer, nitrate has been reduced to less than 20 $\mu g \cdot l^{-1}$ in the euphotic zone with a corresponding accumulation of nitrate in the hypolimnion. Phosphate also accumulates somewhat but not to the degree observed for nitrate. As the lake mixes in the fall, the concentration of nitrate and phosphate becomes uniform and remains so through winter.

The uptake of nutrients by phytoplankton in the euphotic zone and subsequent release and accumulation in the hypolimnion during the summer provide vertical and seasonal nutrient gradients from which water of varying fertility can be drawn for discharge. This combined with alterations in the depth or seasonal pattern of discharge represent potential mechanisms for manipulating the fertility of Lake Mead.

MECHANISMS FOR MANIPULATING FERTILITY

We have developed a simple model to illustrate how moving the discharge depth could influence the nutrient status of a reservoir (Paulson and Baker 1979). If water is discharged from the nutrient-poor epilimnion in the summer, the reservoir will accumulate nutrients, much like occurs in natural lakes. However, if water is discharged from the nutrient-rich hypolimnion, the reservoir will progressively lose nutrients. In a few years, this can have a significant impact on the fertility of the reservoir. The trends predicted by our model have been observed in experiments conducted on Kortowskie Lake, Poland under different discharge regimes (Mientki and Mlynska 1977). Annual nitrogen and phosphorus retention was 28% and -10%, respectively, for hypolimnion discharge but increased to 37% and 57%, respectively, for epilimnion discharge. Similarly, Martin and Arneson's (1978) limnological comparison of a surface-discharge lake and deep-discharge reservoir on the Madison River indicates that discharge depth can influence the nutrient status and productivity of these systems.

Alterations in the seasonal pattern of discharge from hydroelectric facilities can also influence the nutrient status of a reservoir, if seasonal nutrient gradients develop near the depth of discharge. In Lake Mead, nitrate concentration in the hypolimnion reaches a maximum in the late summer and fall. We have compared nitrate output from Hoover Dam from one year of relatively high seasonal discharge against a year of relatively low

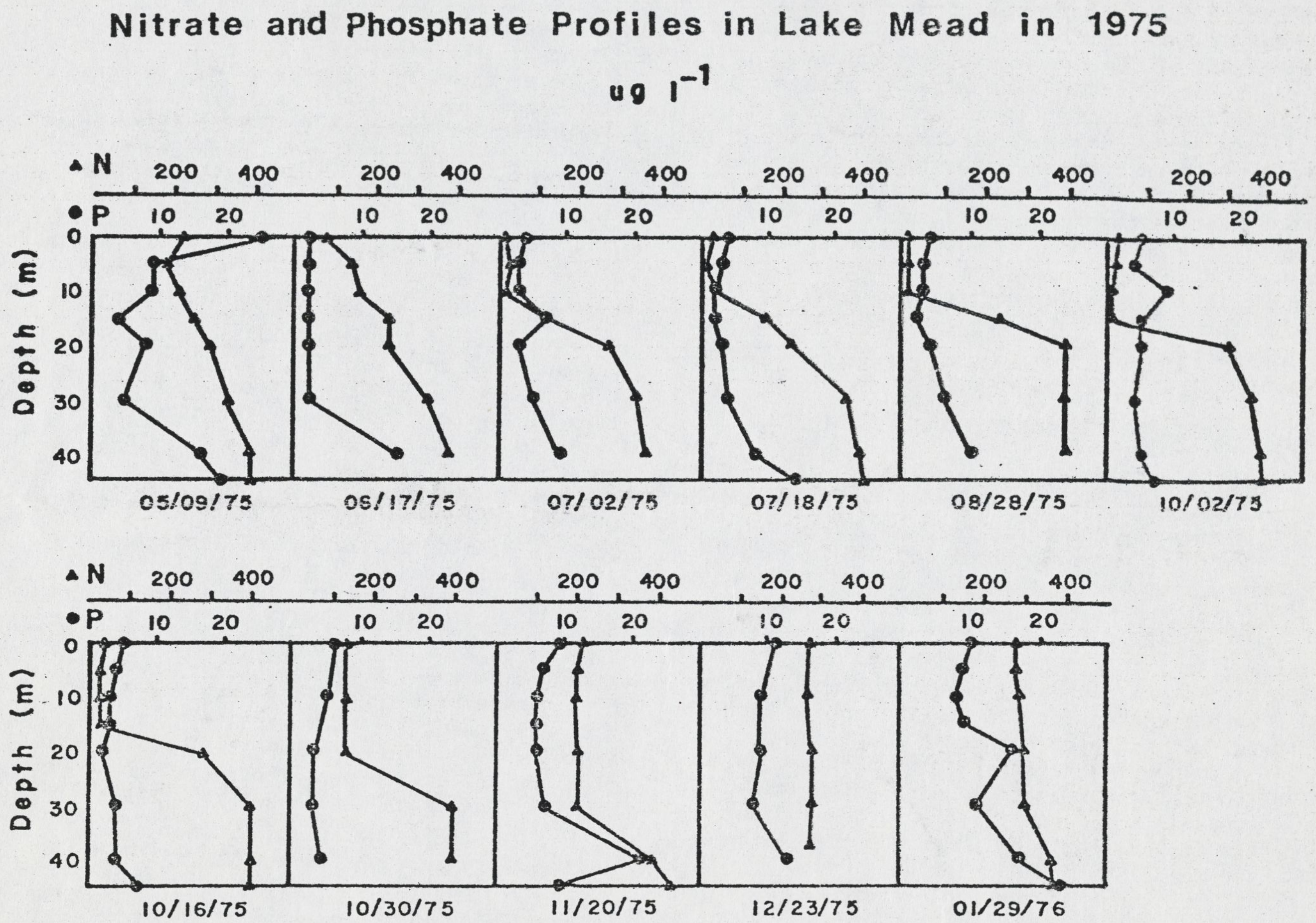

Figure 2.--Nutrient profiles in Boulder Basin, Lake Mead from May, 1975 to January, 1976 (Lake Mead Monitoring Program).

discharge during the late summer and fall (Paulson and Baker 1979). Annual nitrate loss was 15.0% higher during the year when discharge was high. Thus, it appears that the fertility of Lake Mead can be manipulated by altering the discharge regime at hydroelectric facilities. However, there are other factors that must be investigated before this can be used for management purposes.

Alterations in the discharge depth can influence other physical and chemical factors. Reservoirs with epilimnion discharge tend to dissipate heat, whereas those with hypolimnion discharge store heat (Wright 1967, Martin and Arneson 1978). Oxygen concentration in the epilimnion does not vary appreciably with discharge depth, but oxygen in the hypolimnion is typically lower with epilimnion discharge (Stroud and Martin 1973). Altering the discharge depth can also have an immediate impact on limnological conditions of the river and reservoirs downstream. Enrichment of downstream reservoirs is fairly common with hypolimnion discharge (Neel 1967). The upper reaches of Lake Mohave, located immediately downstream from Hoover Dam, are extremely productive due to enrichment from the hypolimnion of Lake Mead. Depending on the prescribed use of the downstream environments, it might not be possible to alter discharge regimes for purposes of nutrient manipulation of a reservoir. However, alterations in the discharge of an upstream reservoir might prove as effective for managing the downstream environment as the reservoir itself. We have identified several such possibilities on the Colorado River system and are planning to further investigate the potential use of discharge for environmental management of this series of reservoirs.

SIGNIFICANCE TO THE LARGEMOUTH BASS FISHING

Angler use on Lake Mead has increased significantly in recent years (Espinosa et al. 1970). However, the total catch of largemouth bass has decreased from about 800,000 in 1963 to the current level of 125,000 (NDFG 1977). The decline in the bass population has been the subject of much local concern and investigation. Arizona and Nevada Fish and Game Departments are currently investigating several possible causes for the decline in the bass fishery, but it appears that it could be related to decreased fertility of the reservoir. Prior to the high nitrate loading in the mid-1950's, Jonez and Sumner (1954) suggested that the bass fishery could be improved by fertilizing Lake Mead. This has never been done directly, although sewage input from Las Vegas has increased phosphorus input to Boulder Basin of Lake Mead. However, the Colorado River provides most (80-90%) of the inorganic nitrogen (NO_3) to Lake Mead, and this has decreased in recent years (Paulson and Baker 1979). Without an additional nitrogen input, the phosphorus cannot be used efficiently by phytoplankton. However, it appears that more nitrogen could be retained in the reservoir by altering the depth or seasonal pattern of discharge. This might prove effective for increasing the productivity of Lake Mead. Since fish yield is closely related to plankton productivity and standing crop (McConnel 1963, Hrbacek 1969, Melack 1976), the largemouth bass population could be expected to increase if more nutrients were retained in the reservoir.

SUMMARY

The physical, chemical and biological processes that operate in reservoirs create vertical and seasonal nutrient gradients from which water of varying fertility can be drawn for discharge. This combined with alterations in the depth or seasonal pattern of discharge at the dam represent potential mechanisms for manipulating the fertility of the reservoir. By increasing the retention of limiting nutrients in the reservoir, the productivity could be expected to increase which, in turn, would sustain higher fish production. Thus, the operation of hydroelectric facilities may prove effective as a fisheries management tool in Lake Mead and other large reservoirs.

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p. 4-5

In Reply Refer To:
FWS/OES

Memorandum

To: Regional Director, Upper Colorado Region, Water and Power Resources Service, Salt Lake City, Utah

From: Director

Subject: Biological Opinion for the Upalco Unit, CUP

This biological opinion replaces the second biological opinion (dated June 1, 1979) prepared in response to your November 17, 1978, request for formal consultation on the proposed Upalco Unit of the Central Utah Project (CUP). This opinion has been prepared as prescribed in the Interagency Cooperation Regulations published in the January 4, 1978, Federal Register and the Endangered Species Act Amendments of 1978.

In a memorandum dated February 15, 1979, we requested a 2-year extension of the 90 days normally allowed for consultation. The purpose was to enable us to obtain more data so we could more precisely assess the effects of the Upalco Unit on the Endangered Colorado squawfish, humpback chub, and American peregrine falcon. In a memorandum dated April 17, 1979, the Bureau of Reclamation (Bureau) denied the two-year extension. The Bureau agreed to extend the consultation period for the peregrine falcon until after the 1979 reproductive season, but requested that the biological opinion for the fishes be completed within 45 days.

The first biological opinion (dated February 15, 1979) focused on the bald eagle and the black-footed ferret. We have received the Bureau's supplemental assessment for the peregrine dated October 4, 1979, and will issue the biological opinion shortly. This present biological opinion is limited to the listed fishes and supersedes the opinion of June 1, 1979, as amended on July 5, 1979.

The Colorado squawfish and humpback chub once were abundant throughout the Colorado River system from the Gulf of California to southwestern Wyoming. Now they are found only in limited areas. The major cause of decline is human alterations of the river environment; primarily conversion of rivers to reservoirs and the depletion of water, altered temperature, turbidity and stream flow patterns caused by Glen Canyon, Flaming Gorge and Hoover Dams as well as other impoundments and water diversions.

Project Descriptions and Impacts

The proposed Upalco Unit is a part of the Central Utah Project (CUP), which was authorized as a participating project of the Colorado River Storage Project Act of April 11, 1956, (CRSP). The cumulative impact of all CUP units was considered in developing this opinion. It should be recognized that other related proposed projects such as the White River Dam, the Cheyenne Water Supply and the Juniper-Cross Mountain project may contribute to a reduction in flow and may have a negative impact on the Endangered Colorado squawfish and the humpback chub. The effects of the CUP units are summarized below:

UPALCO UNIT, CUP

Estimated annual depletion from the Green River system would be 10,300 acre-feet. The estimated increase in salinity at Hoover Dam is 1 mg/l. Taskeech Reservoir is the main feature, receiving its water from the Lake Fork and Yellowstone Rivers. The reservoir would have a total storage of 78,400 acre-feet and cover 1,223 acres. The project will provide irrigation water for Indian and non-Indian lands as well as domestic water for the Roosevelt area.

JENSEN UNIT, CUP

The Jensen Unit is under construction and approximately 30 percent complete. The estimated annual depletion of the Green River would be 15,000 acre-feet and the estimated salt load contribution would be 1.6 mg/l at Imperial Dam.

VERNAL UNIT, CUP

The Vernal Unit was completed in 1962. Estimated annual depletion of the Green River system is 15,000 acre-feet. Estimated increased salt load is 1.3 mg/l annually to the Colorado River System at Imperial Dam.

revised sheet

UINTAH UNIT, CUP

The Bureau plans for the Uintah Unit to be operational by 1985. Estimated annual depletion of the Green River system is 28,200 acre-feet. Additional annual salt load at Imperial Dam would be 3.5 mg/1. The main features are the Whiterocks Reservoir and the Uintah Reservoir. Both reservoirs would be located on tributaries of the Duchesne River and could cause irreversible damage to the fishes of the Green River.

BONNEVILLE UNIT, CUP

The Bonneville Unit is under construction and the presently authorized features are expected to be completed by approximately 1990. The estimated annual depletion is 165,900 acre-feet. This depletion equals 3.2 to 5.9 percent of the Green River, taking into account the flow contribution of the White River, the next tributary downstream. The water for the Bonneville Unit will be taken from nine of the Duchesne tributaries. This is the largest and most complex of the authorized units of the CUP. It includes 10 new reservoirs and enlargement of two existing reservoirs. The Strawberry Aqueduct, about 37 miles long, will collect flows from Rock Creek and seven other stream tributaries to the Duchesne River. Estimated increased salt load is 14 mg/1 at Green River, Utah.

Leland Bench of the Bonneville Unit, CUP

The Leland Bench project is being considered as an addition to the Bonneville Unit. Estimated annual depletion of the Green River system is 45,000 acre-feet. Estimated increased salt load is 11 mg/1 at Green River, Utah.

Cumulative Effects

The sum of the above depletions is 279,400 acre-feet/year. The Bureau has published the figure of 278,700 acre-feet for the entire CUP. Using the latter figure, the cumulative depletion of the flow in the Green River is 5.3 percent in a high water year, and 9.9 percent in a low water year. It is my opinion that even small depletions may be detrimental to the Colorado squawfish. High spring runoff may affect the timing of reproductive activity in this species; therefore, impoundments which alter the pattern of fluctuations in water level possibly hamper reproduction. Overbank flooding replenishes nutrients and provides backwaters where small fish find food and shelter.

The depletions discussed above can eliminate peak flows that provide backwater habitat essential to young fish. Moreover, they eliminate deep canyon areas which are important habitat for the humpback chub.

Biological Opinion

The cumulative impact from the above projects constitutes a serious threat to the existence of the Colorado squawfish and the humpback chub; therefore, it is my biological opinion that the Upalco Unit, along with the cumulative impact of the other related water development projects expected to be completed during the life of the Unit, is likely to jeopardize the continued existence of the Colorado squawfish and the humpback chub.

Alternatives

The Flaming Gorge reservoir inundated 72 miles of endemic fish habitat in the Upper Green River and drastically altered another 65 miles below the dam. The reservoir also altered seasonal flows, decreased summer water temperatures, increased winter temperatures, reduced turbidity, and reduced scouring of the river habitat. Water releases for power generation cause daily fluctuations of 2 to 3 feet in the Green River. After the reservoir was filled (1962-1966) cold water releases prevented or severely restricted spawning of the Endangered fishes downstream as far as Jensen, Utah.

Jeopardy from the Upalco Unit, considered along with other CUP units, could be avoided by operating the Flaming Gorge Dam in a more environmentally sensitive manner. Since modification of the Flaming Gorge penstock in 1978, this reservoir could be operated with much less impact on Endangered fishes. Modified operations would not only compensate for the effects of the CUP, but also could help restore the Green and Colorado Rivers to a healthy condition for the listed fishes.

A Colorado River Fisheries Investigation Team was established in April, 1979 to gather information on requirements of the Colorado squawfish, humpback chub, razorback sucker, and bonytail chub. The latter two species are proposed for listing as Threatened and Endangered, respectively. The fisheries investigation team is staffed with Fish and Wildlife Service (FWS) personnel and is partially funded by the Bureau. Other participants are the Bureau of Land Management, Utah Division of Wildlife Resources, and the Colorado Division of Wildlife. The team is obtaining information via field, laboratory, and hatchery studies. Without results from these cooperative fisheries investigations, we cannot say exactly how the operation of Flaming Gorge should be altered; however, for the well-being of the Colorado squawfish and the humpback chub, we know the operation should be changed at certain seasons to resemble the flows that existed before the closure of Flaming Gorge Dam.

When the Colorado River Fisheries Team has completed its studies, recommendations will be made as to conditions needed to preserve the Colorado River Endangered fishes. Upon completion of these studies, the Bureau should request consultation on the operation of the Flaming Gorge Reservoir. Specific modifications on operational procedures will be developed as a result of the consultation.

Since avoidance of jeopardy from Upalco is predicated on the properly modified operation of Flaming Gorge, no final action on Upalco can be taken until the consultation on Flaming Gorge has been completed; however, further design, planning, and construction of the Upalco project would not foreclose the alternative of modifying the operation of Flaming Gorge; therefore, any action on Upalco short of actually withdrawing water or otherwise modifying river flows could be undertaken by the Bureau prior to completion of a consultation on operation of Flaming Gorge.

To assist the Bureau in carrying out its responsibility to conserve Endangered species, it is further recommended that the Bureau use the results of the above studies to modify existing operations and the design and operation of planned projects, including Upalco, to regulate their flows for the benefit of the Endangered species to the maximum extent possible.

Habitat modification to provide more suitable areas for spawning and rearing of young Endangered fishes could be considered. Potential modifications should entail creation of specific types of backwaters on river sections of reduced flow which these fishes use during certain stages of their life cycles.

The Colorado River fisheries team is identifying these needed habitat types. Present evidence indicates that physical modifications such as select excavations and strategic placement of fill or manipulation of riparian habitat could be accomplished to enhance those habitats specifically required by these Endangered fishes.

cc: Directorate Reading File
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(Confirmation)

Form 3-265 U.S. Fish & Wildlife Service	FAXFORM	
	DATE 12/6/79	TIME 12/6/79 2:30PM
TO: Department of Interior Solicitor's Office Attn: Chuck Kaiser	☐ Deliver on regular mail run	
FROM: Gary Halvorson, USFWS, (SE), Albu., NM	XX Call to have picked up X2172	

SUBJECT: Biol. Opinion of the Effects of Glen Canyon Dam on the Colorado River.

A 7-PAGE MEMO TO BR FOLLOWS:

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May 25, 1978

MEMORANDUM

To : Mr. Harl Noble, Acting Regional Director, Bureau of Reclamation, P. O. Box 11568, Salt Lake City, Utah 84111

From : Regional Director, U. S. Fish and Wildlife Service

Subject: Biological Opinion of the Effects of Glen Canyon Dam on the Colorado River as it Affects Endangered Species

On June 28, 1977, the Bureau of Reclamation formally requested Section 7 Consultation with the U. S. Fish and Wildlife Service concerning the effects of Glen Canyon Dam on endangered species in the Colorado River between Lee's Ferry and Lake Mead. Section 7 of the Endangered Species Act of 1973 states:

> "The Secretary shall review other programs administered by him and utilize such programs in furtherance of the purposes of this Act. All other Federal departments and agencies shall, in consultation with and with the assistance of the Secretary, utilize their authorities in furtherance of the purposes of this Act by carrying out programs for the conservation of endangered species and threatened species listed pursuant to section 4 of this Act and by taking such action necessary to insure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of such endangered species and threatened species or result in the destruction or modification of habitat of such species which is determined by the Secretary, after consultation as appropriate with the affected States, to be critical."

Before Glen Canyon Dam was built in 1963, eight endemic species of fish were maintaining populations between Glen Canyon and Lake Mead:

Rhinichyhys osculus	speckled dace
Gila robusta robusta	roundtail chub
Gila cypha	humpback chub
Gila elegans	bonytail chub

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Ptychocheilus lucius	Colorado squawfish
Catostomus latipinnis	flannelmouth sucker
Pantosteus discobolus	bluehead sucker
Xyrauchen texanus	razorback sucker

In addition, two other native fish species have been reported or suspected from this reach, but probably never maintained viable populations:

Lepidomeda mollispinis mollispinis	Virgin River spinedace
Plagopterus argenissimus	woundfin

Three of the above native fish species are presently listed by the Department of the Interior as endangered: Colorado squawfish, humpback chub and woundfin. In addition, the bonytail chub and razorback sucker have officially been proposed for listing in the April 24, 1978, Federal Register. Our biological opinion will deal only with those listed species (squawfish and humpback chub) that are known to have maintained viable populations in the Colorado River between Glen Canyon and Lake Mead. However, Bureau of Reclamation should be aware that if and when the bonytail chub and razorback sucker are listed, they too will come under protection of the Endangered Species Act.

Past and present distribution of Colorado squawfish and humpback chub is well documented between Lake Powell and Lake Mead, in spite of the difficulties involved with collecting in these remote areas and the fact that *Gila cypha* was not described until 1946 (Miller 1946). Minckley and Deacon (1967) and Minckley (1973) recorded squawfish collections from Glen Canyon, Grand Canyon (Little Colorado River and Bright Angel Creek) and a short distance upstream from Lake Mead. The last records of squawfish in this reach are two specimens from immediately below Glen Canyon Dam collected by Arizona Game and Fish personnel in 1962 through 1966 (Minckley and Deacon, 1967) and one specimen at the mouth of Shirumo Creek in 1972 (Charles Minckley, pers. comm.). *Gila cypha* have been recorded from prehistoric Indian sites below Hoover Dam throughout the Colorado River in the Grand Canyon and immediately below Glen Canyon Dam (Miller, 1961; Minckley, 1973). The type locality for this species is the Colorado River at the mouth of Bright Angel Creek. Although neither fish may have ever been abundant through this reach of the Colorado River, both were widespread and at one time maintained viable populations.

Recent pollections of fish between Lake Powell and Lake Mead have failed to discover Colorado squawfish (Holden and Stalnaker, 1975; Minckley and Blinn, 1976; Suttkus, 1976). Gila have fared somewhat better, with moderate numbers collected in 1976, 1977, and 1978 at the confluence of the Little Colorado River and in Marble Canyon (Minckley and Blinn, 1976: Charles Minckley, pers. comm.).

It is our opinion that the major reason for the decline of both listed fish species in this reach of the Colorado River has been the abnormal water conditions that result from the operation of Glen Canyon Dam. The foremost problem has been the cold, hypolimnic waters from Lake Powell. Below Glen Canyon Dam, Cole and Kubly (1976) found annual temperatures to range between 7^{o} and $10^{o}C$, whereas the pre-dam Colorado River showed a seasonal variation of nearly $30^{o}C$. Cole and Kubly also recorded temperatures between the two dams for a one year period between April, 1975, and March, 1976. They found a slight warming trend downstream, but never recorded water temperatures higher than 16°C anywhere on the mainstream between Powell and Mead. The extensive canyons between the two reservoirs tend to limit solar warming of the waters. Bureau of Reclamation data (1966-1977) indicate somewhat higher temperatures below Glen Canyon Dam, especially during the early filling period of Lake Powell (1966-1970) when some epilimnic water may have been withdrawn, but since 1970 few water temperature measurements have exceeded 10°C.

A second Colorado River parameter that operation of Glen Canyon Dam has altered is the normal fluctuations of water levels. There is no doubt that the Colorado River once showed dramatic water level fluctuations, However, this flood/drought cycle was at least partially predictable, high waters coming during the spring runoff from snowmelt in the high mountains and again in late summer during the thunderstorm season. Between these two high water periods, water levels were generally declining or stable. Demands for hydroelectric power generation at Glen Canyon Dam now result in discharges that vary by a factor of about 5 over a 24 hour cycle, resulting in a daily vertical variation of the Colorado River by as much as 15 feet (Bureau of Reclamation Environmental Assessment, 1976). The <u>mean</u> daily high discharge from the dam is about 20,000 cfs and the <u>mean</u> daily low is 4,600 cfs. Depending upon power demands, this fluctuation varies through the extremes of 27,000 cfs and 2,000 cfs in a single day.

The effects of the altered water temperature and water level fluctuations on the endangered Colorado squawfish and humpback chub are fairly clear. Vanicek and Kramer (1969) reported water temperature and receding water levels as impottant spawning stimuli. During the three spawning seasons they studied Colorado squawfish in the Green River, ripe fish were taken approximately one month after the water temperature had reached 18°C. Toney (1974) reported on rearing Colorado squawfish in Willow Beach National Fish Hatchery below Hoover Dam. He found ripe squawfish only after water temperatures exceeded 21°C, although the maturation process began at slightly lower temperatures. Thus it appears the cold, hypolimnic waters issuing from Glen Canyon Dam do not attain temperatures that allow the Colorado squawfish to spawn (18-21°C) anywhere in the Colorado River between Lake Powell and Lake Mead.

<u>Gila</u> appear to mature at slightly lower temperatures, as the fish Vanicek and Kramer (1969) studied were found to be ripe at 18°C. As this temperature is not now reported in the mainstream Colorado River between the two reservoirs, humpback chub spawning appears to be limited to the proximity of inflowing streams where warmer water may provide minimal spawning requiremants, either by tempering the mainstream for short distances or allowing the fish to enter the tributaries and escape the colder, mainstream waters, The Little Colorado River provides 27% of the water inflow into the Colorado River between the two reservoirs, but accounts for less than 3% of the total flow below that point (Bureau of Reclamation Environmental Analysis, 1976). In any case, the

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only remnant population of Gila cypha known to exist between the two reservoirs inhabits the Colorado and Little Colorado rivers around their confluence.

Effects of the constant fluctuations of water levels may also be dampened by the tributary inflows, but only humpback chubs seem able to survive the existing conditions. Further information on habitat requirements of the two listed species are needed, as is the relationship between mainstream and tributary habitats and the general movement of fish in the tributary areas. The language of Section 7 is quite specific about Federal actions affecting listed species and critical habitat (actions authorized, funded or carried out should not jeopardize the continued existence of listed species or result in the destruction or modification of critical habitat). The Colorado River Fishes Recovery Team recommended the Colorado River between the Little Colorado River and Diamond Creek as critical habitat for the squawfish in 1975 and for Gila cypha in 1977. This reach has not been included in the final squawfish critical habitat proposal because the species is presently believed to be extirpated there. There is little doubt the Colorado River around the mouth of the Little Colorado will be included in the upcoming Gila cypha critical habitat proposal, as only two other small areas in the drainage are presently known to support this species.

Additional Information

In September, 1977, the National Park Service sent out a Natural Resources Management Plan that included suggestions for the Grand Canyon portion of the Colorado River (National Park Service, 1977). This plan included the following:

> "Explore economic, biological, political and time elements toward a plan of restoring the Colorado River and its tributaries to be more conducive to native fish. Though massive change has occurred in park riparian habitat because of Glen Canyon Dam, it may be possible to mitigate some impacts by raising the water intake of the generating penstocks to allow for warmer water to pass through the dam."

In reply to this suggestion, the Arizona Department of Game and Fish, in a letter to the National Park Service dated February 16, 1978, stated:

> "The Grand Canyon National Park's 'Natural Resources Plan' calls for manipulations of the Colorado River below Glen Canyon Dam which would result in a substantial change in the ecosystem of the river between Glen Canyon Dam and Lake Mead. The stated purpose of the alterations is to enhance this portion of the river for endangered fishes. While the Arizona Game and Fish Department agrees that enhancement of endangered species habitat is a laudable objective, we feel that the methods proposed, i.e., raising the water temperature of the river, limiting sport fishing to fly only and cessation of trout stocking programs, will not

accomplish the desired results. Conversely, raising the water temperature of the river will allow exotic fishes now found in Lake Powell and Lake Mead to expand into the area where they are absent, or present in limited numbers due to the low water temperatures. The resulting presence of these exotic species will place more stress on the endangered species through increased predation and competition, than do the trout which presently occupy this portion of the river."

The question the State of Arizona did not raise is if the potential influx of exotic species would be more damaging to endangered species than the existing water temperatures and water fluctuations?

Biological Opinion

Incorporating all of the above information, it is the biological opinion of the U. S. Fish and Wildlife Service that:

1. Past, present and proposed future operations of Glen Canyon Dam have had, are having and will have an adverse affect on the essential habitat of the endangered humpback chub and is jeopardizing the continued existence of this species by limiting its distribution and population size.

2. The operation of Glen Canyon Dam is modifying a major portion of the known *Gila cypha* habitat and is limiting the ability of this endangered species to recover from its presently reduced state.

3. Operation of Glen Canyon Dam is limiting the recovery of Colorado squawfish by altering and rendering unsuitable that reach of the Colorado River between Lake Powell and Lake Mead once known to support this endangered species.

Suggestions

It appears there are several alternatives available to reduce or eliminate the present and future jeopardy to endangered species resulting from the operation of Glen Canyon Dam. However, the problems suggested by the State of Arizona seem real enough for us not to recommend alterations in the Dam operation until the impacts of this action are more clearly known. We, therefore, recommend instead that the Bureau of Reclamation fund specific, long-term studies on the following:

1. The potential impact of warming the river below Glen Canyon Dam on endangered species. The data presently being gathered by the Bureau of Reclamation on the new multiple penstock operation at Flaming Gorge Dam should provide an excellent starting point for this study.

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2. The ecological needs of the endangered species in the Colorado River between Glen Canyon Dam and Lake Mead.

3. Methods of reducing or eliminating the known constraining factors of low water temperature and frequent water flow fluctuations on endangered species.

4. The relationship between mainstream and tributary habitats and their utilization by endangered species.

The Service will be pleased to meet with the Bureau to evaluate the present options available to you and assist in planning the above studies. One of the major goals of the draft Colorado Squawfish Recovery Plan is to restore the species to portions of their former range. The goal is also being incorporated into the Humpback Chub Recovery Plan presently being prepared. In order to achieve these goals, close cooperation between several Federal agencies involved in managing the Colorado River will be necessary. An excellent start towards recovery of these species and their eventual removal from the Endangered Species List would be the recovery of the Colorado River below Glen Canyon Dam. We hope this goal is possible, and are willing to work with the Bureau of Reclamation in any way possible in order to achieve it.

(SGD) W. O. NELSON, JR.

bc: AFA, Washington, DC
OES, Washington, DC
Regional Director, Region 6 (SE)
Area Office, Salt Lake City
Area Office, Phoenix
BR, Boulder City

JEJohnson:js

cc: Tad Lane, RD, Region 6/11-20-79/va

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[1979]

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

SE

POST OFFICE BOX 1306
ALBUQUERQUE, NEW MEXICO 87103

December 28, 1979

2-1-80-F-~~8~~ 13

- Dif. in jeopardy
- Reg. II vs. VI

MEMORANDUM

TO: Regional Director, Water and Power Resources Service
P.O. Box 11568, Salt Lake City, Utah 94147

FROM: Acting Regional Director, Region 2

SUBJECT: Formal Section 7 Consultation on the Animas-La Plata Project

On October 16, 1979, I initiated formal Section 7 consultation, as provided by the Endangered Species Act as amended, with Water and Power Resources Service, as a result of my review of your biological assessment on the Animas-La Plata Project. At that time, I requested additional information which I received December 5, 1979.

This consultation involves the endangered bald eagle (Haliaeetus leucocephalus), peregrine falcon (Falco peregrinus), and Colorado squawfish (Ptychocheilus lucius), as identified in our March 9, 1979 species list to Water and Power Resources Service and your June 27, 1979 biological assessment. The consultation concerns the effects of the proposed Animas-La Plata Project upon these endangered species. The effects of coal development on the two Ute Indian Reservations, as a result of the Animas-La Plata Project, will not be addressed because of development ambiguities.

The following information and biological opinion is founded upon review of the Animas-La Plata Draft Environmental Statement (INT DES 79-45), the biological assessment, data from the administrative files of the Fish and Wildlife Service, and discussions with personnel of the Colorado Division of Wildlife, New Mexico Department of Game and Fish, U. S. Forest Service, and other people familiar with the involved species.

The project will be located in La Plata and Montezuma Counties in southwestern Colorado and San Juan County in northwestern New Mexico. The four river systems of the Upper Colorado River Basin that will be affected include the Mancos, La Plata, and Animas Rivers which are tributary to the fourth River, the San Juan. To effect this project, an average 169,400 acre feet of water will be diverted from the Animas River to the La Plata and Mancos Drainages and about 17,000 acre feet from the La Plata River to the Mancos Drainage. In total, considering reuseable return flows, it is estimated 198,200 acre feet of water will be diverted.

To accomplish this water diversion the project will include the construction and operation of the Ridges Basin and Southern Ute Dams and Reservoirs, the Durango and Ridges Basin pumping plants, several conveyance systems, two diversion dams on the La Plata River (La Plata and Southern Ute), and an electric power transmission line and associated facilities. It is estimated facility construction will take 10 years to complete.

Non-project facilities that would likely be built, as a result of the project, include two municipal water treatment plants, several pumping stations that would develop necessary water pressure for sprinkler irrigation, and numerous buildings.

The project irrigation water may be provided to 70,100 acres of land in private ownership and the Ute Mountain Ute and Southern Ute Indian Reservations. To accommodate the 118,100 acre feet of irrigation water, about 70 percent of this area will need sprinkler distribution systems, clearing, and land leveling. The Indian land would require extensive clearing. The 80,100 acre feet of water for municipal and industrial use would be divided with approximately forty-one percent of this amount furnished to the two Ute Indian Reservations primarily for development of their coal resources. The remaining water would go to Durango, Aztec, Farmington, other towns and the Navajo Indian Reservation.

The peregrine falcon, an inhabitant of the project area, was listed as endangered in 1970. The decline of their population is attributed to the presence of chlorinated hydrocarbon pesticides in their food supplies which causes eggshell thinning, non-viable eggs, and increased adult mortality. This species feeds largely upon migratory birds and typically hunts riparian areas. Eyries are associated with cliff environments and bluffs of gentle terrain.

A pair of peregrine falcons formerly nested on cliffs north of the proposed Ridges Basin Reservoir. This historic eyrie was last occupied by breeding peregrines in 1963. Recent sightings have been reported near the proposed reservoir, though there is no post-1963 evidence of breeding.

The historical eyrie is suitable for peregrine occupancy. However, there are larger more typical peregrine cliffs in southwestern Colorado. The Colorado Division of Wildlife does not consider the historic site as exceptional. Further, the surrounding hunting habitat is judged to be of marginal quality. The Ridges Basin Reservoir may improve the habitat for some peregrine prey such as swifts and swallows; however, the fluctuating water tables will create a barren shoreline reducing the likelihood that blackbirds and other prey species would be available to peregrines. We believe the proposed reservoir will neither destroy good peregrine habitat nor enhance existing habitat; consequently, it is my biological opinion that the proposed action is not likely to jeopardize the continued existence of the peregrine falcon.

On March 16, 1978, the bald eagle, another project inhabitant, was listed as endangered in the conterminous United States except for several northwest and lake states where it was designated threatened. The decline of this eagle has been attributed to the loss of breeding habitat, illegal shooting, and the presence of chlorinated hydrocarbon pesticides in their food supply which caused egg deterioration and reproduction failures.

The bald eagle is a wide ranging species associated with and dependent upon water. Its food base may include fish, small mammals, waterfowl, and all forms of carrion though fish appear to be the stable food item.

Within the project area, the Animas River south of Durango to Farmington supports approximately 20 wintering bald eagles. This population may be the maximum winter population this riverine system can support. In addition, there exists one active bald eagle nest near the Animas River, south of Durango.

My main concern is the impact of reducing the Animas River stream flows upon the nesting bald eagles. This reduction in stream flow could reduce availability of warm water fish for these eagles as well as change fish species composition. Data indicates flannelmouth sucker dominance may be replaced by white suckers, but pounds per acre of fish will not change significantly. With these considerations, it is my biological opinion that the proposed action is not likely to jeopardize the continued existence of the bald eagle.

The Ridges Basin and Southern Ute Reservoirs may support some bald eagle needs during the summer. It is doubtful that Ridges Basin Reservoir will be available to wintering bald eagles because of ice cover. Conversely, the Southern Ute Reservoir has potential to support these wintering birds. To afford the bald eagle full consideration in the design and management of the project we suggest a Bald Eagle Reservoir Management Plan be developed for the reservoirs.

The Colorado squawfish, listed as endangered in 1967, was once widespread and abundant throughout the mainstream Colorado River and its major tributaries, including the San Juan and Animas Rivers. Dams, diversion of water and reclamation of pre-impoundment rivers are all factors that have reduced the range of the largest minnow in the United States by about 75%. Additional factors believed to limit squawfish include competition with exotic fish species and pollution in the form of pesticides and chemicals.

The San Juan River is one of only a few Colorado River streams where any squawfish have been found in recent surveys. Prior to the construction of Navajo Dam (1962), squawfish were regularly reported from the San Juan River in New Mexico and, to a lesser extent, in Colorado and Utah. In preparation for development of a quality trout fisheries in the Reservoir and below the Dam, large reaches of the San Juan River and its tributaries were reclaimed. The reclamation and habitat changes associated with the Dam apparently eliminated squawfish from the upper river, as several fish surveys in the late 1970's failed to locate the species. Both the Animas and La Plata Rivers now regularly go dry along once permanent reaches because of diversion, and no longer are believed to be suitable squawfish habitat.

In April 1978, a survey crew sponsored by the Bureau of Reclamation did locate a juvenile squawfish in the San Juan River at the mouth of McElmo Creek, near Aneth, Utah. The size (170 mm) and locality of the specimens indicated it was spawned in the San Juan River, probably in 1975 or 1976, making the San Juan River one of only three known rivers where successful reproduction has occurred in the last five years.

As proposed, the project will reduce the average annual inflow of water into the San Juan River by 198,200 acre feet, or 13% of the 1939-77 average annual flow. In addition, the project will increase the salinity of the remaining San Juan River water from 470 to 520 mg/l. Both of these impacts will be maximal during vital biological periods in the life cycle of squawfish, the summer spawning period and the winter, cold-water period.

Fluctuations in water levels and salinities are the rule rather than the exception in the Colorado River Basin, and even under natural conditions, the San Juan River had periodic salinities higher than 520 mg/l and the flow occasionaly dropped to zero during short time periods. The endemic fish species adapted to these variable conditions in a variety of ways, two of which were an extended life span and larger size. These adaptations result in a high, prolonged reproductive potential that can accommodate several years of unsuitable conditions between successful spawnings. However, these fluctuations will be buffered by the Animas-La Plata Project, resulting in stable higher salinities and lower flows than presently or naturally found in the San Juan River.

It is my biological opinion that in spite of the alterations to the San Juan River as a result of the proposed project, the action is not likely to jeopardize the Colorado squawfish as a species nor destroy habitat essential to their survival. During the time between the fish reclamation (in 1961) and the present, Colorado squawfish have not re-established their abundance in the San Juan Rivers as they did in the Green River, but do appear to have maintained a small, isolated population in the lower river. The proposed project is likely to further degrade the San Juan River to a point that this population will be lost. However, because of the apparent small size of the San Juan River squawfish population and its already tenuous hold on survival, its possible loss should have little impact on the successfully reproducing Green and Colorado River squawfish populations and therefore the species itself. Thus, the "no jeopardy" opinion. However, Section 7 (a) of the Endangered Species Act calls on all Federal agencies to "...utilize their authorities in furtherance of this Act by carrying out programs for the conservation of Endangered Species...." I find the Water and Power Resources Service Draft Environmental Statement woefully negligent in meeting this portion of the Act for this project, and make the following suggestions in an attempt to bring your activities more closely in line with purposes of the Act.

1. Thoroughly survey the native fish populations of the San Juan River.

2. Determine the environmental needs of the Colorado squawfish.

3. Attempt to meet those needs by adjusting the myrid of projects now on the San Juan River Drainage (Navajo Indian Irrigation Project, Animas-La Plata, Gallup-Navajo, etc.) to the benefit of the species.

4. Provide and fund artificial facilities in which to spawn and rear Colorado squawfish until such times that suitable habitats in the San Juan River can be developed and maintained.

I understand at least the first two of these suggestions are already underway for other Service projects. The remaining two are definitely needed if the San Juan River is to maintain a Colorado squawfish population.

I appreciate the cooperation you have afforded me during this consultation and offer my assistance to you in your management of the bald eagle and Colorado squawfish. Further consultation is not required unless new information becomes available that addresses the welfare of the species discussed, new threatened or endangered species are listed that may be affected by your action, or the action is significantly modified.

Sincerely yours,

/s/ Robert F. Stephens

Acting Regional Director

cc: Washington, D.C., OES
Salt Lake City Area Office, Salt Lake, Ut
Phoenix Area Office, Phoenix, AZ
Field Supervisor, ES, Albuquerque, NM
Field Supervisor, ES, Salt Lake City, Ut
Regional Director, Region 6 (SE)
AEV, Region 2

Colorado-Ute Electric Association, Inc.
P. O. Box 1149
Montrose, Colorado 81401

May 12, 1981

Mr. Roland C. Fischer
Secretary-Engineer
Colorado River Water Conservation District
3rd Floor, 1st National Bank Building
P.O. Box 1120
Glenwood Springs, Colorado 81601

Dear Rolly:

Juniper Cross Mountain
Endangered Species Consultation

Enclosed is the Biological Opinion the U.S. Fish and Wildlife Service submitted to REA regarding withdrawing water from the Yampa River for the Craig 3 Project.

Very truly yours,

Jerry A Walker

Jerry A. Walker
Manager, Environmental Services
System Planning and Resource
Control Division

JAW/lz

enclosure

Site - Craig
Endangered Spec

P33-2.7(1)

FA/SE/REA—Colorado 46 Ute
Craig Station Unit 3 Proj.
(6-5-80-F-48)

MAR 13 1980

Mr. William E. Davis
Acting Director
Western Area-Electric
Rural Electrification Administration
Washington, D.C. 20250

Dear Mr. Davis:

We prepared this biological opinion in response to your November 7, 1979, request for consultation for the proposed third unit of the Craig Station. Unit 3 is planned for construction near Craig, Colorado. Consultation is required by Section 7 of the Endangered Species Act and is described in the Interagency Cooperation Regulations published in ~~5~~ 50 CFR 402. You requested Section 7 consultation because the Rural Electrification Administration (REA) is contemplating guarantee of a loan for construction of Unit 3.

Funds guaranteed and loaned by REA were made available for Units 1 and 2 of the Craig Station beginning in 1974. Funds still are being provided for Unit 1, inasmuch as construction of this unit is not yet complete. Section 7 consultation for Units 1 and 2 was carried out in late 1973 and early 1974 in conjunction with procedures of the National Environmental Policy Act; thus due to these particular circumstances further consultation will not be needed for completion of this Federal action.

BIOLOGICAL OPINION

Construction and operation of Unit 3 are likely to jeopardize continued existence of the Colorado squawfish and humpback chub, both Federally listed as endangered species. Unit 3 is not likely to jeopardize continued existence of the black-footed ferret, bald eagle, American peregrine falcon, Uinta Basin hookless cactus, Mesa Verde cactus, and spineless hedgehog cactus.

PROJECT DESCRIPTION

Colorado-Ute proposes to construct and operate a 400-megawatt coal-fueled generating unit (Unit 3). This unit would be constructed approximately

4 miles southwest of Craig, Colorado (Fig. 1), at the site of the Craig Station where one coal-fueled unit already is in operation (Unit 2) and where another (Unit 1) is nearing completion of construction. Unit 1 is scheduled to begin operation in the spring or early summer of this year. The Craig Station is 1.5 miles south of the Yampa River.

No new transmission lines would be required. An existing 230-kilovolt line would be uprated to handle 345 kilovolts. Water for Units 1 and 3 would be diverted from the Yampa River through an existing intake structure which supplies Unit 2. Creation of a reservoir is not planned because two upstream reservoirs store water for the Craig Station. An onsite water storage pond with a capacity of 500 acre-feet serves Unit 2 and will suffice for Units 1 and 3 as well.

Each of the three Craig units would consume approximately 6,400 acre-feet of water annually. Water for the Craig Station comes from the Yampa River. Most of the water for Unit 3 will be diverted to the station by virtue of Colorado-Ute's flow rights. In low-flow periods, if the station is not allowed to divert water because of priority of Colorado-Ute's flow rights, water from Yamcolo Reservoir could be released for Unit 3. In addition, Colorado-Ute has purchased water from the Four Counties Project and other flow rights that may be used as part of the water supply for Unit 3.

depletions 20,000 a.f.

BASIS FOR OPINION--JEOPARDIZED SPECIES

A primary area of concern in this opinion is the Yampa River from its confluence with Milk Creek downstream to the confluence with the Green River. Of equal importance is the Green River from the mouth of the Yampa downstream to the confluences with the White River and the Duchesne River. These two reaches of river comprise important habitat for the Colorado squawfish and humpback chub. The extent of spawning by either fish in the Yampa is not known, but this river provides habitat for subadult and adult squawfish and humpback chubs. Moreover, the Yampa is important in providing water to the Green River to offset effects of major mainstem water impoundments and diversions. In an average year, the Yampa River provides approximately 49 percent of the water in the Green River as measured at Jensen, Utah. The Green River and the Colorado River above Lake Powell provide almost all the remaining spawning habitat for the squawfish and the humpback chub. Tributaries to the Green and the Colorado River also may provide some spawning areas but the extent is not known.

The squawfish and the humpback chub once were abundant throughout the Colorado River system from the Gulf of California to southwestern Wyoming. Presently the squawfish is limited to the upper mainstem and major tributaries of the Colorado River system. The humpback chub is found only in limited areas within the river system in Colorado, Utah, and Arizona. The primary cause of decline for both species is human alteration and degradation of the river environment. Major impoundments and water diversions have depleted water and altered temperature, turbidity, and stream flows, thus reducing habitat for both fishes.

A less important cause of decline may be the increased numbers of exotic fishes, but this increase in exotics also is a function of habitat changes. Although correlations exist between declining native fish populations and increasing populations of exotic fish, cause and effect are not fully understood. However, we believe fewer exotic fishes would be present if the river more closely resembled its natural state.

A serious problem posed by the Craig Station is depletion of water from the Yampa River and the Green River including effects on flow patterns. Effects of the project will extend into the Green River, which has undergone drastic physical, chemical, and biological changes largely because of Flaming Gorge Dam and water withdrawals. The lower the water level, the greater the percent of water confined to the river channel and the fewer the backwater areas that remain. Also, relationships among pools, riffles, water velocities, and gravel bars are changed, producing effects difficult to predict. As water is withdrawn, less habitat is available to fish and the variety of habitat types is reduced, often resulting in lower reproductivity or survival.

We evaluated the condition of habitat remaining for squawfish and humpback chubs in the Green and Yampa Rivers. If conditions deteriorate further, these fishes may never recover to the point they can be removed from the list of endangered species. Flaming Gorge Dam has extensively modified the Green River by inundating 72 miles of endemic fish habitat and by severely restricting spawning for approximately 65 miles downriver. Adverse physical, chemical, and biological changes have resulted from releasing cold water and causing large daily fluctuations in the river. A major reason the Yampa should not be degraded is its ameliorating effect on the Green. It increases temperature of the Green and adds a needed volume of water which dampens the severe flow fluctuations caused by Flaming Gorge. At this point, we must assume the Yampa will retain its importance as a moderating factor for the Green at least until consultation is completed on water releases from Flaming Gorge and until we analyze results of studies being conducted on the endangered fishes.

In addition to the water needed for cooling the Craig Station, more water would be needed to meet personal needs of individuals drawn to the area because of Unit 3. The environmental impact statement (EIS) for the Craig Station reported that approximately 1,500 people may be added to the local population during the peak of the construction period. This includes workers and their families. The EIS estimated that 300,000 gallons per day would be used by these persons. This water would come from the Yampa River hydrologic system. However, we expect that 70 ~~percent~~ of this volume would be returned to the river; thus, we estimate that 90,000 gallons per day or an additional 101 acre-feet would be consumed annually during construction in addition to the volume needed to cool the three units of the Craig Station.

The EIS estimates the long-term increase in the human population at 133 people after Unit 3 begins to operate. Using the Environmental Protection Agency's estimate of 200 gallons per day per individual, it appears that approximately 26,600 gallons per day would be used over the long term. If 70 percent of the water returns to the river, then approximately 7,980 gallons per day or 8.9 acre-feet would be consumed annually in addition to the water needed to cool the Craig Station.

In addition to reducing river flows, operation of Unit 3 will alter river temperatures slightly, primarily because of infrequent water releases from Yamcolo and Elkhead Reservoirs. Whether temperatures are increased or decreased will depend on the season when reservoir releases are made. The biological assessment stated that most releases would be made during fall or winter with an increase in river temperatures of a few degrees for a short distance downriver. Although temperature often limits spawning and distribution of fishes, it is our opinion that temperature changes in this case will not be limiting to the squawfish and humpback chub. This is true largely because neither species is found at the Craig Station and the station's effects on water quality are overshadowed by runoff and tributary inflows between the station and the area where these fishes are expected to occur. Squawfish have been collected 8 miles downriver from Craig Station, and humpback chubs have been collected in Dinosaur National Park. Either species may occur further upstream because collection records in the Yampa are limited, but we do not expect them to extend upstream closer than a few miles below Craig Station.

We expect Unit 3 to have very little effect on turbidity or salinity. Water withdrawn from the river will not be returned to the river. Suspended particles settle out of the water stored in Elkhead and Yamcolo Reservoirs; however, this affects a small volume of water, especially when we consider only the volume to be stored for use by Unit 3.

In summary, flows in the Yampa River are reduced by withdrawals for municipalities, industries, power generation, and agriculture. Depletions are made possible by direct diversions and by reservoirs on tributaries of the Yampa. Unit 2 of the Craig Station is in operation and is consuming 6,400 acre-feet from the Yampa in an average year. Unit 1 is expected to begin operation this summer and will consume another 6,400 acre-feet most years. Pursuant to Section 7 of the Endangered Species Act, the flows and the habitat of the Yampa River should not be reduced through further Federal actions unless compensatory measures are taken. Such compensatory measures are recommended for Unit 3 in the alternatives section of this biological opinion.

STUDIES ON RARE NATIVE FISHES

We do not know all specific requirements and exact distributions of the Colorado squawfish and the humpback chub, partly because these fishes have been of little interest to society until recent years. Also, these fishes are difficult to capture or observe because the waters they inhabit are usually swift and turbid. Moreover, access to many of the canyon reaches is limited. Nonetheless, we are rapidly gathering information on the squawfish and the humpback chub as well as the razorback sucker, proposed for threatened status, and the bonytail chub, proposed as endangered.

A Colorado River Fisheries Investigation Team was established in April 1979. This team is staffed with FWS personnel and has funding from the Water and Power Resources Service (WPRS), the Bureau of Land Management (BLM), and FWS. Other participants are the Utah Division of Wildlife Resources and the Colorado Division of Wildlife (DOW).

typical 'standard' of in 79-81 period

From this study we will learn additional specific life history requirements of the listed fishes. Because WPRS and BLM are funding the study, most of the field work is in the Green and Colorado Rivers where the fishes reproduce and where WPRS and BLM projects will have the greatest impacts. Approximately 16 months from now, we expect the information obtained via field, laboratory, and hatchery work will enable us to make specific recommendations to produce and maintain more favorable habitat for the listed fishes in the Green and Colorado Rivers. The information also will aid us to a lesser extent in developing recommendations for the fishes in the Yampa River and other major tributaries.

= July 1981

In addition to this study on the endangered fishes of the Green and Colorado Rivers, other studies have been and will be conducted on the Yampa River and other tributaries. Bio/West Incorporated, Logan, Utah, under contract to FWS, is studying effects of modifying the penstock of the Flaming Gorge Dam. Bio/West also recently completed a study for the National Park Service on the relationship of flows in the Yampa River to rare fishes in the Green River. From 1975 to 1978, Colorado State University conducted a survey of the White and Yampa Rivers for BLM. This survey was to obtain baseline data to complement work by DOW and other resource agencies prior to stripmining of coal in northwestern Colorado. Also, the DOW has monitored fishes in major tributaries of the Green and Colorado Rivers. This year a more intensive study will be initiated by DOW's research division.

The information gained from the studies discussed above will render valuable information for managing the endangered fishes in the Yampa River. The information should be adequate to guide the actions needed to compensate for adverse effects from Unit 3. This is because impacts of Unit 3 are fairly straightforward, being limited primarily to the effects of water withdrawal. However, these studies will not answer all questions concerning endangered fishes, and additional data probably will be needed to answer questions related to other planned water developments that may affect the Yampa to a greater extent or in more complex ways.

ALTERNATIVES

Section 7 requires FWS to recommend reasonable and prudent alternatives for any proposed project likely to jeopardize continued existence of a listed species. The purpose is to avoid jeopardy to a listed species while allowing implementation of the proposed project or an alternative that would accomplish the desired objective.

Section 7 requires the consulting Federal agency (in this case REA) to ensure that its actions will not jeopardize a listed species. Additional depletion of water from the Green and Yampa Rivers could jeopardize the fishes of concern; however, implementation of one or more of the following recommended alternatives would avoid this prospect.

Water Management Alternative

When the aforementioned studies are completed, we will provide Colorado-Ute and REA with specific requirements of the endangered fishes and paricularly the flow releases that are needed to compensate for the withdrawals of unit 3. Colorado-Ute, with the assistance of FWS, will then develop a water management plan for Unit 3 based on the requirements established by FWS.

Most years, Unit 3 would divert approximately 6,400 acre-feet from the Yampa River. In the biological assessment, REA stated that Colorado-Ute has agreed to purchase about 4,000 acre-feet of water in Yamcolo Reservoir and that the Craig Station project participants own rights to 8,310 acre-feet in Elkhead Reservoir. In addition to this stored water, Colorado-Ute has purchased other water rights along the Yampa River. Release of water from these or other sources in a timely manner would eliminate adverse effects of withdrawing 6,400 acre-feet annually at a relatively constant rate from the river.

Although we are studying the endangered fishes of concern, we cannot at present recommend specific flows that should be released into the Yampa River to offset water depletion by Unit 3. However, study results will be available before Unit 3 is scheduled to become operational so impacts on the river will not be felt until after Colorado-Ute and REA have an opportunity to develop the water management plan described above. Until the water management plan is completed, we propose that REA require Colorado-Ute to be prepared to release as much water into the Yampa River as would be consumed by Unit 3.

Our fisheries studies may reveal that flow releases totaling less than 6,400 acre-feet annually are adequate for the fishes to survive in the areas and in the numbers necessary for them to be removed from the list of threatened and endangered species. The full 6,400 acre-feet of water may not be required to be released every year to offset these withdrawals from the Yampa River. Nonetheless, REA should require that Colorado-Ute be prepared to release amounts equal in volume and time to the water consumed by Unit 3. We recognize that for compensatory water to be released from upstream reservoirs, they must be filled annually pursuant to their respective priorities.

Flaming Gorge Alternative

Colorado-Ute proposed an alternative which we evaluated. Colorado-Ute offered to work with the FWS to arrange for make-up flow releases from Flaming Gorge Reservoir into the Green River in lieu of flow releases into the Yampa River. This proposal included an offer from Colorado-Ute to produce electrical power to be transmitted according to the desires of the WPRS in order to compensate for any power production that might be foregone because of this alternative. If availability of water in Flaming Gorge is not a problem, this alternative would provide for endangered fishes in the Green River, but it would offer no protection for the same fishes in the Yampa. For this reason, we cannot now recommend this alternative to REA although we may find it to be a reasonable prospect after we evaluate results of the studies on the Yampa and Green Rivers.

Reduced Electrical Output Alternative

A third alternative is to temporarily reduce electrical production from the Craig Station during critical periods for the fishes and to combine such modified operations with flow releases from upstream water storage. Colorado-Ute views this alternative as unacceptable because of high costs and expected strong power demand. However, this alternative may be worthy of further consideration if the reduced-load period were brief and maintenance of one of the three units could be scheduled for that period.

Dry Cooling Tower Alternative

A fourth alternative is to construct and use a dry cooling tower for Unit 3 instead of the conventional mechanical draft tower as presently planned. A wet-dry tower also would reduce water consumption and is another prospect. We estimate that a dry cooling tower might reduce consumption by up to 4,000 acre-feet annually. Plans for Unit 3 are advanced and to alter designs and construction would be expensive. Colorado-Ute views this alternative as unacceptable because they believe that construction and operating costs would make this alternative not economically feasible. However, this alternative combined with one of the above alternatives may eliminate the likelihood that the Craig Station would jeopardize continued existence of the squawfish and the humpback chub. This alternative might be adequate in and of itself after the previously mentioned studies reveal the specific needs of the endangered fishes and the specific contributions of the Yampa River to these fishes.

Consideration For Future Projects

Use of saline groundwater is not a feasible alternative for cooling Unit 3 because construction is scheduled to begin soon. However, this possibility should be considered for future power plants. Using saline groundwater for power plants would require innovations such as equipment to keep the salt balance at the right level, water filtering and chemical treatment, and sizable evaporation ponds so waste water could be disposed of in an environmentally sound way. However, surface water in the arid west is being depleted rapidly. As water is removed from the Colorado River system, remaining flows have increasingly high environmental value. Some minimum level of water must remain in our streams and rivers if we are to maintain fish and wildlife.

Researchers at Utah State University have evidence that use of salty ground water for power plant cooling is feasible technically and economically (pers. comm. J. Batty, Utah State Univ.).

Criteria For Selecting An Alternative

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Until we draw conclusions from the current studies approximately 16 months from now, Colorado-Ute and REA cannot assume that we will accept the alternative of flow releases from Flaming Gorge Reservoir into the Green River. Therefore, REA cannot use this possibility to ensure that the action of guaranteeing a loan for Unit 3 would not jeopardize continued existence of the endangered fishes.

By contrast, the alternatives of water management, reduced electrical output, and a dry cooling tower (or a combination thereof) are reliable ways to avoid jeopardy. We pointed out earlier that Colorado-Ute has some stored water available, holds some flow rights, and probably can acquire control of more water in the Yampa River. Therefore, the water management alternative is not only feasible hydrologically, but seems reasonable economically.

Because jeopardy from Unit 3 can be avoided, selection of one of the recommended alternatives would allow financial assistance to be made and construction to be carried out. REA is to select an alternative and develop a plan to implement it. REA then should reinitiate consultation by requesting our review of the plan. When REA makes this request probably will depend on which alternative it selects. If water management is a major feature of the alternative, however, we will be unable to offer detailed advice until we have analyzed information from the studies on the endangered fishes. Consultation with FWS is to be completed before water is diverted from the Yampa River for Unit 3.

As we have discussed with REA and Colorado-Ute, we encourage further suggestions of alternatives which would avoid jeopardy. The consultation mentioned above can include evaluation of any additional alternatives that might be conceived.

BASIS FOR OPINION--NONJEOPARDIZED SPECIES

We concur with your biological assessment that the proposed project would not impact the peregrine falcon, bald eagle, black-footed ferret, Uinta Basin hookless cactus, spineless hedgehog cactus, and Mesa Verde cactus.

The Craig Station is not located in habitat used by nesting peregrines. Although bald eagles winter along the Yampa River, they would not be impacted by the project. There are no prairie dogs in the project area, thus we believe there would be no impact on black-footed ferrets which prey primarily on prairie dogs and dwell in their burrows.

The Uinta Basin hookless cactus may occur in the vicinity of the project; however, this species would not be impacted by the project because gravel bluffs and rocky soils which support this species do not occur near the Craig Station. We agree with the biological assessment that the spineless hedgehog cactus would not be impacted because it does not occur near the project site.

We appreciate the cooperation which the REA and Colorado-Ute have given us during this consultation.

Sincerely yours,

/s/ [illegible]

Regional Director

Attchment (Fig. 1)

bcc: Area Manager, Salt Lake City
ARD, Env

SE/S16/Reviewed:WWathen/mb:3/12/80

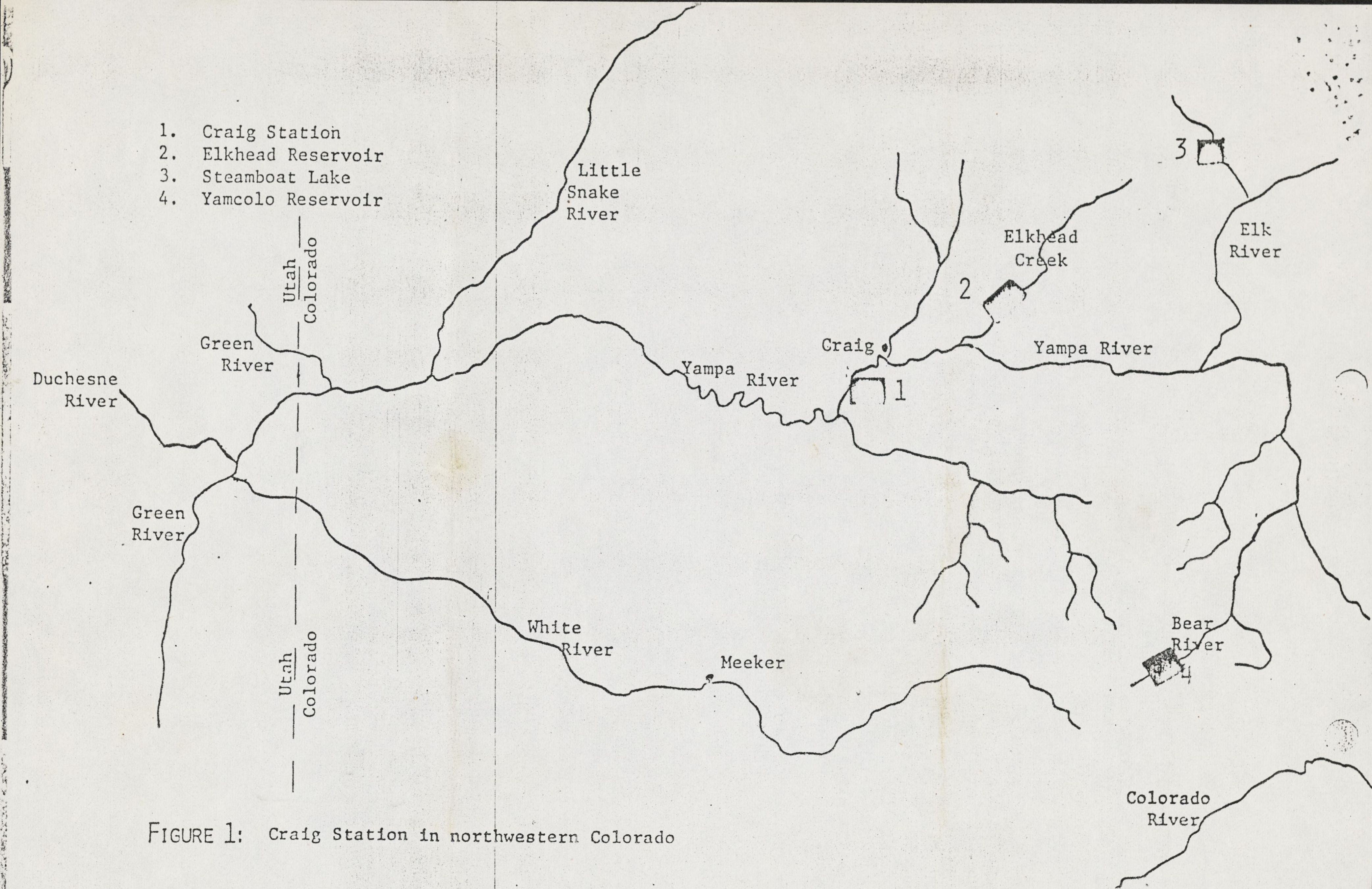

FIGURE 1: Craig Station in northwestern Colorado

Rec. Meet. | 524-4430
St. George ~~Jury~~ — FTS 588-4430
12-13

SLC/SE:6-5-82-F-006 (COE--
Taylor Draw Dam and Reservoir)

p. 3-4

DRAFT

Thur. May 27
Meet, 9-4PM

1982

Colonel Paul F. Kavanaugh
District Engineer
U. S. Army Corps of Engineers
Sacramento District
650 Capitol Mall
Sacramento, California 95814

Dear Colonel Kavanaugh:

We prepared this biological opinion in response to your request for consultation for the Taylor Draw Reservoir Project (TDRP) proposed for construction east of Rangely, Colorado in Rio Blanco County. This opinion has been prepared as prescribed in the Section 7 Interagency Cooperation Regulations, 50 CFR 402, and the Endangered Species Act (ESA), 16 USC 16 _et seq_. Data sources and information referenced herein are part of the administrative record of this opinion and are located in the U. S. Fish and Wildlife Service's (FWS) Salt Lake City Office.

BIOLOGICAL OPINION

Operation of the TDRP as described below, which includes conservation measures designed to aid in the survival and recovery of the Colorado squawfish (_Ptychocheilus lucius_), is not likely to jeopardize the continued existence of the bald eagle (_Haliaeetus leucocephalus_), peregrine falcon (_Falco peregrinus anatum_), whooping crane (_Grus americana_), humpback chub (_Gila cypha_), bonytail chub (_Gila elegans_), or the Colorado squawfish.

PROJECT DESCRIPTION

The applicant, Water Users Association No. 1 (WUA) a subdistrict of the Colorado River Water Conservation District, proposes to construct and operate a dam and reservoir on the White River. The TDRP would be located approximately five miles east of Rangely, Colorado, about 300 feet upstream from the confluence of Taylor Draw and the White River.

The basic purpose of the TDRP is to provide a dependable municipal and industrial water supply to the town of Rangely and provide needed flood control and recreation. Current population estimates project the present population of the town of Rangely to increase 1.5 to 3 fold during the twenty year planning period ending in the year 2000. Another potential purpose would be

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hydroelectrical generation. The outlet conduit would be sized to accommodate a 2,000 kw power plant in the future. Studies estimate that the power plant could generate an estimated 10 million kwh of electricity on an average annual basis. When and if the power plant were built it would have to operate as a run of the river plant unless storage water was assigned strictly for power.

The reservoir would be about 6 river miles long and would inundate approximately 615 surface acres when filled to capacity. The reservoir would have an active storage capacity of ~~13,800~~ acre-feet (af) and a dead pool storage of 2100 af, for a total of ~~15,900~~ af. The dam would be constructed of earth and rock-fill materials and would be approximately 64 feet high. 11,700 13,800

The majority of the time the reservoir would be operated as a run of the river reservoir where the outflow from the dam would be the same as the inflow coming into the reservoir. During drought years (such as 1977) the dam will release a minimum of 200 cfs (144,800 af) or natural flow, whichever is less. The operation plan calls for filling the reservoir once/year during the peak runoff months of April, May, and June. This would occur after drawdown of the reservoir in dry years. During normal spring flows, it is expected that the reservoir will fill in 2 to 3 days. However, for the first 16 years it is predicted that the reservoir will remain full. Between 2500 (3.5 cfs) and 21,160 af (29 cfs) (this includes 1500 af (2 cfs) as average annual evaporation loss from the reservoir) would be depleted from the White River annually.

The only action discussed in this biological opinion is the applicant's proposed project. The draft EIS (DEIS) prepared by the U. S. Army Corps of Engineers (COE) discusses 5 alternatives to the TDRP. If one of the alternatives other than the proposal addressed in this opinion is selected, Section 7 consultation should be reinitiated. Additionally, should information become available in the future which was not available at the time of this consultation and which may show additional adverse impacts to listed species that was not considered in this biological opinion, Section 7 consultation should be reinitiated.

PROJECT IMPACTS TO THE AQUATIC ENVIRONMENT

The White River near the Colorado-Utah State line USGS (Watson gage), approximately 20 miles below the TDRP, had an average annual discharge of 502,800 af (695 cfs) during the period 1923-1978. The lowest annual flow over this 55 year period was 223,200 af (308 cfs) in 1977. Late spring peak flows average 2,172,000 af (3000 cfs) to 2,896,000 af (4000 cfs). The minimum historic flow rate was 7964 af (11 cfs) recorded once in 1972 and again in 1977. The maximum flow rate was 5,907,840 af (1860 cfs) recorded on 15 July 1929.

Flow in the White River near the Colorado-Utah State line would be depleted due to the TDRP between 2500 af (3.5 cfs) and 21,160 af (29 cfs) per year or approximately a 0.5 to 4% depletion of the average annual discharge of the White River. As was mentioned previously, reduced flows downstream from the reservoir during filling should be minimal because it will occur during peak spring flows. Even in an extremely dry year like 1977 the flow in the White River would have been in excess of 217,200 af (300 cfs) downstream from the dam during filling.

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During the period between 1963 and 1978 (after the closure of Flaming Gorge Dam) the Green River near Green River, Utah, had an average annual ~~flow~~ discharge of 3,990,688 of (5512 cfs). This location near Green River, Utah, is 120 miles up the Green River from its confluence with the Colorado River. The lowest annual flow during this period was 1,662,600 af (2,300 cfs) in 1963 and the highest was 5,388,300 (7,429 cfs) in 1973. The lowest monthly flow was 47,500 af (772 cfs) recorded in October 1964.

Flow in the Green River at Green River, Utah, would be depleted due to the TDRP between 2500 af (3.5 cfs) and 21,160 af (29 cfs) per year or approximately a 0.006 to 0.5% depletion of the average annual discharge of the Green River.

The reservoir is expected to strongly stratify in June and July and would be subject to eutrophication. It is expected that water temperatures in the White River below the TDRP would not be significantly affected by the presence and operation of the TDRP. The DEIS depicted a temperature change of approximately 2°C less than natural conditions (from 21°C to 19°C) during a high flow year for the month of July at the dam site. During a low flow year measured in July, the change from natural conditions would range from approximately 5°C (from 21°C to 16°C) at the dam site to approximately 1.5°C (from 21 to 19.5°C) 30 miles downstream from the dam. During a very low flow year measured in July, the change from natural conditions would range from approximately 10°C (from 20°C to 10°C) at the dam site to no change 25 miles downstream from the dam.

It is estimated that the proposed project would result in an increase of salinity of 0.7 mg/l as measured at Imperial Dam, California.

The average annual silt load of the White River would be reduced as a result of the TDRP. This will result in a modification of the downstream channel morphology below TDRP in the White River over a period of years.

Both the Green and Colorado Rivers have experienced significant peak flow reductions due to existing reservoir operation and an overall depletion in water for various purposes. Peak flow levels, magnitude, and duration primarily determine river morphology and habitat conditions. Peak flows have been drastically reduced in the Colorado River system resulting in sediment buildup in certain areas, water temperature changes, and other chemical changes in the River system (FWS 1982). The TDRP would change the peak flow regime of the White River during spring runoff by reducing the amount of water reaching the Green River during this time period. This will further add to the chemical and physical changes occurring in the Green River. These insignif. physical and chemical changes would probably benefit the introduced exotic fishes while having slight detrimental effects on the endemic and endangered species in the upper Colorado River system (FWS 1982). w/o conservation measures

To increase knowledge of the Colorado River endemic fishes' (primarily the listed species) habitat requirements, a Colorado River Fishes Investigation Team was established in April 1979. This team is staffed with FWS personnel and has funding from the FWS, BLM, and the Bureau of Reclamation (BR). Other participants are the Utah Division of Wildlife Resources (DWR) and the Colorado Division of Wildlife (DOW). The major objective of the team's study is

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to learn additional life history requirements of the listed fishes. Under our funding agreement with BR and BLM, most of the field work is in the Colorado River system where impacts from BR and BLM projects will be the greatest. Information obtained during the study via field, laboratory, and hatchery work has made it possible to provide recommendations in this opinion to maintain and develop more favorable habitat for the listed fishes. no way!

BASIS FOR OPINION

COLORADO SQUAWFISH

Early records indicate that the Colorado squawfish was once found throughout the Colorado River system from the upper Green River in Wyoming to the Gulf of California, including the Gila River basin in Arizona. It was abundant over all of its range prior to the 1850's (Seethaler 1978).

The present range of the Colorado squawfish is restricted to the Upper Colorado River Basin. It is found inhabiting about 360 mi of the mainstem Green River, from the mouth of the Yampa River to its confluence with the Colorado River. It's range extends 108 mi up the Yampa River and 150 mi up the White River, tributaries to the Green River. In the mainstem Colorado River it is found from above Lake Powell extending about 200 mi upstream and from the lower 30 mi of the Gunnison River, a tributary to the mainstem Colorado River. Approximately 67 mi of known squawfish habitat above the proposed dam site (about 9% of the total known squawfish habitat) will be adversely affected due to the TDRP, primarily because the dam will physically block seasonal movement of squawfish in and out of this 67 mi section of habitat above the proposed dam. The Taylor Draw dam site is located approximately 83 mi upstream from the confluence of the Green and White Rivers. In addition, at least 6 mi of riverine habitat will be converted to lentic habitat.

136

67 vs 80

4%

Studies in the White River have documented occurrence of squawfish in several locations. There are unsubstantiated reports of squawfish that were commonly caught by hook and line in the 1940's from the White River from the bridge near Bonanza, Utah (Seethaler 1978). Several adult squawfish were observed or collected in the upper White River in Colorado (near Piceance Creek) in the late 1960's (May 1970) and in 1977 (Prewitt et al. 1978). Six adult squawfish were captured and at least seven others observed in the lower 12 mi of the White River in July and September 1978. Two squawfish were captured in the White River 29 mi and 42 mi above the mouth in May and June 1979, respectively (Lanigan and Berry 1979). Two squawfish were found in Colorado 52 mi upstream from the Utah border in 1978. The DOW collected 1 adult squawfish about 122 mi up the White River in 1980 and collected 1 adult squawfish and saw one other 150 mi up the White River in 1981 (Personal Comm. with Ed Wick, February 1, 1982). Squawfish have been found consistently in the Green River at the mouth of the White River.

In the only intensive systemic study carried out in the White River, during the 1981 field season, the FWS collected 51 Colorado squawfish, of which, 37 (72%) were adults over 400 mm total length (TL) and 14 (27%) were juveniles

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ranging in size from 60 to 400 mm TL. Only 15 of these 51 squawfish (29%) were collected above the proposed dam site. The upper range of distribution appears to be 150 mi up to the White River. No young-of-the-year (YOY) squawfish have been collected in the White River.

Decline in populations of Colorado squawfish correlates very closely with the construction of dams and reservoirs, and the removal of water from the Colorado River system. Colorado squawfish evolved in and apparently require habitat conditions typified by great seasonal fluctuations in flow, high turbidity and silt load, and warm summer temperatures. Additionally, it appears that the Colorado squawfish requires relatively unrestricted movement to satisfy all of their life history requirements. Movement of adult Colorado squawfish appears to be related to flow, temperature, feeding and spawning behavior. Movement and spawning migrations have been documented by tagging and radio-tracking programs (FWS 1982). A potential movement between the White and Green Rivers is indicated by the capture of a large number of squawfish at the mouth of the White River, the recapture of a squawfish in the lower White River tagged in the Green River, and the movement of two radio-tagged fish between the Green and lower White Rivers. In addition, one radio-tagged squawfish moved from the lower White River into the lower Green River and returned back into the lower White River, traveling almost 400 mi from May 29 to October 7, 1981, when contact was lost.

In the White and Yampa Rivers upstream and downstream movement occurs in association with spawning. There is evidence of homing behavior with some radio-tagged fish returning to areas where they were originally tagged following extensive migration (FWS 1982).

FWS (1982) concluded from collections of larvae and YOY Colorado squawfish below suspected spawning sites that there is a downstream drift of larvae and YOY following hatching. This movement can be any distance from a few miles (1-10 mi.) to many miles (up to 100 mi.). There is also evidence that, after their first year, some juvenile fish may move progressively upstream to areas of better feeding including lower sections of tributary streams.

Apparently, natural spawning of squawfish occurs between 20 and 22°C. Spawning both in the hatchery and in the field occurred between June 15 and July 15. At 13°C, egg mortality was 100% in a controlled test. At 16-18°C, development of the egg is slightly retarded, but hatching success and survival of larvae were higher. At 20-26°C, development and survival through the larval stage were up to 95% (FWS 1982). Juvenile temperature preference tests showed preferred temperature that ranged from 21.9°C to 27.6°C with an estimated final preferendum of 24.6°C, which was approximately the same as that for adults.

To complete its life cycle, the Colorado squawfish requires water temperatures of 20 to 28°C from mid-June to October. A temperature of about 20°C is required for spawning while temperatures that are near 24°C, the preferred temperature, are needed for optimal development and growth of young (FWS 1982).

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Although no Colorado squawfish spawning has been documented in the White River, a potential spawning site exists in the lower 50 miles (below the proposed White River Dam) of the White River. A radio-tagged squawfish was tracked to River Mile 34 on July 16, 1980, where apparent spawning behavior was observed on a riffle (FWS 1982). The significance of this is that there is only one other known squawfish spawning site in the upper Colorado River basin (lower 20 mi of Yampa River). A key to preserving the Colorado squawfish is the preservation of the integrity of its spawning site and the maintenance of conditions conducive to egg survival (FWS 1982).

The proposed TDRP, without the conservation measures, would adversely alter habitat characteristics in the White River believed essential for continued existence of the Colorado squawfish. The project would reduce peak spring flows, reduce turbidity and silt load, and reduce annual flows.

The project could potentially isolate squawfish above the dam site, preventing these fish from migrating. Conversion of a lotic habitat into a lentic habitat, via the construction of the proposed reservoir, would create habitat favorable for non-native fish species resulting in decreased habitat for the native species. This apparently will not adversely affect the adult life stage as adults in good condition have been collected in Lake Powell. This could potentially contribute to the further proliferation of non-native fish species in the upper Colorado River basin.

It is our opinion that the TDRP will not significantly alter the temperature regime below the proposed dam, during normal and low flow conditions. However, during drought years the temperature will be significantly altered for the first 20 miles immediately below the dam.

The White River is one of two tributary streams in the entire Green River Basin still considered acceptable habitat for squawfish. Other historically important tributaries have been so altered that they no longer receive significant use from squawfish. Alteration of the upper mainstem Green River by Flaming Gorge Reservoir has increased the importance of the major tributaries. The relatively natural flows of major tributaries entering the Green River below Flaming Gorge help to ameliorate the effects of that reservoir. In light of the above, the TDRP would have been likely to jeopardize the continued existence of the Colorado squawfish without changes to the project that have been agreed to as is discussed in the Conservation Measures section of this opinion.

It is also recognized that should the White River dam in Utah be constructed (refer to biological opinion issued by the FWS on February 24, 1982 to the BLM) the effects of the TDRP on the migration, spawning and rearing of squawfish would be decreased substantially. Until more information becomes available, the portion of the White River above the proposed White River dam is considered habitat for juvenile and adult squawfish. Spawning and YOY rearing is thought to occur below the proposed White River Dam.

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HUMPBACK CHUB

The only major populations of humpback chub conclusively known to exist in the upper Colorado River basin are located in Black Rocks (river mile 135-137) and Westwater Canyons (river mile 116-124) on the main Colorado River. Incidental captures were recorded from Cataract Canyon; throughout Gray and Desolation Canyons on the Green River; and at the lower end of Cross Mountain Canyon and in Yampa Canyon on the Yampa River. Populations of indistinct taxonomy were identified near Coal Creek in lower Gray Canyon and in DeBeque Canyon (river mi 195-197) on the main Colorado River (FWS 1982).

Since the TDRP will not have any significantly measurable effect on the Colorado River at the sites where known humpback chub populations occur, in our opinion, the proposed project is not likely to jeopardize the continued existence of the humpback chub.

BONYTAIL CHUB

The only recognized pure population of bonytail chub occur in Lake Mohave, Arizona (FWS 1982). Since the WRDP will not have any significant effect on the lower Colorado River basin, in our opinion, the proposed project is not likely to jeopardize the continued existence of bonytail chub.

BALD EAGLE

The bald eagle occurs in the project area mainly as a winter resident and a spring and fall migrant. Bald eagles congregate at specific wintering sites in Utah and Colorado from late October through March. Open water on the White River during spring and fall attracts eagles because of fish and waterfowl availability. Deer carcasses along the riparian zone and rabbits on the nearby uplands provide additional food. The eagles also roost in the cottonwood trees along the river.

Eagle use along the White River, in winter, is marginal because the river is usually frozen over, reducing prey availability. We suspect that the period of highest eagle use in the project area occurs during spring migration. Canada geese and other waterfowl populations increase in the spring offering eagles an additional food supply.

It is doubtful the proposed TDRP would produce benefits for the bald eagle. Habitat suitable for wintering bald eagles should contain large open perch trees near adequate food supplies. Many reservoirs in Utah and Colorado lack these requirements and use by eagles is minimal.

The proposed project is not likely to jeopardize the continued existence of the bald eagle because no nesting birds are involved, and because the species has broad winter habitat requirements, and is an opportunistic feeder. Additional riparian habitat occurs above and below the project impact area. However, the loss of 6 miles of riparian habitat would be part of a cumulative loss of eagle habitat along the White River. Future energy exploration and development will place futher demands on river water, contributing to the loss of additional riparian habitat, and therefore the following alternatives are recommended which will contribute to the conservation of the bald eagle.

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RECOMMENDATIONS FOR BALD EAGLES

Section 7(a) (1) of the ESA states that all Federal agencies shall utilize their authorities by carrying out programs for the conservation of endangered and threatened species. The following will help with the conservation of bald eagles.

The main objective in managing wintering bald eagles is to provide them with suitable habitat so they can return to the breeding range in healthy condition. Suitable winter habitat involves maintaining adequate food supplies, and protecting roost sites from human development and disturbance. We recommend that cottonwood stands below the dam be maintained. Furthermore, we recommend planting of cottonwood trees along the shoreline where soil and water conditions favor their development.

Because eagle electrocutions are a serious problem in Utah, electrical distribution lines, especially those between 4 kilovolt and 69 kilovolt should be constructed according to specifications in the 1975 manual "Suggested Practices for Raptor Protection on Powerlines." This would be applicable if the hydroelectric generation facility were constructed.

PEREGRINE FALCON

Populations of the peregrine falcon sharply declined in the 1940's, and the species has disappeared as a wild breeding brid east of the Mississippi River. There appears to be limited use of the project area by peregrine falcons. Consequently, in our opinion the proposed project is not likely to jeopardize the continued existence of the peregrine falcon.

WHOOPING CRANE

The experimental population of whooping cranes that pass through the area from Idaho should not be affected by the TDRP because no use has been established. Therefore, the TDRP is not likely to jeopardize the continued existence of the whooping crane.

CONSERVATION MEASURES FOR THE COLORADO SQUAWFISH

The following conservation measures have been incorporated as a part of the project by the applicant and are being considered as project features in this opinion. The applicant will provide funding to insure that the following conservation measures are implemented. Specific details on time frames, funding, and responsibilities will be contained in a memorandum of agreement (MOA) entered into by appropriate officials of the WUA, DOW, and FWS, and such agreement will be reached by July 1, 1982.

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1. Operation of the dam

   a. Temperature releases for the TDRP supplied by the applicant indicate that recommended temperatures for the various life stages of the Colorado squawfish would be met during normal and low flows. During drought conditions the recommended temperatures for YOY rearing and spawning would not be met for the first 20 miles below the dam. Presently, no squawfish spawning or YOY rearing has been documented or suggested from this area of the White River. It is uncertain whether squawfish spawning occurs naturally during drought conditions. Should future studies document squawfish spawning in this section of the White River, every effort should be made by the applicant, in consultation with the FWS and DOW, to protect and enhance it for spawning and/or YOY rearing.

   b. Flow releases for the TDRP supplied by the applicant indicate that recommended flows for the various life stages of the Colorado squawfish would be met. The majority of the time the TDRP will be operated such that the outflow form the dam is the same as the inflow into the reservoir. During drought years the dam will release a minimum of 144,800 af (200 cfs) or natural flow entering the reservoir, whichever is less. Based upon the applicants flow information, flows for the various life stages of the squawfish will also be met during the reservoir filling period.

   c. Beginning with the reservoir filling period and continuing after the reservoir begins operation, annual meetings will be held between the WUA, DOW, and FWS. The purpose of these meetings will be to analyze operating critieria for the project facilities and to discuss and incorporate new biological information into the project's operation. If the White River Dam is constructed, these meetings could be held jointly with those, which are designed for the same purpose (determining annual operation criteria for the White River Dam project). This would aid in coordinating recovery efforts for the squawfish in the White River in Utah and Colorado.

2. Monitor the squawfish habitat below the dam to the State line on the White River.

   a. A plan will be jointly developed (as part of the above mentioned MOA) by the WUA, DOW, and FWS, to:

      1) Monitor the squawfish population below the dam (to the State line) and obtain an estimate of the total number of squawfish in this area.

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2) Analyze the flows and temperature releases from the TDRP and, if necessary modify releases as FWS and DOW determines advisable. (This is based upon the results of 2.a.1.)

3) Carry out habitat enhancement work for the squawfish below TDRP (to the State line) if determined feasible (based upon the results of 2.a.1.) by the FWS and DOW.

3. Monitor the squawfish habitat above the dam.

a. A plan will be jointly developed (as part of the above mentioned MOA) by the WUA, DOW, and FWS, to:

1) Monitor the squawfish population above the reservoir and obtain an estimate of the total number of squawfish in this area.

2) Carry out habitat enhancement work for the squawfish above the reservoir if determined feasible (based upon the results of 3.a.1.) by the FWS and DOW.

4. Determine the feasibility of squawfish passage around or through the dam. These conservation measures relating to the upstream population do not guarantee that there will be a self-sustaining subpopulation in the area above the dam. However, in our opinion the potential loss of that subpopulation will not result in the likelihood of jeopardy of the species. This study could be combined with a similar studying being carried out by the State of Utah for the White River Dam.

a. This will require investigation of several techniques such as fish passage ways, trucking, etc.

b. If determined feasible by DOW and FWS, a plan will be implemented to move squawfish around or through the dam.

5. Participate in carrying out actions and measures to be identified in the forthcoming conservation plan for the endangered Colorado River fishes. This likely will include but not be limited to supporting the development of an endangered species hatchery and contributing a share of the manpower, equipment, materials, or equivalent funding for hatchery planning, site selection, design, and fish stocking. The extent of participation will be based upon percent of impact this project has on the entire population of Colorado squawfish equitably measured, based upon stream flow depletion and/or percent of habitat impacted.

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6. Develop a fishery in the reservoir that will not compete with the native species in the White River.

We appreciate your strong interest in conserving endangered species.

Sincerely,

United States Department of the Interior

FISH AND WILDLIFE SERVICE
AREA OFFICE COLORADO—UTAH
1311 FEDERAL BUILDING
125 SOUTH STATE STREET
SALT LAKE CITY, UTAH 84138

IN REPLY REFER TO:
SLC/SE:6-5-82-F-005

18 March 1982

MEMORANDUM

TO: Regional Director, Bureau of Reclamation
Lower Missouri Region, Denver, Colorado

FROM: Acting Area Manager, Fish and Wildlife Service
Area 5, Salt Lake City, Utah

SUBJECT: Biological Opinion on the Sale of 7,850 Acre-feet of Water from Ruedi Reservoir

Reference is made to your 16 December 1981 request for formal consultation on the sale of 7,850 acre-feet of water annually from Ruedi Reservoir. A biological opinion for the Battlement Mesa Community Development Project was issued on 6 November 1981. That biological opinion considered the use of 1,250 acre-feet of water from Ruedi Reservoir. Thus, this opinion addresses the remaining 6,600 acre-feet of water considered in the water sale. This biological opinion has been prepared as prescribed by the Section 7 Interagency Cooperation Regulations (50 C.F.R. 402) and the Endangered Species Act (ESA) 16 U.S.C. 1531 et seq.

BIOLOGICAL OPINION

The sale and subsequent diversion from the Colorado River, of 7,850 acre-feet of water annually from Ruedi Reservoir is not likely to jeopardize the continued existence of the bald eagle (Haliaeetus leucocephalus), American peregrine falcon (Falco peregrinus anatum), and the bonytail chub (Gila elegans). The project as described below, which includes conservation measures designed to offset jeopardy to the Colorado River fishes, is also not likely to jeopardize the continued existence of the Colorado squawfish (Ptychocheilus lucius) and humpback chub (Gila cypha).

PROJECT DESCRIPTION

The purpose of the water sale is to provide a maximum firm water supply of 7,850 acre-feet per year from Ruedi Reservoir to supplement water supplies for the Colony Shale Oil Project, the community of Battlement Mesa and the Basalt and West Divide Water Conservancy Districts.

The Colony Shale Oil Project, located in Garfield County, approximately 16 miles north of the town of Parachute, (Grand Valley) Colorado, is a mining and retort operation being developed by Exxon Company, U.S.A. and The Oil Shale

Corporation to produce oil from shale. The project, when fully developed, will mine 66,000 tons of oil shale per day for 27 years with an estimated production of 47,000 barrels of oil per day.

The oil shale development will require water for mining, coarse ore storage, retorting and upgrading, processed shale disposal, general plant and personnel and construction. The primary source of water contemplated for these industrial uses is the diversion of water from the Colorado River by the Dow Pumping Plant and Pipeline. The Dow Pumping Plant and Pipeline is decreed for a total of 178 cubic feet per second (cfs), 20 of which has been conveyed to Battlement Mesa, Inc. for municipal purposes. The remaining 158 cfs of this water right diverts from the north bank of the Colorado River to the Colony Development site. The water rights are subject to curtailment by senior water rights during months of low flows. Thus, the Colony Shale Oil Project needs supplemental water to assure the continued operation of an oil shale development.

As a result of predicted population growth, Battlement Mesa, Basalt, and West Divide need additional water supplies to meet increased demand for water. Therefore, an additional firm supply of water is required to augment the present water supplies, particularly during periods of high demand.

Ruedi Dam and Reservoir located on the Fryingpan River about 13 miles (mi) upstream from the town of Basalt, Eagle and Pitkin Counties has been identified as a potential source of water for the purposes stated above. Ruedi Reservoir was constructed to provide storage for replacement of water diverted from the western slope to the eastern slope and an additional regulated water supply for other uses on the western slope of Colorado.

The reservoir has an active storage capacity of 101,280 acre-feet and 1,082 acre-feet of inactive and dead storage. The firm annual yield of Ruedi Reservoir averages 77,800 acre-feet. Of this amount, up to 28,300 acre-feet could be used for replacement of Fryingpan-Arkansas Project diversions to protect senior western slope water rights and 49,500 acre-feet (firm yield) would be the maximum amount available for other uses. The sale of water to Exxon Company, U.S.A., Battlement Mesa Inc., and the West Divide and Basalt Water Conservancy Districts would represent the first sale from Ruedi Reservoir regulatory storage.

Exxon Company, U.S.A., as operator of the Colony Shale Oil Project, proposes to purchase a maximum of 6,000 acre-feet per year from Ruedi Reservoir to meet supplemental water needs for operation of the Colony Shale Oil Project. Addititionally, Battlement Mesa, Basalt and West Divide propose to purchase 1,250 acre-feet per year, 500 acre-feet per year, and 100 acre-feet per year, respectively. Therefore the total purchase from Ruedi Reservoir amounts to a maximum of 7,850 acre-feet per year. However, as stated previously, this opinion addresses the sale of 6,000 acre-feet of water to Colony, 500 acre-feet to Basalt, and 100 acre-feet to West Divide.

Based on studies of water supply and demand on the Colorado River for the period 1941-1970, the estimated replacement water need for the Colony Shale Oil Project would have ranged between 892 acre-feet in 1962 to 4,550 acre-feet in 1954 and 1963 with a mean of 2,879 acre-feet per year. The request for

6,000 acre-feet is intended to be a "worst case" situation which would account for exceptionally dry years. Based on needs in a dry year (1977) and an average year (1974), water releases would have been required during five months each year. The amount of water required in any one month would range between 833 and 922 acre-feet.

Releases for Basalt and West Divide would have ranged from 349 acre-feet to 599 acre-feet per year with a mean of 362 acre-feet annually. Thus, the average annual depletions resulting from the Colony Shale Oil Project, and the diversions to Basalt and West Divide would be 3,241 acre-feet. Exxon Corporation has agreed to incorporate into their project a provision for funding compensating measures to be undertaken to offset the impacts of the project on endangered species, particularly the endemic species of fish.

BASIS FOR OPINION

BALD EAGLE, AND AMERICAN PEREGRINE FALCON

The Fish and Wildlife Service (FWS) concurs with the biological assessment prepared by Environmental Research and Technology, Inc. for the Exxon Company concerning the American peregrine falcon. The sale of water from Ruedi Reservoir will not affect the falcon.

We have also concluded that the water sale would not jeopardize the continued existence of the bald eagle. However, the FWS is concerned that the secondary impacts of the Colony Shale Oil development near a bald eagle high use wintering area may adversely affect the use of this important wintering area. Therefore, we strongly encourage Exxon, working with Battlement Mesa, Inc. to implement the following measures:

1. Purchase land around the roost sites and provide fenced protection from human activity during winter.

2. Protect vegetation along the river in the vicinity of the project.

3. Avoid construction activities within a half-mile of eagle roost areas during winter.

4. Establish a half-mile (minimum) buffer zone between the river and any major development with protection from human activity.

5. Establish an education program encompassing the above suggestions and other inputs from State and Federal agencies.

6. Develop a management plan encompassing the above suggestions and other inputs from State and Federal agencies.

7. Coordinate all management plans with Colorado Division of Wildlife (DOW).

BONYTAIL CHUB

The bonytail chub have not been known to occur in the area to be impacted by the Ruedi Reservoir water sale within recent times. It is probably extirpated from the mainstream of the Colorado River except for senescent populations of adults in lower basin impoundments.

COLORADO SQUAWFISH AND HUMPBACK CHUB

Colorado squawfish and humpback chub were once abundant throughout the Colorado River System from the Gulf of California to southwestern Wyoming. Presently, the squawfish is limited to the upper mainstem and major tributaries of the Colorado River System. The humpback chub is found only in limited areas within the river system in Colorado, Utah, and Arizona. The primary cause of decline for these fish species is human alteration and degradation of the river environment. Major impoundments and water diversions have depleted water supplies and altered the temperatures, turbidity, salinity, and flows of the stream, thus reducing habitat for endemic fishes.

There are three major interacting factors that explain in major part the present status of the endemic species of the Colorado River Basin. These are: 1) reservoirs, 2) diversions of water from the Basin for various uses, and 3) environmental changes in the river brought about by 1) and 2).

The most obvious and clearly identifiable factor contributing to the decline of native species is the large dams and reservoirs that converted hundreds of miles of river habitat into great impoundments. Prior to the listing of the endangered fishes, the preservation of these fishes was not considered in the planning and operation of these projects. It has been determined that Colorado squawfish and humpback chub do not reproduce successfully in large reservoirs. The alterations resulting from the large dams changed a river of great extremes of flow, temperature, and turbidity into a series of reservoirs discharging cold, clear water at a relatively constant temperature. Since the native fishes' life stages requirements are based on the natural river conditions, they could not adapt to the changed conditions, and populations rapidly declined. The adults present in the river when a dam is constructed may continue to live in a reservoir and may thrive and grow, but the populations consist of fewer, larger, and older fish each successive year until they all die of old age or other causes.

Water depletions both directly by diversion and indirect by consumption and evaporation from the Colorado River Basin have drastically altered flow patterns, water quality parameters, and river channel characteristics, and have contributed to the elimination and alteration of the backwater nursery areas of the endemic Colorado River fish species.

For the Colorado squawfish much essential habitat is no longer present. There is general agreement among Federal and state biologists studying endangered fishes of the Upper Colorado that the natural flow regime of high spring and early summer flows followed by a gradual period of decreasing summer flows are beneficial to Colorado squawfish and humpback chub reproduction.

A less important cause of decline may be the increased number of exotic fishes, but this increase in exotics also is a function of habitat changes. Although correlations exist between declining native fish populations and increasing populations of exotic fish, cause and effect are not fully understood. The evidence of harmful effects of non-native species on the endangered Colorado River fishes is largely circumstantial. However, there is no doubt that fewer exotic fishes would be present if the river more closely resembled its natural state.

note no final date given for completion of 'research'

Ruedi water sale to Exxon 1982

To increase knowledge of the fishes' habitat requirements, the Colorado River Fishery Project (CRFP) team was established in April 1979. This team is staffed with FWS personnel and has funding from the FWS, Bureau of Reclamation (BR), and the Bureau of Land Management (BLM). Other participants are the Utah Division of Wildlife Resources and the DOW. Major objectives of the team's study were to learn additional life history requirements of the listed fishes. Under our funding agreement with BR and BLM, most of the field work was in the Green and Colorado Rivers where impacts from BR and BLM projects are the greatest. Information obtained during the study via field, laboratory, and hatchery work has made it possible to provide recommendations to maintain and develop more favorable habitat for the listed fishes. As a result of the CRFP study the FWS has determined that the Colorado squawfish and humpback chub are experiencing declines in their present habitat and without active reclamation action will become extinct. Any further degradation of their environment such as water depletion will accelerate the extinction of these species if not properly offset by active conservation measures.

wrong!

In analyzing the impacts of the Ruedi Reservoir water sales we confined our analysis to the main Colorado River and to the endangered Colorado squawfish and humpback chub.

Colorado squawfish, while not abundant anywhere, were captured consistently throughout a major portion of the upper Colorado River system. Adult squawfish were especially widespread in their distribution, a reflection of their predatory nature and the prevalence of suitable habitats throughout the river system. Juvenile and young-of-the-year (YOY) squawfish exhibited a much more localized distribution due to an affinity for habitats that were much more restricted in distribution.

Investigations by the CRFP team over the past three years have demonstrated that adult squawfish are inhabiting some 360 mi of the mainstem Green River and that their range of occupation extends 134 mi up the White River and 108 mi up the Yampa. On the mainstem Colorado above Lake Powell, Colorado squawfish were collected in the lower 200 mi of river and from the lower 30 mi of the Gunnison River.

because of spawning

Collections were variable throughout the sampling period, but 41% of the adult squawfish collected from the main Colorado River were from a 50 mi reach between river mile (RM) 125 and 175, the section of river between Grand Junction downstream to the head of Westwater Canyon. This also is the area where the major impact of water depletion incident to the Ruedi Reservoir water sale will occur.

Life stages of the Colorado squawfish most critical to its continued existence include spawning and YOY rearing. In the Colorado River reproduction of Colorado squawfish is suspected to occur in the Loma to Black Rocks area and the Professor Valley area near Moab, Utah. YOY rearing areas are located downstream from these suspected spawning areas.

Related to spawning of Colorado squawfish is the migration and movement of these fish to a spawning area. FWS studies have demonstrated the occurrence of spawning migrations in the Green and Yampa Rivers and we now believe a similar movement occurs in the mainstem Colorado River.

Movement of adult Colorado squawfish appears to be related to flow, temperature, and feeding. Adults were recorded further upstream, in the mainstem rivers and in tributaries such as the Yampa and White, during postrunoff than in prerunoff periods. The total movement picture suggests that adult squawfish move upstream during runoff and this movement, in part, is associated with spawning. There appears to be a general trend of upstream movement after runoff. Downstream movement occurs between postrunoff in the late fall and winter, and runoff the following spring-summer. Downstream movement is probably related to cold water temperature in the fall, inactivity and selection of deep-pool overwintering areas.

There is a downstream drift of larvae and YOY Colorado squawfish following hatching. This movement can be any distance from a few miles (1-10 mi) to many miles (up to 100 mi). There is also evidence that, after their first year, juvenile fish move progressively upstream to areas of better feeding including lower sections of tributary streams.

The life-stages that appear to be the most critical for the Colorado squawfish are during the period from the initial spawning act on through its first year of life. It has been demonstrated that these phases of a squawfish's development are also tied very closely to some very specific habitat requirements and are the major reason for their being critical. There is a very real need for the proper flows and temperatures during this critical life stage to provide the specific habitat requirements of the Colorado squawfish.

Spawning is generally a highly vulnerable period for most fishes where a relatively minor environmental change can be devastating to a population's reproductive success. This appears to be true with the squawfish. Spawning habitats are very limited and they must meet some very rigid requirements to be suitable.

Only one documented spawning site was identified for Colorado squawfish during the 3-year CRFP study, but based on young fish collection FWS believes an area exists between Loma and Black Rocks and another area near Moab on the mainstem Colorado River.

The progression from egg to yearling is another segment of this fish's life history that is very finely balanced between adequate recruitment to maintain a viable population and slow decline to extinction. Indications are that larvae drift, probably passively for a time, downstream into more moderate reaches which offer sanctuaries in the form of backwaters. This drift appears to be up to 100 mi distant. These larvae and fry have exhibited such a strong attraction to backwaters that one can only conclude that backwaters are very critical to these fish's survival. Observations suggest that those backwaters that are not permanent throughout the hydraulic cycle, those flushed by high flows and dewatered by low flows, generally supported more young squawfish.

Not enough information exists to establish whether the juvenile stage of the Colorado squawfish is critical. Adult squawfish are not especially demanding in their habitat needs. Suitable habitats are quite prevalent throughout much of unimpounded sections of the upper basin.

In summary the Colorado River squawfish is most vulnerable during spawning and during the first year of growth. Required flows and associated water temperatures are needed to initiate spawning behavior in adult Colorado squawfish and to maintain the desirable characteristics of the spawning grounds and YOY rearing areas. Reduced flows in the Colorado River will impair this habitat and behavior. Passage for spawning migrations must be maintained and spawning grounds and YOY rearing areas must be preserved and if possible enhanced.

The only major populations of humpback chub conclusively known to exist in the upper basin are located in Black Rocks (RM 135-137) and Westwater Canyons (RM 116-124) on the main Colorado River. Incidental captures are recorded from Cataract Canyon; throughout Gray and Desolation Canyons on the Green River; and at the lower end of Cross Mountain Canyon and in Yampa Canyon on the Yampa River.

Humpback chubs are very restrictive in the habitat preferred and occupied. The species in all life stages were concentrated in canyon areas of great depths and fast water velocities with bedrock, boulder, and sand substrates. Microhabitat preferred within these canyons indicate the humpback do not spend most of their time in the swifter, turbulent waters but preferred the associated slower pools and eddies with velocities of 0 to 3.8 ft/sec but averaging 0.2 to 0.3 ft/sec.

The highly turbulent, harsh habitat where the humpback occurred harbored fewer fish species than most areas of the river. This suggests the humpback lives in a highly specialized environment that excludes other species, particularly exotics.

Temperature is a very critical environmental factor for humpback chub. Areas occupied not only were very unique and limited physically, but also required specific temperature for reproduction. Temperatures of 16-18°C needed to be attained for initiation of spawning and best hatching success and larvae survival occurred at about 20°C. In order to survive the Black Rocks and Westwater Canyon humpback chubs habitat must be maintained with its natural temperature regime.

Reproduction has not been directly observed for the humpback chub in the wild but it is suspected that spawning takes place within the boundaries of the deep, swift water canyons. All ages of chub were found in the few areas where they occurred, which supported the conclusion that reproduction and recruitment is taking place from a limited restricted area. In the Upper Colorado River Basin pockets of clean rubble-gravel areas are probably utilized for spawning within the immediate canyon area and in associated areas upstream. Young fry have been taken in and around the boulders and depression of the bedrock areas within the deep canyon itself which supported the conclusion that all life stages are occurring within the limited area of known adult populations and that the fry are not drifting downstream to any significant degree.

In summary any modification of the Colorado River which alters the very specialized environment of the humpback chub by opening its current ecological niche to exotic fish species will complicate the already precarious state of existence for this species.

Therefore, the FWS concludes that the sale of water from Ruedi Reservoir and the subsequent diversion of the water from the Colorado River will adversely affect the Colorado squawfish and humpback chub without implementation of the conservation measures discussed in the following section of this biological opinion.

CONSERVATION MEASURES

— only 'research' done – no habitat 'manipulation' ever attempted w/ $

The following conservation measures have been approved by Exxon Company, U.S.A., to be carried out in accordance with the National Environmental Policy Act, the Fish and Wildlife Coordination Act, and the Endangered Species Act.

In a letter dated 17 February 1981, Exxon Company, U.S.A., informed BR that it would fund certain measures for the conservation of the endangered fish since the FWS has determined that the measures are needed. The project proposal for the sale of water from Ruedi Reservoir has been modified accordingly to include a mechanism to implement conservation measures which we believe will adequately reduce the impact of the sale and use of the water on the endangered fishes. A detailed conservation plan for the endangered fish of the Upper Colorado River is being prepared at the present time. Funds contributed by Exxon will be used primarily for habitat manipulation and monitoring of existing habitat. These measures along with a fish culture program are briefly described below.

but never done.

Habitat manipulation is an important part of an overall management program for these fishes. These actions could include gravel placement for fish spawning, creation of still-water areas for rearing by excavation, or placement of large boulders, or manipulations that could alter velocities, depths or substrate in the backwater areas. Attempts to create young squawfish rearing habitat have already been made in the river by gravel mining companies and others, but unfortunately, these areas have not been monitored to see how effective, if at all, they are for the endangered fishes.

explain

Monitoring and continued research is definitely needed in the Basin. Intensive studies will examine backwater areas in the basin in an attempt to determine the value of these areas as nursery habitat for young squawfish. Water velocities, depth, quality, and other parameters will be determined for backwater areas being used by squawfish. Spawning habitat requirements for the endangered fishes will be studied in an attempt to learn the extent to which such habitats are a major limiting factor for recovery of the species.

Fish culture should not be thought of as a recovery management program in itself because the Endangered Species Act sets forth the need to conserve natural ecosystems upon which endangered species depend. However, periodic stocking of fish in the Colorado River System could be a legitimate way to alleviate problems now encountered by the fishes. We suspect that habitat problems associated with reproduction and early life stage have caused these fish to decline over the past few years. If this proves to be the case, then a management program with fish culture and stocking may play a part in recovery and delisting of these species.

Exxon's share of the Conservation program is based on an average annual depletion of 2,879 acre-feet. The share of the Conservation program attributable to Basalt and West Divide Water Conservancy Districts is based on average annual depletions of 300 acre-feet and 62 acre-feet, respectively.

Any alternative that would develop water sources for use at the Colony Shale Oil Project, Basalt and West Divide which would not deplete flows of the Colorado River, either directly or indirectly, would avoid impacts to endangered fish species and would not be subject to the funding requirements outlined above.

This biological opinion covers the depletion of water from the Colorado River for use by the Colony Shale Oil Project. It also covers the use of water by Basalt and West Divide Water Conservancy Districts. Should there be any change in the total amount of depletion which may affect any endangered or threatened species, the FWS should be contacted to determine if further consultation is required.

The cooperation that you have extended us is appreciated, and if we can be of any further assistance please let us know.

William C. Ellite

Dr. Behnke

United States Department of the Interior
OFFICE OF THE SOLICITOR

DENVER REGION
P.O. BOX 25007
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

AUG 28 1981

COLORADO RIVER WATER
CONSERVATION DISTRICT

August 25, 1981

Mr. William W. Lindsay
Director, Office of Electric
Power Regulation
Federal Energy Regulatory Commission
825 N. Capitol Street, N.E.
Washington, D.C. 20426

Re: Juniper-Cross Mountain Project No. 2757, Colorado

Dear Mr. Lindsay:

We appreciate the opportunity to review the Applicants' response to your supplemental data request. As a cooperating agency for the EIS, we are pleased to provide the enclosed information and analyses on those areas which are within the Department of the Interior's jurisdiction by law and/or special expertise. We believe that this will assist your agency in completing the EIS for this project.

For your information, we have also enclosed the United States' Motion for Reconsideration of the Opinion and Order in Colorado River Water Conservation District v. Andrus, C.A. No. 78-A-1191. The Opinion and Order were sent to you by the Applicants on August 12, 1981.

Sincerely,

Margot Zallen

Margot Zallen
For the Regional Solicitor
Rocky Mountain Region

Enclosures

cc: ✓Roland C. Fischer, Secretary-Engineer
Colorado River Water Conservation District
P.O. Box 1120
Glenwood Springs, Colorado 81601

John J. Bugas, President
Colorado-Ute Electric Association
P.O. Box 1149
Montrose, Colorado 81401

Robert L. McCarty
490 L'Enfant Plaza East
Suite 3306
Washington, D.C. 20024

Robert J. Golten, Counsel
National Wildlife Federation
Natural Resource Clinic
Fleming Law Building, Box 401
Boulder, Colorado 80309

Western River Guides Association
416 East 5th South, 2nd Floor
Salt Lake City, Utah 84111

GAO Report: Hydro Power Needs Boost

WASHINGTON (AP) — The Carter administration has failed to put enough emphasis on developing hydroelectric power as an energy alternative to imported oil, the General Accounting Office said Friday.

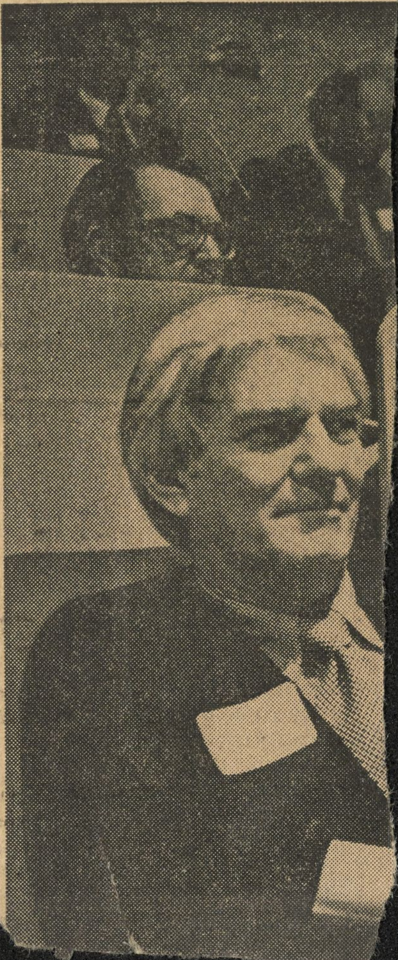
"Despite the administration's interest in small-hydro development, its actions have not matched its talk," the congressional investigative agency said in a report.

A number of energy specialists have urged the construction of smaller electric power plants, especially in New England, for the development of additional sources of electricity.

In its report, the GAO said President Jimmy Carter had made hydroelectric development a part of his energy plan, but that the Energy Department has done little to carry out his wishes.

The GAO study said two years have passed without any federal money being awarded for small demonstration power plants.

The investigators found that the hydroelectric program suffers from "lack of staff and clear direction."



Holling, C.S. (ed.) 1978. Adaptive environmental assessment and management. John Wiley & Sons; 377p.

Holling - myths

- Uncertainty ;? - re esp. flows

Re: Aquatic Ecosystem stability, resilience of ecosystems

I terms of NEPA human envir - change will beneficial

(quantifiable in enormously greater recreation days -

II Squawfish, humpback chub -

* p. 12: team approach to study - - removed fr. policy mak

p. 36 - institution - re envirn. assess. .

p 120 - . Effective communication! - as impt. as analysis.

132-33" prediction never perfect

living w/ uncertainty * how as 'master plan' of operation to work?

see links at J CM 4.6.

foreclose options? - refinement over years - adjust, fine tune

XIF6 descriptive model represent abstraction of reality

- 1 pg abstract of Bible, Hamlet, .

- critique Prewitt ↔ me - - FWS study - consult. - FERC - Battelle when do I begin to

- flaws meaningful discussions on action!?

- symp. - - Bound problem - begin to focus attention not diffuse focus on objectives

my paper

Justice to ancillary, insignif., irrelevant issues.

goal description for sake of description

* Coping w/ unexpected - when mgt. models are uncertain,

mgt. actions can generate information that contribute to

understanding underlying mechanisms.

X rooted macrophytes -> goal replace w/ phytoplankton

Bennett( ) reduce fish production

filamentous green algae stream Cladophora

replaced by Spirogyra in lacustrine + bluegreen -

catfish food! - .

Ward & Stanford:

Hynes (75) for stream biol. lotic

- River continuum & Cummins - - lentic environment

interrupted by dam! - lotic to lentic - phys., chem., biol. ch...

on in reserv. & river below changes in ... influ. by temp, stratific., pH, dissolved O_2 ...

Cannot predict w/ precision but - bottom line greater benefits to human

environment. - asimulids > Hydro cg... - but academic int.

but irrelevant to issues at hand! - No ... to ... ...

this fund, if knowledge invest is wisely!

p. 2 - > 12,000 dams (1973) > 50 ft. high constructed in ... ...

US.WPRI, Corp. Engineers, FERC, SCS, = FWS River basins, 2 ... from ...

- - ... - - many years - . fund of info ...

* Jack 'Sanford - Montrose - Delta as
father - big giant Colo.-etc hand tris.

Hynes - holistic integrated fluvial ecosystem

Cummins · periphyton - diatoms, attached algae Cladophora - more abundant
w/ scour floods! - (film)

River continuum hypothesis - downstream communities
depend on upstream processes

3-20 ft. 1-2-3 order. upper
headwaters - leaf litter (veg. rel. to stream width) -
dominated by shredders . collector - - grazers, predators few (scraper)

30-200 ft 4-5-6 order middle
Shredders greatly reduced
collectors stay abundant .
grazers great increase - autotrophic - diatom (periphyton)

7 - 11 order
downstream . predators ;

Ward So Platte · below Cheesman gr algae . Cladophora +
Ulothrix = 72% of epilithon further down only 14-23%

unicellular Diatoms - several gen & sp.

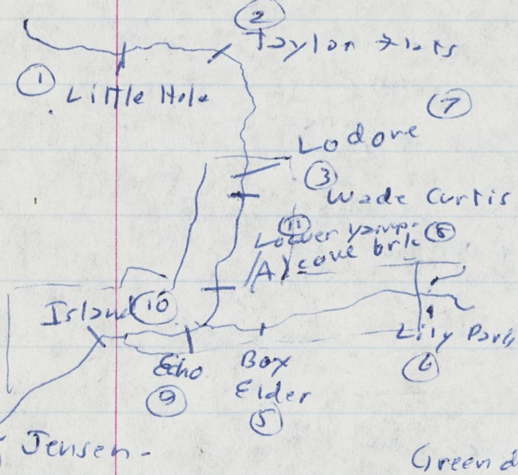
- moderate swift 1-2 1.5 ft sec. vel. w/o large
fluctuations favor luxuriant growth of periphyton
Lowe (p.27) + reduced turbidity below dams
favor light penetration - photosynthesis ↑

· Hannan - water chemistry in reservoir
varies greatly in time and from one res. to another.
- Chem. changes generally accented in stratified
reservoirs w/ hypolimnion release

TDS salinities of FW · Ca^{++}, Mg^{++}, Na^{+}, K^{+} (cations), HCO_3^{-} $CO_3^{=}$, $SO_4^{=}$, Cl^{-}
influence of dissolved organic matter
- even out variation - rainstorm - sediment, coli. form bacteria ↑ dilution
- reservoir = smooths out .
- epilimnion nutrient depletion for photosynthesis
- hypolimnion - below light (phototrophic) - respiration (decomposition) - greatest metabolic
activity occur at upstream end of reservoir a progressive
downstream decrease in chemical concentrations
anoxic conditions in hypolimnion begin at upstream end, (shallower)
progress down . July (?) (larger volume deeper areas)
- anaerobic conditions chemical reduction (redox processes).
extreme H_2S (hydro sulfide gas) develops.

Holden, P. B. and L. W. Crist. 1980. Draft annual report - 1979. Documentation of changes in the macro-invertebrate and fish populations in the Green River due to inlet modification of Flaming Gorge Dam. PR-16-4 Bio/West, Inc. Aquatic and terrestrial resource management and problem solving.

WPRS funded 3 yr. study 78, 79, 80 supplemented by funds NPS, FWS for sampling Yampa



Dam ↓

1-6 invert. sampling

7-11 fish + 6, 4.

1. 7 miles
2. 16.5 miles
3. 49 miles
4. 94 miles

x̄ cfs 79		June	July	Aug	Sept
Greendale		1468,	2022,	1539	1410
Jensen		10,550	4,456	2238	1633
x̄ daily Temp.	G.	10.5	12.7	12.7	12.7
	J.	19.5	23.6	21.1	19.3

Echo Park Aug. 10 21° 2030 cfs.

Lily Park, Lower Yampa - June 16 12000 cfs 12°

June 11 8800 12°

Lily - Aug. 12 25° 570 cfs

Lower Yamp Aug 28 18° 800 cfs

x Baetid mayflies, chironomids, simuliids, most common + abundant - greatest density at Little Hole Taylor Flats * first 2 below dam.

Diversity increases → Jensen (as expected!) -

- filters
- ePOM,

78 79

20 ~~25~~,000	4 samples, (1) ~~25,000~~ 1 sample on	T. ...	Diversity 1.7
~~14~~ 11,000	(2) ~~29,000~~	16.5 -	1.3
4 11,0 35 7,500 -	- (3) 3,500	.49 miles	1.6
4 34 5000	- (4) 5,000	- 74 mile.	2.6
	- Yampa		
	Lily ca. 3000		2.3
	Box Elder < 3000		2.9

Baetis abund. corr. w/ temps., 7.9 - 12.6° sampled lesser and ... corr. w/ chironomids.

1 adult squawfish Alcove brk. 61 miles

		J.	A.	O.	Juv. Lodore
redside shiner	Juv.	11	311	2	4
	Ad.		8	8	-

red shiner . 170 228 716 all juv.

Sand shiner 2 juv.

1 razorback

* 20 Pantosteus platyrhynchus

Holden 1978. 16 y.o.y. 8 juv. 6 ad. at Jensen squawfish

1 pike Echo park 65 mile

4 adult squawfish Echo Park

2 juv., 1 adult Island Park 78 mi.

1 humpback · Echo Park

redside - ca 300 juv. 470 ad. Echo* + Island

red . > 4000 juv. -

sand - 59 -

3 razorback,

squawfish Jensen - 8* young. yearling 3 juvenile. 2 adults

redside - 5 juv 7 ad.

red > 3300

12 razorbacks

- Need sorter of info - in spirit NEPA CEQ - no more proselyt. by analysis

* Flows IFG - problems of precision - (Vanicek - no way could predict)

- W2-51 - USGS - trace elements very low below limit of detection

temp. - fig 2.2.5

bacteria - Maybell grade? - fecal [illegible] from livestock.

/ Primary production - periphytic algae (epiphytal - epilithon

grazing substrate - diatoms -

primary - ph. / secondary - inverts / tertiary - fishes

convert nutrients into organic matter

virtually no macrophyte - unusual scouring the -

Elodea in spring holes.

* USGS - phytoplankton data years - (dislodged

diatoms) - Chrysophyta (diatoms).

Chlorophyta - green algae Cyanophyta blue green

food chain - much terrestr. - leaf, organ. detritus -

invert. sp. composition governed by substrate type.

M.S. thesis done! - enough! -

- how [invert] to get primary prod to fishes, but only few catfish

2nd - producers (some tertiary by pred.

Phylum Mollusca, 3 gen. snail (Gastropoda) 1 gen clam (Pelecyp)

mainly fine-grain bacterial detritus, scrapers - for decomposition

organic - autochthonous sunlight → organic matter

- allochthonous ↓

leaves - decomp by bacteria release nutr - dead - bacteria → mollusks

abund. // 1. mayflies 2. caddisflies

Annelid - ...

Arthropod - non-insects 2 groups - minor

mites. springtails... crustacea - Cladocera

Carlson, et al - some role but virtually all pathways food → fish insects -

- catfish food - . Cladophora - doubt restrict diet to algae!

p. 134.

see App. VI p. 247

- algae mat may cover substrate in some area > Spirogyra

filamentous algae at low flow.

Res. fish. - suckers - white - longnose - mott. bluehead flannelm. whitefish brown trout R.B.

littoral redside

fathead - Zooplank. - Cladocera Cladophora + ... catfish

- insects. Diptera - some larvae also mayflies, caddis

rec. Gammarus Chironomids

crayfish - S.M. bass - catfish - trout

- pred. walleye striped bass

S.M. bass / s.b. x w.b. hybrid

pike - R.T.

Mysis kokanee - Dillon stress

diversity – NEPA human environment CEQ – EV
– many shopping lists but no comments w/ cook who prepares meal
much wasteful in this a resource – hope to focus on what impt. who
do we deal w/ – – aquatic – comes down to end. sp. – FERC DOI sufficient exp.
to predict pot. problem
Scenario
– diagnosis –
medical – diagnosis –
/ no need to vaccinate against
but – Envir. Control pos

Wydoski RCF
only 20% flow, really impor – if could sort out wheat fr
chaff – common sense – adaptive assessment (Holling) – need a
too much ancillary superfluous data masks significant issues –

p126 – defend prog. flows – – Tennant's table –
% ann flow.

– Yampa hydrograph downstream Little Sn.
figs – pre normal
– post.

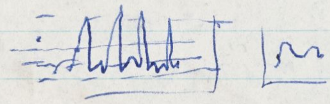


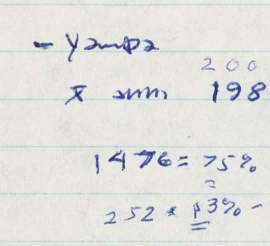
fig 2.2.2

Little Sn. – 6400 cfs – 85% Apr. May June (near Lily)
mid July no cease to reach Yampa
unres – Mar. –

– Yampa
2000
$\bar{x}$ ann 1986 40% = 800 cfs – Zimmerman invert.
– Tennant – stable ↑
1476 = 75% Nelson – fish
252 = 13% – inc

+ 1982 basin wide plan! – operation Flaming Gorge Kelly – has USFWS begun
negotiations yet? If not, why not? – need some commitment re operate
fluctuations (peak pwr increase!) – reregulate? – Temp.? – oper
July – Aug – flow temp at Echo Park season = – 1 yr. to grand plan
what about T.G.!?

p. W2-45 Stage-flow relationship – Lily Park above L.S. +12,736 cfs ↑ 6.5 ft.
below Little Sn. +17,455 cfs ↑ 4.6 feet. (2 mo. period).
table 2.2.8 cfs 13,200 ↓ 1.5 ft. 3.5 below Little Sn. cfs 18000 ↓ 2.6 ft.
4,800 ↓ 3.1 ft 3.2 6,300 ↓ 3.9 ft.
464 515



W2-50 Jan Mar 76
Suspended sed. – 4.8 mg/l → 425.5
Yampa (Maybell) – $\bar{x}$ 308,000 tons/yr !
Little Sn. $\bar{x}$ – > 1 mil. tons/yr. (3.5 x greater)

– Nitrogen ($NO_3 + NO_2$) – ca. 0 to .95 extreme low flow $\bar{x}$ ca. .1 mg/l. normal
NO_3 prob. limiting – .2 low flow yrs. – (low-moderate – Trout fish. Binns .25)
phosphorous – rel. low – .05 – .24

[Penn Counts 1984]

— Hanka . MI

Scrape in Dec 2.

Archa — Quebec – St. Lawrence R.

Upper – Ohio

— Mid Col – Snake

Confl – Cascades (Dalles)

– [illegible]

– Yakima

— Whitefish – Walbee

P-22
Cutthroat
Priest rapids
? ?
?
– redband ?)

Dr Behnke,

The lake I believe I caught Sunapee Trout from, about which I wrote to you recently is called Dewy Lake, close to Chinook Pass where road no. 410 - Washington crosses the crest of the Cascade mountains.

In summer 1968 we caught ~~a~~ about 8 Brook Trout 9-11 inches and one apparent Sunapee of about the same size. Perhaps it would be worth checking out for the local fisheries Dept. It was bright orange in the lower flanks & shaped like a Brook Trout. I don't think it was a Bull Trout. Ladislav

P.S. The local paper carries an ad from particularly viscious fisheries. Perhaps some society for prevention of cruelty to fishes ought to be notified about these battered fish.

Best Wishes

L.R. Hanka
1146 Douglas
Kalamazoo MI
49007

KALAMAZOO MI 490
1 PM
13 JUN
1994

Dr. Robert Behnke
Dept of Fisheries
Colorado State U.
Fort Collins CO
80523

A8

UNITED STATES GOVERNMENT

memorandum

DATE: ~~May 2~~ June 14, 1984

REPLY TO ATTN OF: Project Leader, Leavenworth NFH
Leavenworth, WA 98826 (Tel. 509-548-7573).

SUBJECT: Enclosed MS titled, "Interpretation of dam counts of resident fishes in the Columbia River, 1934-19~~38~~40", for submission to the AFS, North American Journal of Fisheries Management.

TO: Bob Behnke

Your critical comments regarding the subject heading would be most appreciated. If at all possible we would appreciate your comments within six weeks. We realize this may represent a considerable imposition. Nevertheless, we hope you will bear with us and provide comment in your area of expertise or interest. Inevitably, feedback of any kind or quantity proves invaluable, so don't be bashful. We will acknowledge your assistance if and when the MS sees the light of day.

Thanking you in advance,

Jim
James W. Mullan
Project Leader

Please look at section on trout if nothing else. I did not discuss possible introduction of arctic char on page 55 and the more I think about it, the more I think I should. There must be non-anadromous stocks (Dick Baldes has ~~my~~ copy of Balon at the moment) that would be desirable. Predacious habits, especially in cold water, and the possibility of reproduction in the reservoirs are worthwhile traits. The threat they represent, or might represent to salmon and steelhead smolts, undoubtedly would raise hackles. What do you think?

OPTIONAL FORM NO. 10
(REV. 1-80)
GSA FPMR (41 CFR) 101-11.6
5010-114

United States Department of the Interior

FISH AND WILDLIFE SERVICE

3/12/85

Dear Bob,

Just read your latest missiles and have a few minutes for reply. I have not met Bruce Crawford and I'm not acquainted with his in-house reputation. Aside from a few dedicated individuals of high character, like area biologists Larry Brown and Ken Williams, I have become increasingly disillusioned by WD Game. Many individuals seem to be no more than prostitutes with a very superficial grounding in fisheries management. At the slightest suggestion of a development project, the first question raised is mitigation, not the pros & cons of the situation. The organization is constantly crying poverty and license fees have been hiked regularly since I came to the state in 1976, but there is little to show in North Central Wa for their presumed concern. The hatcheries, public hunting and fishing areas, deer wintering ranges, etc, have all been paid for and are maintained either by the Public Utility Districts or the Bur of Rec-

Their latest cry for dollar help was a proposal to raise the steelhead punchcard from $5 to $20. The Northwest Steelheaders and others (e.g. Trout Unlimited) reduced the proposal to $15 with a $5 rebate on returning the card - Everything seems to be a shoe-string operation with someone else paying the bill. WDG was the real Indian hater in the Boldt War and the tribal attorneys massacred WDG witnesses and lawyers in Court. Currently, excess river otters trapped here at Leavenworth are involved in a 3 or 4 way swap in which Washington gets Texas turkeys. I could go on, but I won't.

Troop morale is at an all time low - A hotshot director (Lockhart) from Indiana 4 yrs ago resigned back in Dec. and the current director is an old timer (Wayland) previously passed over for the post. He has made a determined effort to correct the chronic funding problem with a 1/10 of 1% increase in the sales tax. There was no way this could pass the legislature without giving up Game's self-righteous, "nonpolitical commission", and of course the ploy failed. Due to an unexpected ~~the~~ democrats ~~test~~ win in Nov, my friend Don Moos was interested in the directorship. Don is an unusual politician-statesman with an excellent record as a 16 year veteran of the legislature, ex director of the Departments of Agriculture, Fisheries, and Ecology, etc, with a keen mind and deeply versed in natural resource issues, yet the ~~Wd~~ Game Commission didn't even bother to interview him. So all I say is hammer away at them, the current structure and mentality (hatchery) can't last.

Bill McConnell is sad. Dave Anderson called me up when this controversial involvement with the bulb-turbine test first arose and I encouraged his participation, and we subsequently met here in Wenatchee. He is an excellent man and we have some mutual friends.

Your Dolly Varden article is excellent. I'm going to send Dick Whitney & Larry Brown a copy. This should stir Whitney up, who lives close by and is a collaborator on various projects. I can only marvel at and admire your writing style. I believe such articles are important, constituting a link between the scientific community and the world of political reality. Very few people are concerned with such a bridge, which I find unfortunate. There is a keen interest and demand for such a stretch by, admittedly, a small segment of the angling community. Nevertheless, a lot of these guys are the pace-setters.

After another winter of crunching the literatures for facts so as to identify management options for anadromous and resident fishes here on the mid-Columbia, I'm groggy and, as usual, not seeing too clearly. I've also got a back problem compounding the problem, but I'm recovering from a bout of spasmatic pain that I didn't think possible. I'm also deeply frustrated by how long everything takes for the slightest progress. So what else is new, huh?

Enclosed are 2 publications of WDG, which I can't remember if I sent to you before. One of them — basic mgt strategy — might come in handy in any dialogue with Crawford on steelhead mgt. I'd like these back.

Sincerely,

Jim Mullan

[J. W. Mullan]

Interpretation of Dam Counts of Resident Fishes in the Columbia River, 1934-1983

DRAFT

Abstract

Fish species other then migratory salmonids have been counted ascending fish ladders at seven dams on the Columbia River, either for a number of years or on a continuing basis, during the period of hydroelectric development, 1934-1983. Ecological and management implications of these counts of "millions" of other fishes are interpreted by species life history information, by analogy, by correlation, and by the process of elimination.

Pacific lamprey, abundant up until 15 years ago, have virtually been extirpated from the mid-Columbia River mainstem due to inundation of spawning and rearing areas. Demise of lamprey paralleled population irruption of introduced American shad in the lower river as a result of impoundment. Response of mountain whitefish, chubs, suckers, squawfish, carp, shiner, dace, centrarchids, and walleye to initial impoundment was positive. Abundance of mountain whitefish, chubs, suckers, and squawfish subsequently experienced long-term decline except for revealing instances to the contrary on the mid-Columbia River.

The mid-Columbia River, although largely altered as a tailwater to Grand Coulee Dam impoundment (Lake Roosevelt), retains its original glacial characteristics. The six back-to-back reservoirs upstream of the confluence of the Snake River to Grand Coulee Dam, are all run-of-the-river impoundments, lacking storage and with water exchanges of a few days duration at most. Limited water retention severly limits plankton production. In common with temperate storage reservoirs, the tailwater has become warmer in fall and winter and colder in spring and summer. Water temperatures for successful

reproduction of fall spawning mountain whitefish have become marginal as a result. Constraints imposed on other endemic species by reduction in spring-summer water temperatures are more vague, but it is clear that exotic warmwater species (i.e., carp, centrarchids, catfishes) achieve variable spawning success only in atypical warm backwaters depending on seasonal water regimes and climate. Infrastructure of habitat peculiar to individual reservoirs also overrides temperature conditions more widespread in their influence by allowing a relative proliferation of some species (i.e., squawfish, suckers), which depress the abundance of other species (i.e. mountain whitefish).

The abundance of individual species in the Columbia River has been radically altered with change from erosional river to flow-through reservoirs. Indigenous salmonids, lamprey, sturgeon, and other large piscivorous species are almost non-existent in mid-Columbia reservoirs, and the fish community is now dominated by small to medium sized, trophic generalists (i.e., sticklebacks, cyprinids, suckers). The species assemblages of the warmer, lower river reservoirs, while retaining species characteristics of the upstream reservoirs, are much less dominated by such tropic generalists. In addition, the lower river reservoirs support a much greater diversity and abundance of introduced warmwater species, as well as planktivorous shad, piscivorous sturgeon, and juvenile anadromous salmonids. It is shown that in the still warmer reservoirs of the lower Snake River that introduced warmwater centrarchids attain a still higher relative abundance, while rearing anadromous salmonids requiring much cooler water are virtually nonexistent. Extensive dispersal of fishes from upstream areas to downstream areas is depicted, and salmon rearing in lower reservoirs doubtless largely originate from wild and artificial spawning in the free-flowing Hanford reach of the mid-Columbia below Priest Rapids Dam. It is suggested that similar, major rearing of anadromous salmonid smolts is possible in reservoirs above Priest Rapids Dam if sufficient densities of sturgeon, walleye, or both could be established so as to reduce competitive interactions at lower trophic levels by holding competitor populations of trophic generalists in check.

Figures

Tables

1. Morphemetric characteristics of the mainstem Columbia River in the United States (from Mullan in press, Bell et. al. 1976, McKern 1976).

2. Relative abundance (percentage of total catch) of fish species or groups of fish as indicated by various sampling of the middle Columbia River, lower Columbia River, and Snake River.

3. Correlations of dam counts of mountain whitefish with water temperatures at Rock Island Dam in year N-5. Plus sign represents favorable aspect of temperature. Minus sign represents unfavorable aspect of temperature.

Interpretation of Dam Counts of Resident Fishes in the Columbia River, 1934-1983

DRAFT

James W. Mullan[1]

Michael B. Dell[2]

Steven G. Hays[3]

James A. McGee[4]

Little is known about the fishes of the Columbia River aside from salmon (Onchorhynchus spp), steelhead trout (Salmo gardneri), and sturgeon (Acipenser spp). Campbell (1979) has described the many reasons why the physical obstacles of researching large rivers have resulted in little holistic understanding of such ecosystems. Accordingly, interrelationships between resident fishes and migratory salmonids have largely been ignored except for concerns of predation on salmonid smolts and vague, often conflicting interests in management for resident species (Pacific Northwest Utilities Conference Committee 1982).

Eleven hydroelectric dams operate on the Columbia River within the United States (Figure 1). The uppermost, Grand Coulee and Chief Joseph, have no fish passage facilities. The lower nine dams each have 2-3 fishways for anadromous salmonids where they are routinely counted in upstream migration. At seven of these dams fish species other then migratory salmonids have also been counted, either for a number of

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1 U.S. Fish and Wildlife Service, Leavenworth, Wa.

2 Public Utility District of Grant County, Ephrata, Wa.

3 Public Utility District of Chelan County, Wenatchee, Wa.

4 Public Utility District of Douglas County, E. Wenatchee, Wa.

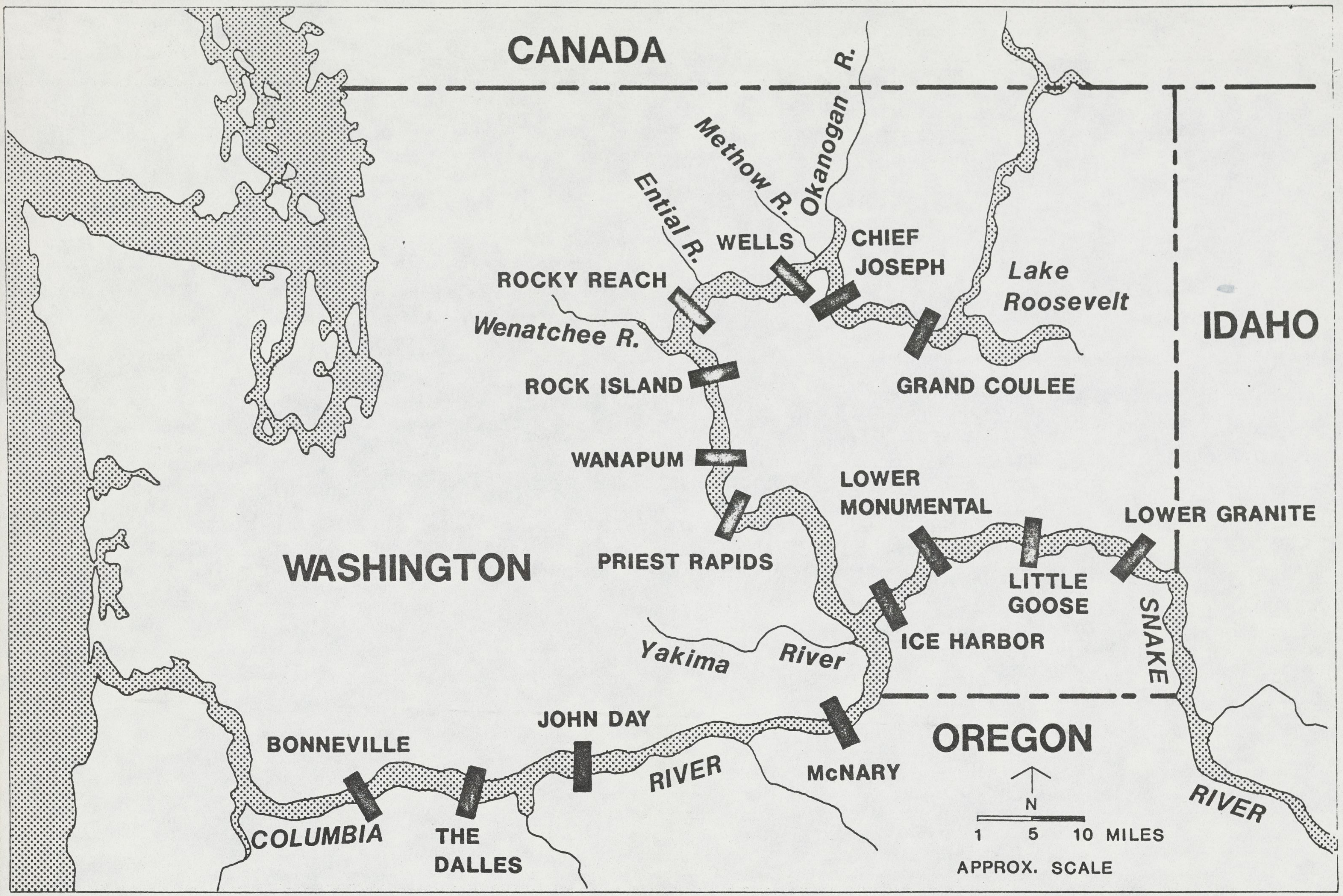

Figure 1. Hydroelectric dams on the mainstems of the Columbia and Snake Rivers.

years or on a continuing basis. In this paper we examine the ecological and management implications of these counts of "millions" of other fishes, which no one has viewed in their entirety.

General Approach

The vagaries of counts of salmon and steelhead at dams are well recognized (Bell et al 1976; Fredd 1966). Factors known to affect a true tally of fish passing a dam are: species misidentification, estimating total fish passage, arithmetical errors, passage through navigation locks, and recounting fallback fish. Fish counts obtained at Columbia River dams nonetheless provide essential information of salmon and steelhead resources of the Columbia River.

Interpreting dam resident fish counts present essentially the same problems as fish samples collected in passive nets and traps. Theoretically, the catch-per-unit-effort (CPUE or annual dam count) of passive sampling gears should be directly proportional to the abundance of fish in the population, but this is rarely the case. Some of the more important variables influencing capture or monitor are season, water temperature, water level, turbidity, and currents (Hubert 1983). Changes in fish behavior result in a great degree of variability in CPUE among species and among year classes within a species because capture or monitor efficiency with passive observation is a function of fish movement. Many movements are unpredictable as a result of our poor understanding of the ways in which environmental factors influence movement tendencies (Hubert op cit).

In Pacific salmon, it is at least known that ascending adults represent spawning migration, which die after reproducing. It is not so clear whether ascending resident fishes represent spawning migration, involving repeat spawners, random movement of adults and juveniles, or responses to environmental perturbation. The problem is all the more confused because no age-growth, length-weight or other accessory information relating to dam counts of resident fish was ever collected. Furthermore, we have only the circumstantial evidence of passage timing and numbers of fish at successive dams in establishing boundaries of populations. Within this vaccuum we have attempted to interpret dam counts of resident fishes with life history behavior and requirements and any other pertinent observations available.

Sources of Data and Comparability

Annual fish counts of resident fishes were obtained from: (1) fish passage reports published by the U.S. Army Corps of Engineers for Bonneville Dam 1938-69 and McNary Dam 1954-69, and unpublished Corps information for McNary 1976, 1981; (2) unpublished accounts by Grant, Chelan and Douglas Counties Public Utilities Districts (PUDs) for Priest Rapids Dam 1961-83, Wanapum Dam 1963-66, Rock Island Dam 1973-83, Rocky Reach Dam 1961-83, and Wells Dam 1967-83; (3) unpublished accounts prepared by the Washington Department of Fisheries (WDF) for Chelan County PUD for Rock Island Dam 1966-67; (4) Chapman (1944) for Rock Island Dam 1934-39; Zimmer and Broughton (1966, 1965a, 1965b, 1964, 1962a, 1962b, 1961) for Rock Island Dam 1959-65; and (6) unpublished accounts by the U.S. Fish and Wildlife Service for Rock Island Dam 1940-58.

We have no way of determining the comparability of these dam counts collected by many agencies and people over many years. Some of the data and details of methodology from early years has been lost, while procedures, circumstances and periods of counting have varied.

In early years fish were counted as they swam across white boards in fish ladders or as the fish were lifted over a dam in navigational locks (i.e. sturgeon-Bonneville). In more recent years fish have been counted through glass windows located in fishway walls, provided with underwater lighting, allowing greater definition of species. Most complete monitoring has always coincided with adult salmon migration from spring through fall during daylight hours. Passage was observed in fractional hours (usually 50 minutes) and counts appropriately expanded. At other seasons or at night, if passage was permitted, the observed count was expanded by off-peak period factors derived from subsampling. In some years at some dams, downstream migrants were recorded, but, as a rule, downstream migrants constituted only a minute fraction of the upstream count, and counts were limited to upstream migrants. Extent of species resolution and periods of counting varied between dams and between years but generally became more standardized and finite over the years.

The variability in fish counting effort and methodology over time and between dams cast doubt on the validity of using annual counts as an index of relative abundance (Hubert 1983). On the other hand, the "reasonableness" of the patterns of fish behavior revealed by the counts suggest a high commonalty of results, particularly considering similar long-term trends between and within resident species. Doubtless the dams act as huge weirs and override many of the biases of smaller, more conventional passive gears, although doubtless injecting other biases.

It is generally not possible to determine the true species composition of a community using passive gears because of species and size selectivity (Hubert 1983). However, there can be little argument that the species composition of annual dam counts can be used to assess differences between communities and trends in communities and species over time.

Relevant water temperatures were extracted from the extensive daily records of the PUDs.

Other Prologue

Alteration of the Columbia River for hydroelectric power over the half century of dam fish counts represents dynamic transformation. Rock Island, Bonneville, and Grand Coulee Dams began operation[1/] in 1933, 1938, and 1941, respectively. By 1967, most of the Columbia River had been turned into a series of impoundments totalling 258,508 acres - an increase over original river area of 141,115 surface acres (Table 1).

Discharge generated within the upper and mid-Columbia subregions is principally late spring runoff caused by snowmelt and peak flooding and extreme drought have been modified (Figure 2). The relatively small volumes and high flushing rates (1-6 days) of reservoirs below Grand Coulee Dam place them in a riverine category, with comparable fluctuations (1-5 feet on average, Fielder and Perleberg 1981) in stage occurring daily rather then seasonally. Mid-Columbia River reservoirs[2/] actually are a tailwater of Grand Coulee Dam, which is the only high dam having storage capacity (Lake Roosevelt) in the United States (Table 1). Other high dams, completed in the early 1970s, exist on headwaters of the Columbia River in Canada, however.

1/ It should not be overlooked in much of what follows that various degrees of impoundment preceded functional operation of all dams even though we were unable to quantify such inundation.

2/ We define the upper river as the area above Grand Coulee Dam, the middle river as the area between Grand Coulee Dam and the head of McNary Reservoir (Confluence of the Snake River), and the lower river as the area below the head of McNary Reservoir.

Table 1. Morphometric characteristics of the mainstem Columbia River in the United States (from Mullan in press, Bell et al. 1976, McKern 1976).

River mile	Reservoir	Distance (miles)			Surface Area (acres)			Average depth (feet)	Storage ratio [1]	Years constructed
		Length	Shore line	Ratio	Reservoir	Original river	Ratio			
0.0	(river)	145.5								
145.5	Bonneville	46.2	144.2	3.1	20,400	15,000	1.36	28	0.004	1933-38
191.7	The Dalles	23.9	76.0	3.2	11,650	6,016	1.94	28	0.003	1952-59
215.6	John Day	76.4	323.6	4.2	51,000	27,570	1.85	46	0.020	1958-68
292.0	McNary	61.0	237.2	3.9	38,800	23,138	1.68	35	0.010	1947-54
353.0	(river) [2]	44.0	156.0	3.5						
297.0	Priest Rapids	18.0	57.5	3.2	8,320	4,315	1.93	24	0.002	1956-59
415.0	Wanapum	38.0	94.0	2.5	14,720	6,950	2.12	49	0.009	1959-63
453.0	Rock Island	21.0	43.0	2.0	3,470	2,781	1.25	33	0.001	1928-33
474.0	Rocky Reach	42.0	93.0	2.2	9,800	4,710	2.08	44	0.005	1956-61
515.8	Wells	29.2	99.8	3.4	9,548	4,162	2.29	31	0.004	1963-67
545.0	Chief Joseph	52.0	108.0	2.1	7,800	4,601	1.70	66	0.007	1950-55
597.0	Grand Coulee	150.0	660.0	4.4	83,000	18,100	4.59	115	0.123	1933-41
Total		747.2			258,508	117,343				

[1] The ratio of the reservoir volume in acre-feet to the average annual discharge in acre-feet.

[2] Hanford Reach

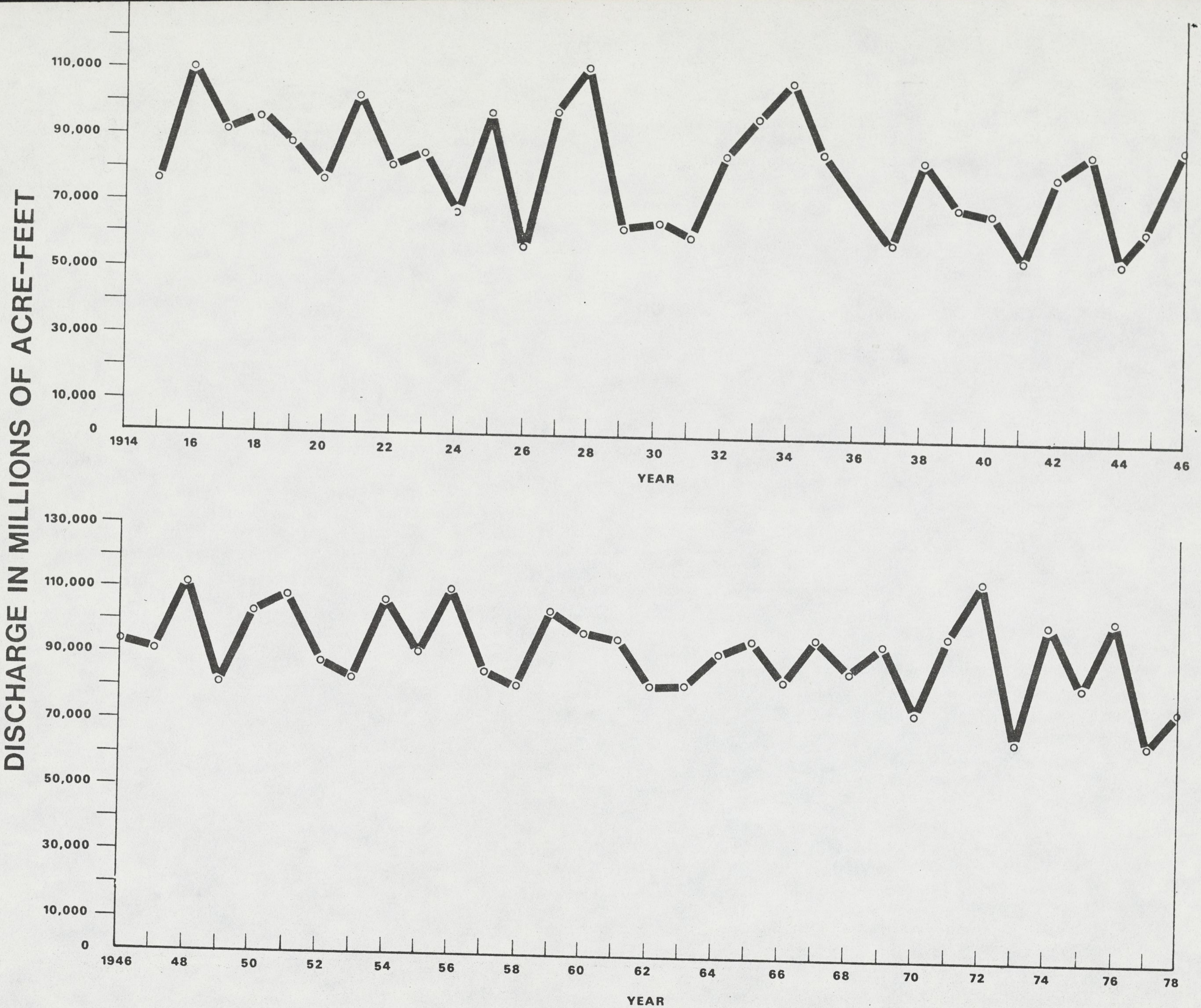

Figure 2. Approximate average annual discharge of Columbia River at Rock Island Dam, 1914-1978.

Construction of Grand Coulee Dam barred anadromous salmonids from 1,140 miles of the upper Columbia River and provided the impetus for the beginning of fish counting at Rock Island Dam. Counts and studies of salmon and steelhead at Rock Island Dam were the basis of a proposal by the Washington Department of Fisheries (WDF 1938) to salvage and enhance the upriver runs. The resulting Grand Coulee Fish Maintenance Project was implimented by the U.S. Fish and Wildlife Service. It featured trapping returning adult salmon and steelhead at Rock Island Dam, diverting them to the Wenatchee, Entiat, Methow, and Okanogan rivers, which are the only tributaries of any consequence in the mid-Columbia River (Bryant and Parkhurst 1950) (Figure 1), and constructing hatcheries on three of these streams (Fish and Hanavan 1948). Indeterminable counts of resident fishes at Rock Island Dam 1939-43 were the result of the interception and relocation of salmon and steelhead during those years.

Fish ascending the lower half of the three fish ladders entered trapping pools through V-shaped tunnels. The trapping pools were floored with gratings which were raised to herd the fish through a second tunnel leading into an elevator. Counts were made as the fish passed from the trapping pool into the elevator. The elevator, consisting of a 500-gallon tank, was raised and the fish released through a trap door into a chute connected with the tank of the distribution truck. Species segregation in the loads was obtained as the fish entered the elevators from the trapping pools. A small gate at the apex of the tunnel was manually opened when fish of the desired species approached and closed at the approach of other species (Fish and Hanavan 1948).

The degree of segregation and the accuracy of counts and fate of resident fishes varied, depending on prevailing logistics and numbers of migratory salmonids and resident fishes present (Fish and Hanavan 1948). At times migratory salmonids and resident fishes were hauled and liberated together, while at other times resident fishes were bypassed or hauled separately. For example, between 5 July and 13 September 1941, 14 truck loads of "scrap" fish (75,000 estimated) were placed in cold storage at the Leavenworth National Fish Hatchery as possible fish food (Kemmerick 1941). Truck loads of all fish distributed in 1941 was 208. This and other surviving bits-and-pieces of information infer significant selective removal of resident fish at Rock Island Dam 1939-43.

Pacific Lamprey

(Entosphenus tridentatus)

The anadromous Pacific lamprey is not a resident species in the usual sense and were identified in counts only at Bonneville, McNary, Rocky Reach, and, for a few years, Rock Island; in other dam counts the lamprey was lumped as a miscellaneous species.

In the 32 years of lamprey counts at Bonneville Dam average run size varied from 32,700 to 379,500 and run strength was cyclic (Figure 3).

Fluctuations in lamprey at Rocky Reach Dam, 329 miles upstream, generally mimicked fluctuations at Bonneville Dam, when counting occurred at both dams (Figure 3). An average of four percent of the lampreys tallied at Bonneville reached Rocky Reach. Fluctuations in abundance at McNary Dam, located approximately equal distance between Bonneville and Rocky Reach dams, also was similar to Bonneville, but with only an average of six percent of the lampreys counted at Bonneville tallied at McNary 1954-69. Of the record run of 379,500 lamprey counted over Bonneville in 1969, only 3,000 were counted at McNary (0.8%) whereas 17,200 (4.5%) were counted at Rocky Reach. The low counts at McNary suggest that a large share

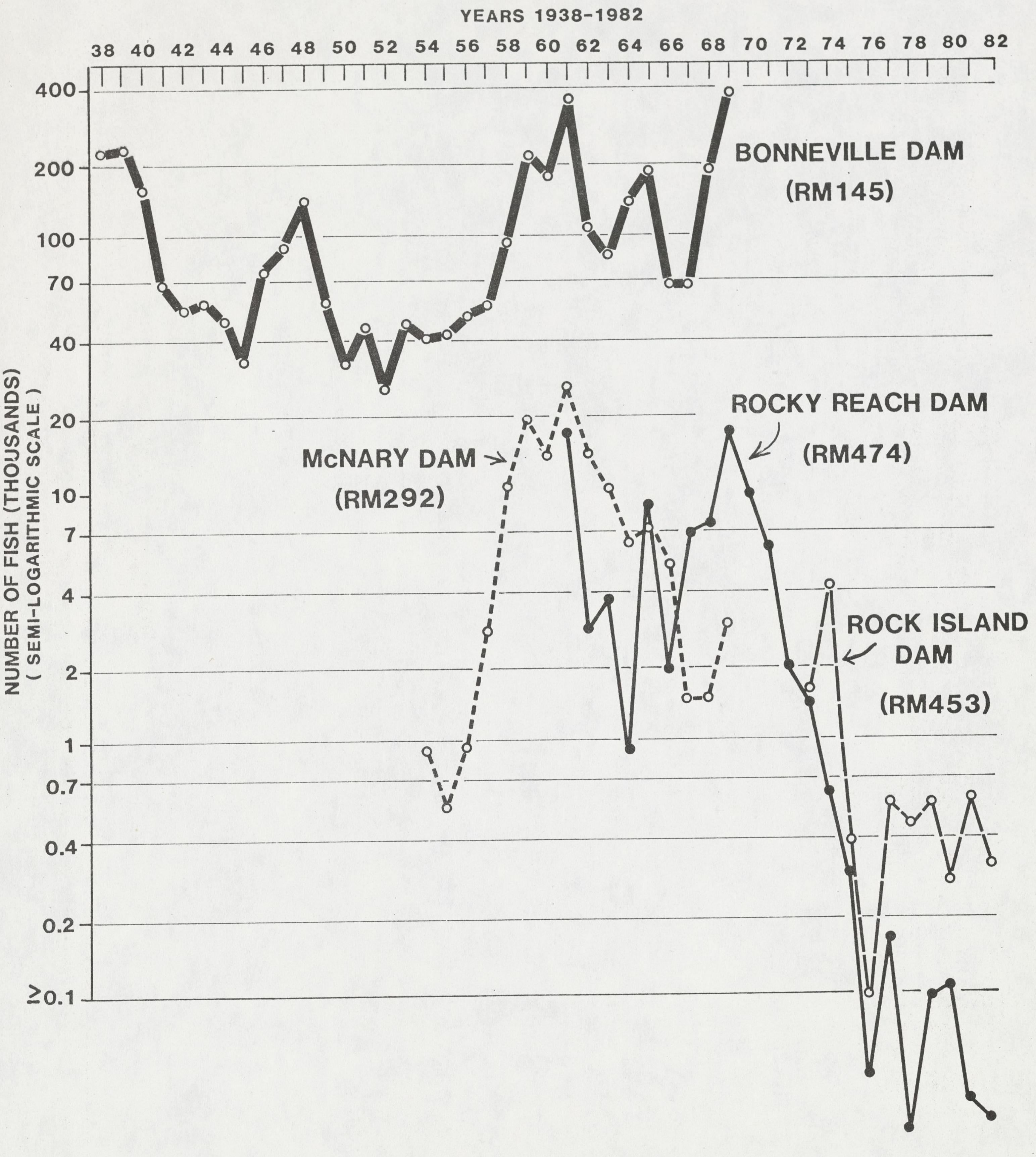

Figure 3. Yearly counts of Pacific lamprey at Columbia River dams.

of the lamprey run surmounted that dam through the navigational locks, an upstream passage option for lamprey at Bonneville as well, but not at any of the five mid-Columbia River PUD dams not equipped for barge traffic.

Lamprey were counted at Bonneville Dam (River Mile 145) as early as March and as late as November, but the majority passed June-September. Peak counts occurred in July or August except for the record run of 1969 which occurred in June. At Rocky Reach Dam, lamprey first appeared May-June, reached maximum numbers August-September and virtually were nonexistent by October-November.

After the record count in 1969 at Bonneville and Rocky Reach dams, counts at Rocky Reach declined precipitously from 17,200 to less then 200 lamprey annually beginning in 1976 (Figure 3). Counts at the downstream Rock Island Dam for years 1973-82 reflected the same trend.

The following life history of the Pacific lamprey is taken from Wydoski and Whitney (1979), Scott and Crossman (1973), and Carlander (1969). Migrating adult lampreys are not sexually mature and spawning does not take place until the following April to July. Spawning occurs in sandy gravel at the upstream edge of riffles. The adults die after spawning. Eggs (mean egg number is 34,000 but can go as high as 106,000 in a 16-inch female) hatch in 2-3 weeks (19 days at 59^{o}F). The resulting ammocoetes burrow into sand mixed with organic debris, or muck that are comparatively free of smothering silts where they spend 5 or 6 years filter feeding on on microscopic plants and animals before metamorphosing into adults. They are usually 4.8-12.0 inches at transformation and migrate to the ocean in spring. There they feed on the body fluids of various fish for 12-20 months before migrating back upstream to spawn at an average size of 21.2 inches.

It is not known for certain how long the lamprey ammocoete life phase is in the Columbia River. The five or six years suggested by the literature, combined with a 1 or 2 year ocean existence, and a brood year that occurs the year following return from the sea, results in a life cycle of 7 to 9 years. The two near identical record runs of about 17,200 lamprey passing Rocky Reach Dam in 1961 and 1969 bracket such a time frame (Figure 3). When the Rocky Reach impoundment was first inundated in 1961, there remained 29.2 miles of free flowing river above Rocky Reach Dam for spawning which was subsequently usurped by the Wells Dam impoundment beginning in 1967. Trautman (1957) makes clear that ammocoetes of all species of lamprey are particularly vulnerable to siltation and the silt trap principle of impoundment of streams is well established (Ward and Stanford 1979). Thus, it is likely that the delayed demise of lamprey involved sequential loss of spawning areas and cumulative effects of siltation.

The Rocky Reach Dam counts reflect a remarkably fine-tuned, but not exclusive fit between the environmental requirements of Pacific lamprey and the orginal free flowing mainstem of the mid-Columbia River. While ammocoetes have been observed in the Wenatchee, Entiat, Methow and Okanogan Rivers, presumably from spawning in these tributaries, this recruitment has not precluded virtual elimination of lamprey from the mid-Columbia River mainstem due to impoundment.

Between 1943 and 1952 the Willamette River, which joins the Columbia River below Bonneville Dam, supported a commercial fishery for Pacific lamprey (Pruter 1966). The average annual harvest was 231,000 pounds and was used for manufacture of animal feeds. In earlier days, the Indians processed lamprey for food (i.e., Indian candy).

The importance of lamprey predation on salmonids in the Pacific Ocean has not been clearly evaluated (Wydoski and Whitney 1979). Scott and Crossman (1973) reported that up to 20 percent of the coho salmon (_O. kisutch_) examined in British Columbia had scars from the Pacific lamprey. Hynes (1970) stressed that the enormous proportion of the life of a lamprey spent as a filter-feeding larva is probably of greater ecological significance than that of the conspicuous and much more frequently observed adult stage. The possible interrelationships of both larval and parasitic stages of lamprey with anadromous salmonids prevailing in the heyday, or even pre-Grand Coulee Dam, of the Columbia River stretch the imagination considering the spring exodus to the estuary of "billions" of newly transformed lamprey larva and "millions" of salmonid smolts.

American Shad

(Alosa sapidissima)

The anadromous American shad is also not a resident species in the usual sense, but, like the Pacific lamprey, is included out of deference to biotic impact and as insight in assessing dam counts of fish species other then migratory salmonids.

American shad, native to the Atlantic coast, was first planted in the Sacramento River, California, in 1871, but soon spread to other waters along the Pacific Coast, including the Columbia River in 1876-77 (Wydoski and Whitney 1979). Counting at Priest Rapids Dam, where shad are largely precluded from further upstream migration, began in 1960 concurrently with major population irruption of the species. Average run size at Bonneville Dam 1938-59 was 15,500 whereas average run size 1960-82 was 450,600. Construction of the upstream Dalles Dam, in 1957, at Celilo Falls, which had been a barrier to upstream migration of shad, is believed to have brought about this large increase in the population of shad (Wydoski and Whitney 1979). An average of 430 shad were counted at the fish ladders at Priest Rapids Dam 1960-68, 6,000 in 1969-75 and 20,000 in 1976-82.

Juvenile shad normally spend the first summer of life in the river where they are spawned and move out to sea in the late fall. Shad mature after three or four years at sea before returning to their home stream to spawn. Spawning has been reported to occur at water temperatures 60^{o} to 65^{o}F. A large female may produce up to 300,000 eggs. The small, semibouyant eggs are laid in the open water of the river and carried downstream as they develop. The fry hatch in 7 to 10 days and first feed on plankton and later on aquatic insects (Wydoski and Whitney 1979). Recent studies on lower Columbia River reservoirs (Hjort et al 1981) and on Snake River reservoirs (Bennett et al 1983) show that yound shad buffer predation on juvenile salmonids and are an important prey consumed by resident fish predators.

Commercial landings of shad on the Columbia River have fluctuated between 150,000 and 1.5 million pounds annually since 1938. The shad run has been consistently underharvested because of low market value and conflicts in run timing with salmon runs requiring complete protection (Wydoski and Whitney 1979).

Mountain Whitefish

(Prosopium williamsoni)

Dam counts of mountain whitefish apparently primarily relate to mass spawning migrations. Mountain whitefish spawn in late fall or early winter, although the eggs do not hatch until spring, and peak counts occurred September-November (Figure 4).

Large numbers of whitefish were frequently still running when counting was discontinued for the year, generally in November. We have corrected for this lack of enumeration by projecting the curve of the counts for the missing counting interval, and or by applying average percentages of the total annual run by months derived from near-complete or year-round counts (Figure 4).

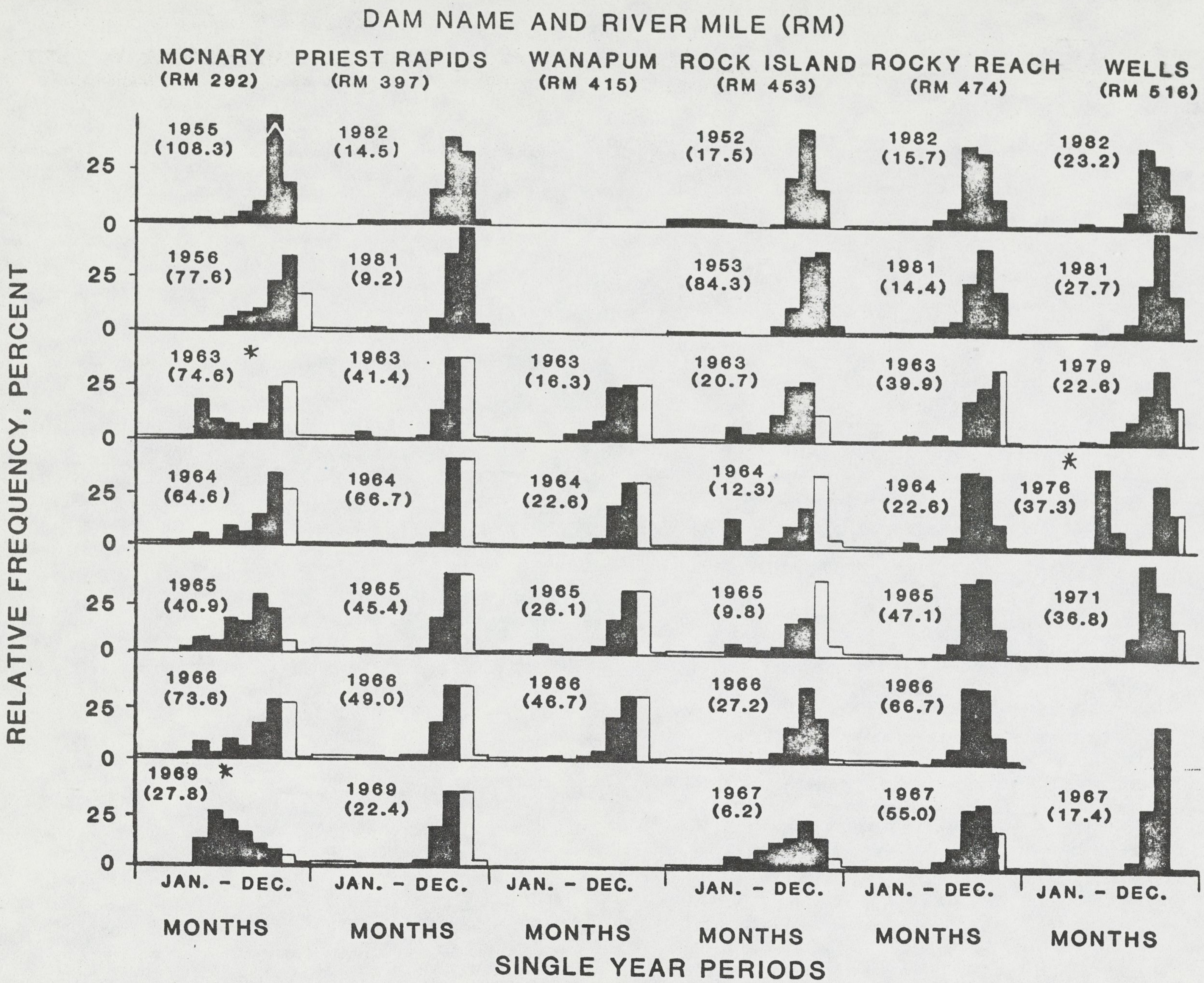

FIGURE 4 Monthly percent distribution of mountain whitefish counted (black) or estimated (white) passing upstream at Columbia River Dams for selected years. Atypical distribution designated by asterik (*) and total run size in 1000s of fish (N).

Corrected or uncorrected long-term counts of mountain whitefish depict highest abundance in initial years of impoundment except for Rock Island where the maximum count occurred 20 years after the dam became operational (Figure 5). Only 12 to 4,200 whitefish were counted passing Rock Island 1934-39 and 1941-42 (counts for 1940, 1943, and 1944 apparently are irretrievably lost) in contrast to 10,300 to 84,400 in the decade that followed (1945-54). Meager counts of whitefish in early years at this earliest of Columbia River mainstem dams could have reflected a stream dwelling population not subject to extensive upstream spawning migration.

McAfee (1966) and Sigler (1951) reported that stream populations of mountain whitefish do not seem to travel long distances to spawn. Brown (1952) observed no mass movements or migrations and no unusual concentrations of stream dwelling whitefish in known spawning areas. However, he did note that small numbers of fish moved into tributary streams from large rivers and used only the lower 300 to 500 yards of the tributary stream.

Fish migrating upstream on the Wenatchee River were counted at river mile 32.7 (Tumwater Dam) in 15 years between 1935 and 1973. Only a few mountain whitefish ($\leq$30) were observed in any year despite constituting a dominant species of the fish fauna and some year-round counts. However, a winter sport fisheries exists in the lower Wenatchee River, primarily in the vicinity of the mouth, in which about 2,000 whitefish are harvested annually (Dobler 1978). Similar fisheries for whitefish exist in the lower Entiat and Methow rivers, but are purported to be much reduced since major dam building on the Columbia River (Williams 1975). Massive runs are said to have extended at least 29 miles upstream on the Methow River. Meekin (1967) observed 777 whitefish ascending the lower Methow River in the summer of 1966, but unfortunately discontinued counts of all but salmon in mid-September.

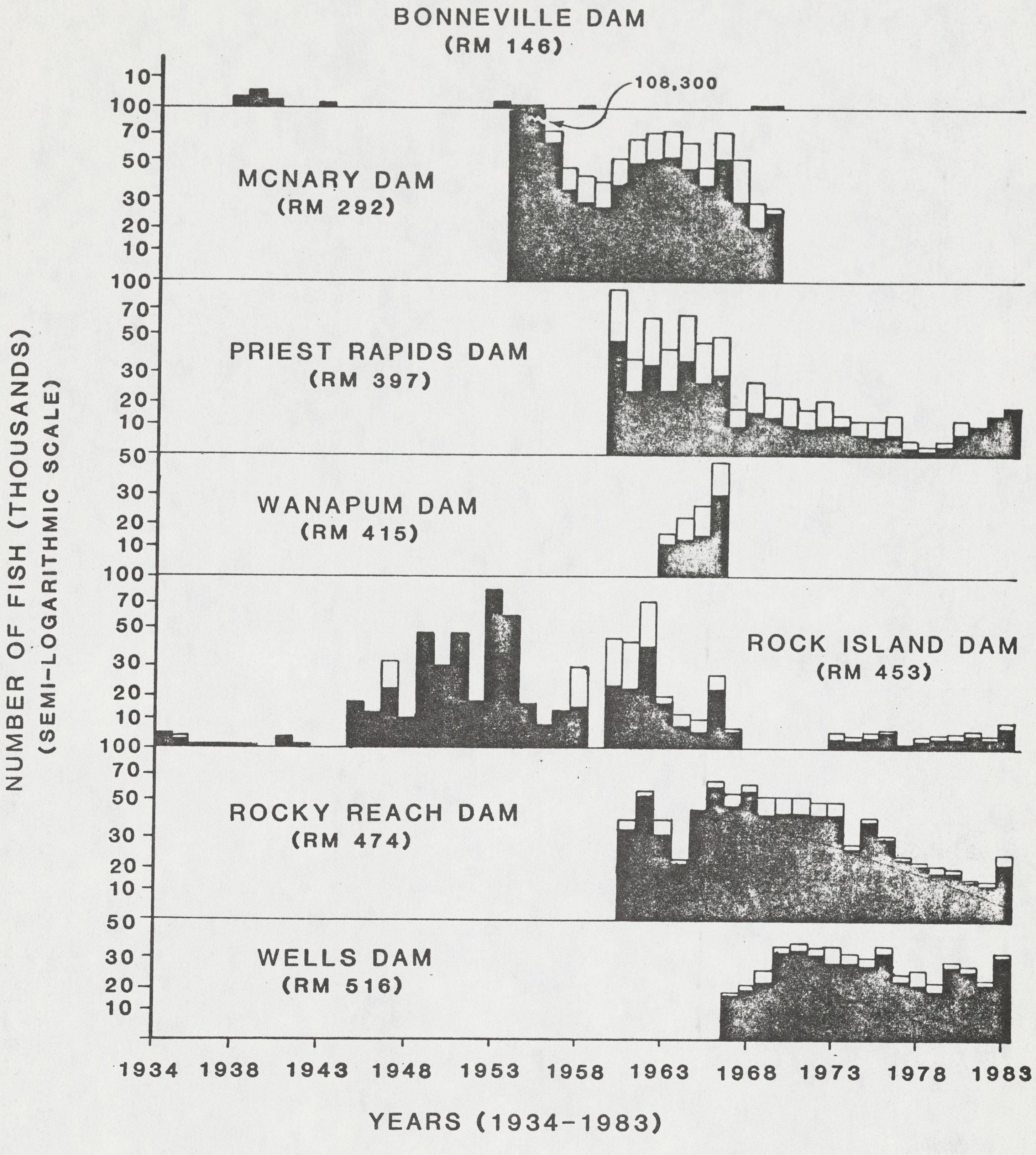

FIGURE 5 Yearly estimates (black=actual counts: white=estimated counts) of mountain white fish passing upstream at Columbia River Dams (River Mile=RM), 1934-1983.

Counts at Priest Rapids Dam, located at the head of the 44 mile-long, free-flowing Hanford reach of the Columbia River, on the other hand, have always (1960-83) reflected the spawning migration of a stream dwelling population of mountian whitefish, unless some of the whitefish counted originated in McNary Reservoir located below the Hanford Reach.

Lake dwelling mountain whitefish populations have been reported to make pronounced spawning runs up tributary streams (McAfee 1966; Simon 1946; Snyder 1918). Large runs come into the South Fork Madison River from Hebgen Lake, Montana (Brown 1952), a distance of about 24 miles. We have no way of determining whether counts at Priest Rapids Dam included fish from McNary Reservoir, but the available evidence suggest that most mountain whitefish counted at any dam originate in the immediate downstream habitat.

Mountain whitefish counts at Wanapum Dam (1963-66), 18 miles upstream of Priest Rapids Dam, averaged only 61% of the whitefish count at Priest Rapids, and counts at Rock Island Dam 38 miles further upstream averaged only 63% of the Wanapum counts. Spawning migrations also tend to begin and peak earlier in an upstream to a downstream direction providing further discontinuity and isolation of counts (Figure 4). For example, in 1967 6,200 whitefish were estimated passing over Rock Island Dam versus 55,000 at the upstream Rocky Reach Dam, with a minimum of about 49,000 whitefish having had to originate in Rock Island Reservoir. Furthermore, the Rocky Reach Dam run peaked in September whereas the Rock Island Dam peaked in October virtually eliminating the possibility of significant double counting (Figure 6). The same relationship occurred in most other years (i.e. 1966, Figure 6).

Erickson et al (1977) has described the 52 mile long Chief Joseph Reservoir located below Grand Coulee Dam as retaining the characteristics

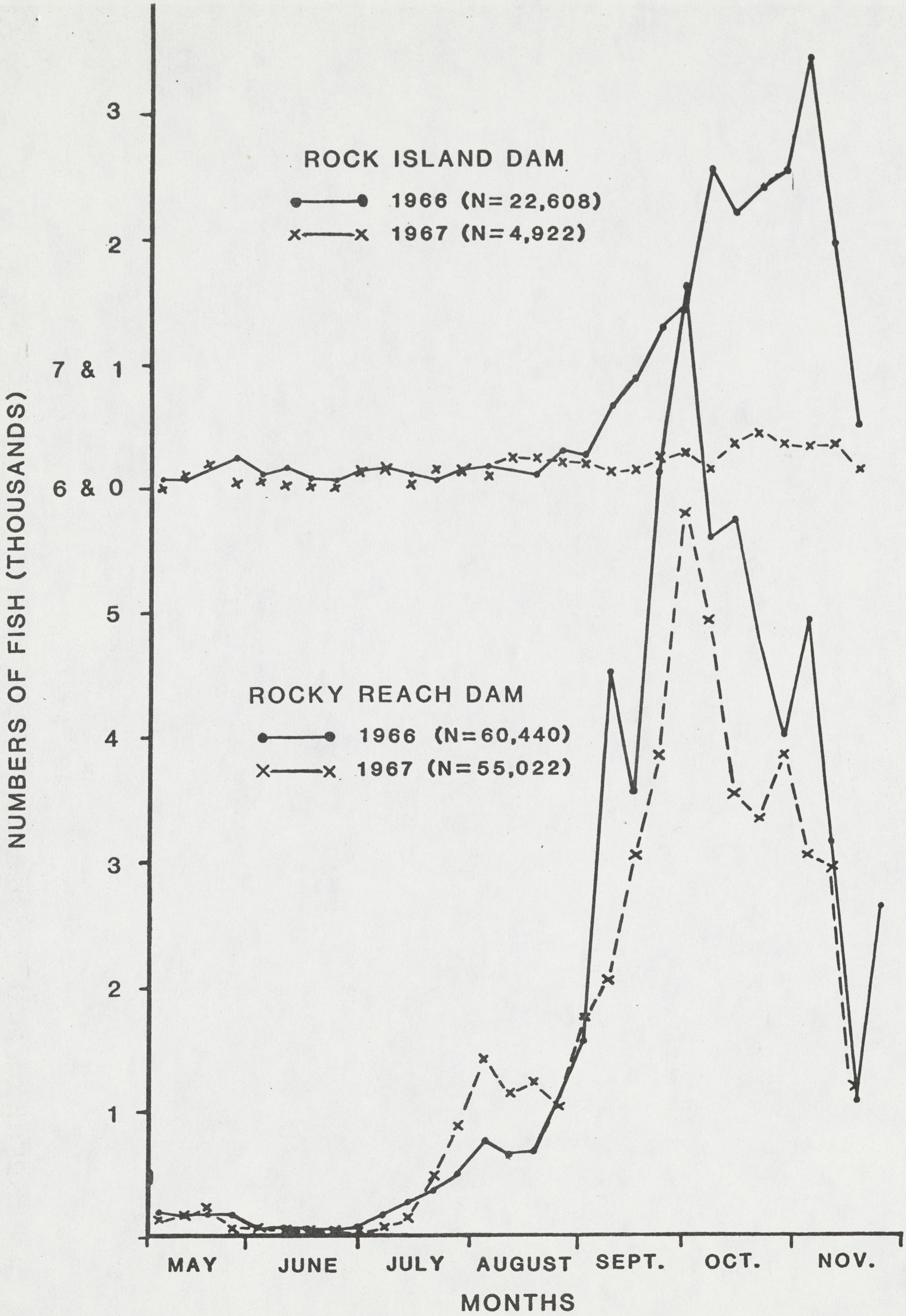

FIGURE 6 Weekly (actual) counts of mountain whitefish at Rock Island and Rocky Reach Dams, 1966-67.

of a free-flowing river in its upstream portion while the lower portions are characteristic of a flow-through reservoir; an apt description of Ryder's (1974) neither lake or stream but somewhere in between definition of a reservoir, which applies to all mid-Columbia River flow-through impoundments. Erickson et al (op cit) found fish stocks occurring in Chief Joseph Reservoir to be extremely low and dominated by non-game species. Mountain whitefish made up only 2.9% (N83) of the number of fish sampled. Total abundance of all fish species declined downstream, indicating a general preference of the resident fishes for the riverine - like section of the reservoir.

Erickson et al (1977) concluded that since anadromous fishes were excluded from this reach of the Columbia River by the construction of Chief Joseph Dam lacking a fish ladder, the fish fauna reverted to an array of resident species which have either found conditions suitable for survival of small numbers in the Chief Joseph Reservoir or are continuously being recruited to the reach from the upstream Grand Coulee Dam reservoir (Lake Roosevelt). The abundance of mountain whitefish has been consistently low in studies of Lake Roosevelt, although lake whitefish (*Coregonus clupeaformis*) have been identified as constituting about 5% of the relative abundance of the fish fauna of this mainstem storage reservoir (Harper et al 1980). However, relative abundance of mountain whitefish in all sampling of Columbia River impountments has been unusually low in comparison to dam counts (Table 2).

The mountain whitefish has a wide destribution in southwestern Canada and the northwestern United States and is common in lakes and streams throughout the Columbia River Basin (Wydoski and Whitney 1979; Scott and Crossman 1973; Daily 1971). The life history of mountian whitefish from other

Table 2. Relative abundance (percentage of total catch) of fish species or groups of fish as indicated by various sampling of the middle Columbia River, lower Columbia River, and Snake River.

Study	Middle Columbia River					Lower Columbia River		Snake River
	1/ Erickson et al. 1976 Chief Jos. Reservoir	2/ Lanmeyer 1972 Chief Jos. Reservoir	3/ McGee 1979 Wells Reservoir	4/ Dell et al. 1975 Five Reservoirs	5/ Gray & Daubler 1973-76 River	6/ Nelson 1981 McNary Reservoir	7/ Hjort et al. 1981 John Day Reservoir	8/ Bennett et al. 1983 Four Reservoirs
Common Name	%	%	%	%	%	%	%	%
Sturgeon	tr.	0.6			0.5	0.1	0.1	0.5
Shad						16.6	40.8	tr.
Lake whitefish	1.3	6.1				tr.		
Mt. whitefish	2.9		0.3	0.6	3.2	0.5	0.1	0.1
Trout	2.0	1.4	0.4	tr.	0.6	0.2	0.2	0.4
Salmon	1.1	3.8	tr.	7.7	39.7	51.0	5.1	0.2
Carp	0.8	1.1	0.6	0.2	0.7	0.7	2.7	3.1
Tench			0.5	tr.	tr.			
Shiner	1.8		12.9	15.6	20.0	tr.	tr.	9.3
Dace	3.7		0.5	0.7	0.4	tr.		tr.
Squawfish	34.3	29.0	8.0	22.5	12.3	12.7	3.2	7.7
Peamouth Chub	12.4	12.4	3.0	11.7	7.5	1.5	7.7	0.2
Chiselmouth "	1.6	2.6	42.9	4.5	2.7	1.1	4.7	4.3
Sucker	20.9	26.0	12.8	16.4	9.4	2.7	23.4	31.2
Catfish			1.3	0.2	0.2	2.6	0.6	4.8
Burbot	tr.	0.3						
Stickleback				17.3	0.2		tr.	
Sandroller				0.3	0.2	tr.	tr.	
Centrarchids	tr.		14.7	0.7	0.2	8.4	6.2	30.4
Walleye	8.4	14.0				0.1	0.3	
Yellow Perch	3.2	1.5	0.1	0.1	0.5	1.0	3.1	7.0
Sculpin	5.6		0.9	1.1	0.7	0.3	1.7	0.6

1/ N 2,902: gillnet, seine, set line, electrofishing.
2/ N 263: gillnet.
3/ N 1,998: seine, trapnet, angling.
4/ Wells, Rocky Reach, Rock Island, Wanapum, Priest Rapids reservoirs, N 32,289: seine, trapnet, angling.
5/ Free-flowing Hanford reach; N21,085: seine, gillnet, trammel net, trapnet, set line, minnow trap, angling.
6/ N 11,508: gillnet, electrofishing, seine, tow net.
7/ N 31,379: gillnet, electrofishing, seine, tow net, trapnet, trawls, fry trap, bongo nets.
8/ Lower Granite, Little Goose, Lower Monumental, Ice Harbor reservoirs; N 52,259: gillnet, seine, trapnet, electrofishing.

areas shows that large streams are preferred over small streams, with deep pools for shelter evidently critical in achieving relative abundance (Mullan 1976; Brown 1952; Sigler 1951). Spawning occurs over gravel-rubble in riffles with no redd prepared. Habitat preferences of mountain whitefish in lakes is less clear, although spawning along shoals has been documented and one instance of beach spawning has been reported for a fluctuating hydroelectric reservoir (Nelson 1965).

Jordon and Evermann (1905) state that mountain whitefish thrive in oligotrophic lakes, whereas Godfry (1955) found that they occur most abundantly in eutrophic lakes with a fairly good supply of bottom food organisms. Some diversity of findings also exists concerning depth preferences in lakes (Godfrey 1955; Echo 1954; Jordan and Evermann 1905), which can be explained by food availability (Carl et al 1967; McHugh 1940). All authorities agree, however, that mountian whitefish require cool water (≤68F). La Rivers (1962) and Sigler (1951) believed that high water temperatures limit mountain whitefish to elevations above 4500 feet in California, Nevada, and Utah. Low water temperatures (≤43F) have also been found essential to the successful development of mountain whitefish eggs (Rajagopal 1979, 1975).

Mainstem Columbia River water temperatures are not greatly different then averages prevailing prior to hydroelectric development (Gould and Wedemeyer 1981; Bell et al 1976), but there have been significant shifts in seasonal and monthly norms. October, November, December, and January water temperatures at Rock Island Dam now average 59.8F, 52.9F, 46.2F and 40.4F versus 56.3F, 46.1F, 39.9F and 36.2F prior to Grand Coulee Dam becoming operational in 1941 (Figure 7). Rajagopal (1975) observed that mortality of mountain whitefish after 36 days of incubation in the laboratory was

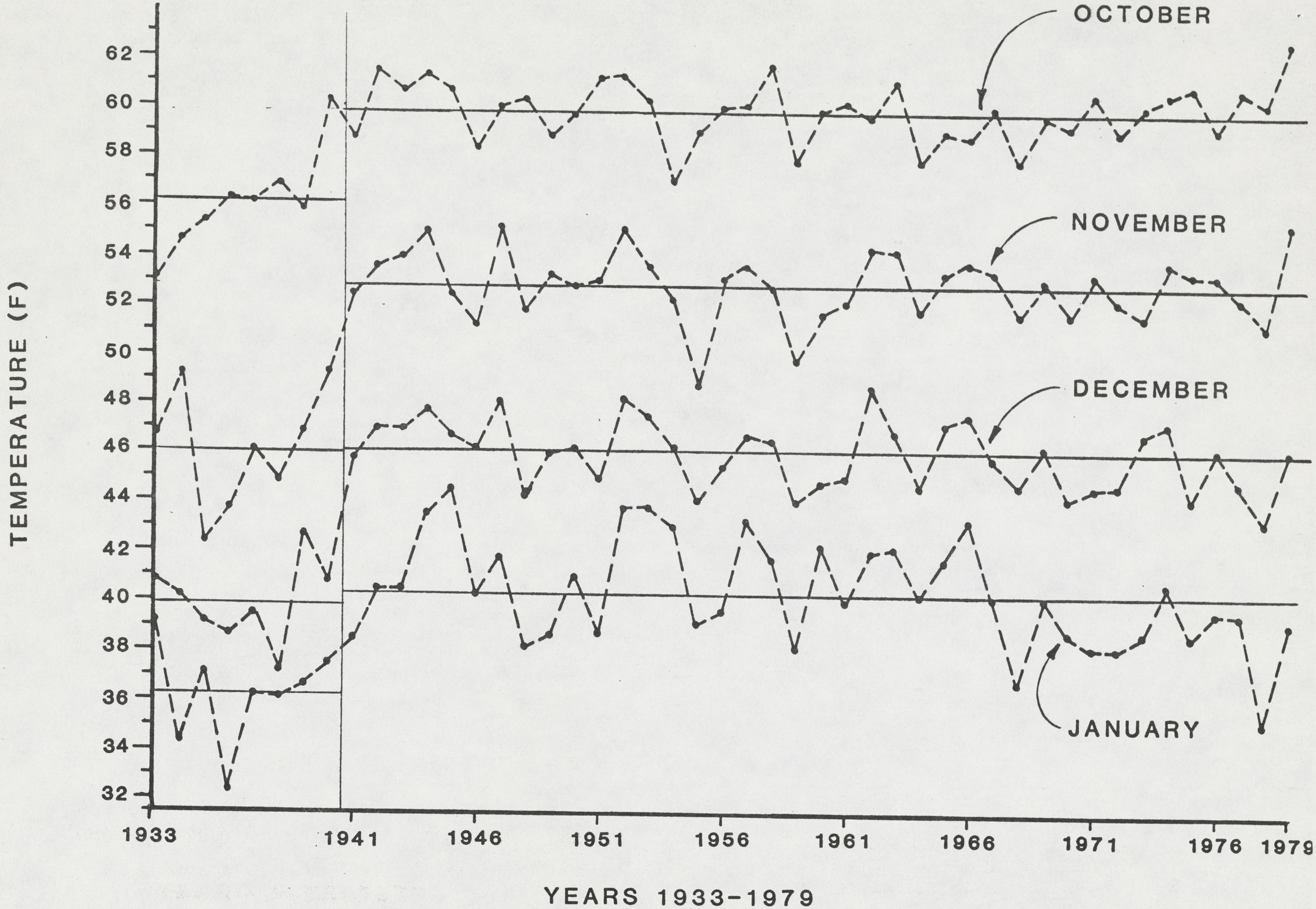

FIGURE 7 Average October, November, December, and January water temperatures at Rock Island Dam for the years 1933-79 (horizontal line represents the long-term average).

8.7% at 42.8F, 34.4% at 48.2F, and 85.1% at 50.0F; mortality was 100% by day 14 for eggs held at 53.6F.

Laboratory and field evidence presented by Rajagopal (1979, 1975), Lawler (1965), Price (1940), and Cobby and Brooke (1970) show that the closely related lake whitefish, lake herring (C. aretedii), and mountian whitefish are all rather precisely adjusted during embryonic development to a narrow range range of temperature close to 33-43F, and that successful spawning at temperatures above 43F is chancy at best. Marginal temperatures in the range of 44-49F for incubation of mountian whitefish eggs in the mid-Columbia River are now the rule rather then the exception during the month of December (Figure 7), which doubtless is close to the outside limit for normal egg deposition.

No age composition data are available for whitefish runs at dams. If we limit ourselves to striking highs or lows in counts of mountian whitefish and assume dominance or lack of dominance by first-time spawners, fish in their fourth year of life with three annuli having a length of about 8.0 to 12.0 inches as commonly reported in the literature (Daily 1971), and affected by water temperatures prevailing in year N-5, the role of water termperature on population dynamics can be placed in some perspective.

Strong run strength at Rock Island Dam was associated with water colder than, or near, the long-term average in eight of 12 years (Table 3). Included was a 482% increase to the record count of 84,400 whitefish in 1953 and a 219% increase of the 1983 run associated with the lowest December and January water temperatures recorded since 1941 (Figure ~~(Table~~ 7). Frequently, too, run strength at Rock Island was mimicked at other dams as illustrated by the 50%, 61%, and 27% increase at Wells, Rocky Reach, and Priest Rapids dams in 1983 associated with recent record low water temperatures in 1978-79.

Table 3. Correlations of dam counts of mountain whitefish with water temperatures at Rock Island Dam in year N-5. Plus sign represents favorable aspect of temperature. Minus sign represents unfavorable aspect of temperature.

	Water temperatures colder than, or near, long-term average (F)							Dam Counts						
Year	Oct (59.8)	Nov (52.9)	Dec (46.2)	Jan (40.4)	Feb (37.8)	Mar (38.7)	Apr (43.0)	Wells	Rocky Reach	Rock Island	Wanapum	Priest Rapids	McNary	Year
								Strong or increasing run (+)						
1940-41	+	+	+	+	-	-	-			+				1945
1942-43	+	-	-	+	-	-	-			+				1947
1944-45	-	-	-	-	-	-	+			+				1949
1946-47	+	+	+	+	+	+	+			+				1951
1948-49	-	+	+	+	+	+	+			+				1953
1949-50	+	+	+	+	+	+	+			+			+	1954
1953-54	+	+	-	-	-	+	+			+			-	1958
1955-56	+	+	+	+	+	+	+			+		+	+	1960
1956-57	+	+	+	+	+	+	+		+	+		-	+	1961
1957-58	+	+	+	-	-	-	-		+	+		+	+	1962
1961-62	+	+	+	+	+	+	+			+				1966
1978-79	+	+	+	+	+	+	+	+	+	+		+		1983
									Weak or decreasing runs (-)					
1943-44	-	-	-	-	-	-	-			-				1948
1945-46	-	+	-	-	-	-	+			-				1950
1947-48	-	-	-	-	+	+	+			-				1952
1950-51	+	+	+	-	+	+	+			-			+	1955
1951-52	-	-	+	+	+	+	-			-			-	1956
1952-53	-	-	-	-	-	-	-			-			-	1957
1958-59	-	+	-	-	+	-	-		-	-	-	-	+	1963
1962-63	+	-	-	-	-	+	+	-	-	-		-	-	1967
1972-73	+	+	+	+	+	+	-	-	-	-		-		1977

Conversely, pronounced weak runs were associated with above normal water temperatures during spawning and incubation in six out of nine years (Table 3).

As pointed out by Lawler (1965) the relationship of temperature to the success of year-classes of whitefish is not absolute even in marginal Lake Erie. Lawler demonstrated that fall temperatures must drop early to 43F; the decrease to the optimum temperatures for development must be steady; and spring temperatures must increase slowly and late to provide prolonged incubation near the optimum developmental temperatures (33F). While these particular considerations would not appear applicable to the Columbia River, due to moderation of temperature extremes resulting from flow regulation, this is not to say that local factors peculiar to individual reservoirs could not override conditions more widespread in their influence. Mountain whitefish have a high reproduction potential and may live up to 18 years and spawn several times. Thus, any number of factors acting singularly or in combination could affect abundance as reflected in dam counts.

High survival of newly hatched mountain whitefish resulting from high food supply due to low density of competitive species and or trophic upsurge in new reservoirs could override poor egg hatch, and such phenomena does seem evident in the trend of the dam counts. However, it should be noted that maximum counts frequently represented year classes of mountain whitefish produced before reservoir rearing was possible (i.e., McNary and Priest Rapids dams, Figure 5).

Another possible artifact of whitefish dam counts is the influence of harvest. Although controversy exists as to the exact harvest, between 18,000 and 94,000 mountain whitefish were reported caught annually by sport fisherman in the Columbia River during the mid-1950s in what are now Priest and Wanapum reservoirs, and another 10,000 to 48,000 below the Priest Rapids dam site (Davidson 1958). Currently little or no sport fishing for whitefish occurs in the Priest and Wanapum reservoirs, although a very viable sport fisheries continues below Priest Rapids Dam (i.e., limit catches of 12 whitefish in one to two hours). Escalating sport fish harvest below Priest Rapids in the post-dam era, but with an initial lag in harvest as fishermen adjusted to the changed situation, could have been responsible for the high initial counts of whitefish and created the impression of subsequent decline. While fisherman harvest doubtless influenced the magnitude of the whitefish run at Priest Rapids Dam, the same is certainly not true to any extent of runs at the other dams that underwent similar decline.

Recruitment from spawning in tributary streams, such as the Wenatchee River, to the reservoirs of the Columbia River is another possible influence on dam counts of mountain whitefish. However, it is possible that the tributary and impoundment stocks are relatively distinct in respect to place of spawning. In the Phelps Lake drainage, Wyoming, mountain whitefish dwelling in the lake spawned in the lake and mountain whitefish dwelling in the tributary streams spawned in the streams (Hagen 1970).

Though there are other factors to which a fish community must adapt to in the Columbia River, which will be discussed later, here we must return to the local temperature regime as the most omnipresent for mountain whitefish.

Comparatively high summer water temperatures doubtless explains the lack of mountain whitefish at the lowermost Bonneville Dam (Figures 5 and 8). Highest abundance of mountian whitefish at McNary Dam doubtless represented some combination of more fertile, larger downstream habitat and a temperature regime affected by the inflowing Snake River subject to ambient air temperatures. At the time of the McNary dam counts (1954-69), the Snake River was little altered by hydroelectric development and Davidson (1958) reported that the greater share of the

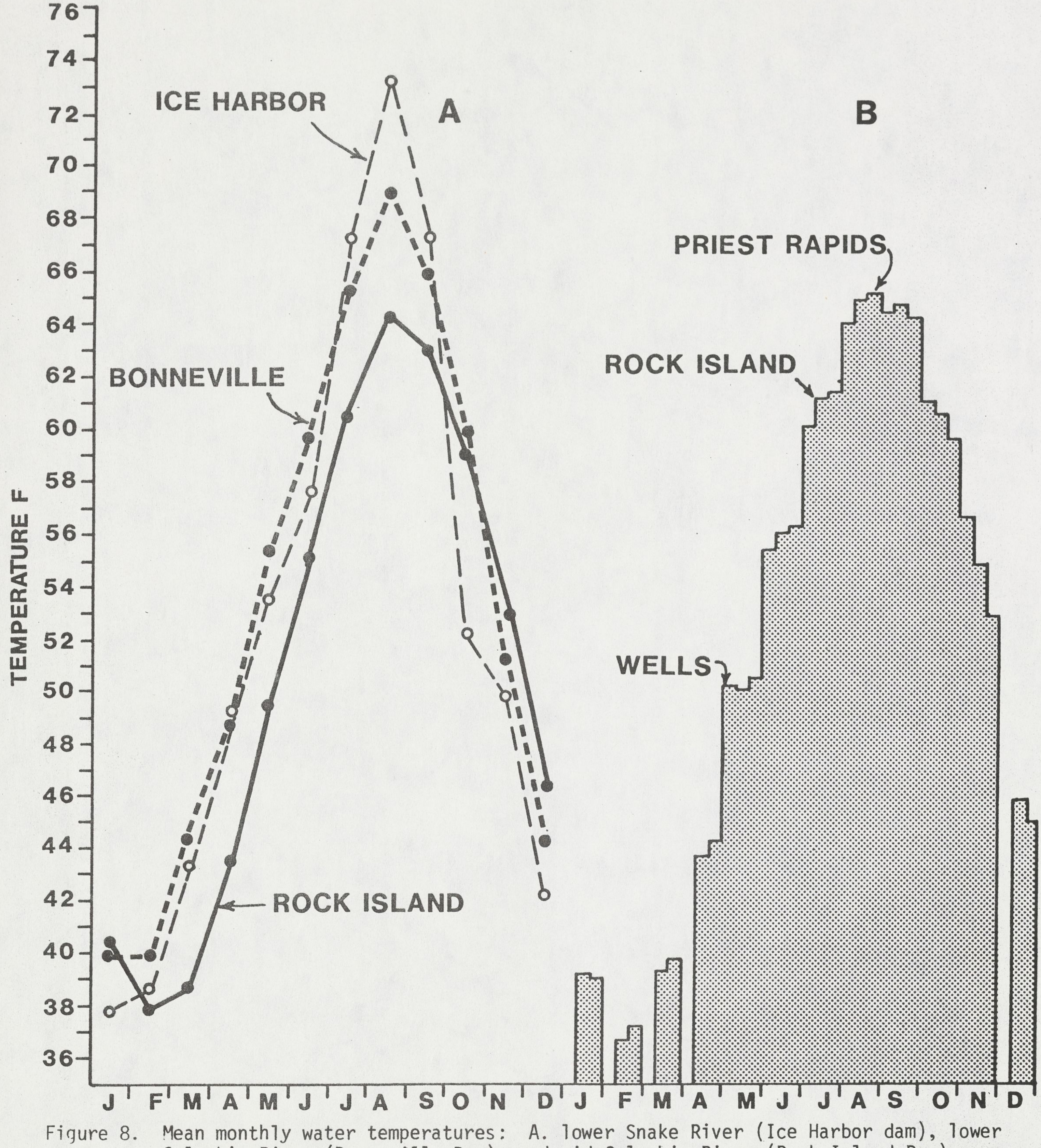

Figure 8. Mean monthly water temperatures: A. lower Snake River (Ice Harbor dam), lower Columbia River (Bonneville Dam), and mid-Columbia River (Rock Island Dam) 1963-74 (Bell et al. 1976); B. mid-Columbia River at Wells (RM 516), Rock Island (RM 453), and Priest Rapids (RM 397) dams, 1974-83.

mountain whitefish counted at McNary Dam spawned in the Snake River.

There is also the persuasiveness of temperature in explaining why Columbia River mountain whitefish possibly originally not subject to extensive spawning migration subsequently adapted such behavior, as indicated in the Rock Island Dam counts. Rock Island was not only the first impoundment on the Columbia River, but is also impounded the least water and least increased the surface area of the original river of any of the mainstem dams that followed (Table 1). Accordingly, the impoundment evidently had little effect on water temperatures (Figure 7). With the advent of Grand Coulee Dam in 1941, however, the temperature regime of the river underwent drastic change. In common with temperate storage reservoirs (Ward and Stanford 1979), the tailwater, extending at least to the confluence of the Snake River at the head of McNary Reservoir, became warmer in fall and winter and cooler in spring and summer. Mountain whitefish undergoing sexual maturation in late-summer, early-fall and evolutionary attuned to declining temperature were then subjected to rising temperature and propelled to seek more suitable temperatures for gonadal development. The influence of photoperiod and temperature on gonadal maturation is well known (Hoar 1969), as attested by the frequent manipulation of these factors to stimulate fish to spawn outside the normal spawning season.

Little is known about behavioral thermoregulation of mountain whitefish outside of the spawning and incubation period (Ihnat and Buckley in press), except that the optimal temperature for development and growth after yolk absorption is about 10^{o} (53F) higher then the optimal temperature for incubation (Stalnaker and Gresswell 1974). Anomalous departures evident in monthly passage timing of mountain whitefish at dams could involve phenological disruptions relating to behavioral thermoregulation (i.e. McNary

1963, 1969, Rock Island 1964, Rocky Reach 1976, Figure 4), or return of fish displaced downstream in the spring flood. However, it is unlikely that the lesser fluctuation and greater sustained relative abundance of annual mountain whitefish at the two uppermost dams (Wells and Rocky Reach) compared to the three lowermost dams (Priest, Wanapum, and Rock Island) on the mid-Columbia River can be ascribed to climatic factors alone (Figure 5). Slightly cooler temperatures prevail from upstream to downstream in spring, early summer, while slightly warmer temperatures prevail from upstream to downstream in late summer, fall, an inverse relationship for optimum reproductive success (Figure 8B).

The whitefishes (Coregoniae) constitute one of three subfamilies of the salmonid family and a profussion of literature depict these cold water fishes as comparatively intolerant of interactions with other fishes, particularly if environmental conditions are marginal. It can be concluded that mountain whitefish are primarily a stream species, otherwise there would be little evolutionary reason for lake whitefish, even though this is a gross simplification regarding a perplexing group of fishes (Scott and Crossman 1973). Relatively high and sustained counts of mountain whitefish at Wells and Rocky Reach dams are in keeping with the river-like Rocky Reach and Rock Island reservoirs from which the migrants originate. Both reservoirs are almost devoid of backwaters or sloughs as reflected in shorelines that are almost exactly double that of reservoir length (Shoreline ratios of 2.2 and 2.0, Table 1). In the downstream Wanapum and Priest Rapids reservoirs, with shoreline ratios of 2.5 and 3.2 (Table 1), sloughs and backwaters are more common and there is a proliferation of competitive species.

Proof that some combination of climatic and species interaction regulates mountain whitefish abundance can be gleamed from the apparent demise of the once abundant mountain whitefish in McNary Reservoir. Recent, extensive sampling of McNary and the downstream John Day Reservoir with a variety of gears, regardless of the selectivity involved, shows that mountain whitefish have virtually disappeared since the dam counts of 1954-69 (Hjort et al. 1981; Nelson 1981). Both of these reservoirs feature a much more diverse assemblage of fish species compared to upriver reservoirs and the requisite sloughs and backwaters (shoreline ratios 3.9 and 4.2) for proliferation.

Trout Species

Abundance of trout in dam counts seems related to circumstances peculiar to individual dams. Conclusions, however, are confounded by a lack of species differentiation and confusion surrounding the major trout groups in the Columbia River drainage.

The coastal rainbow trout (Salmo gairdneri) is native as both resident and anadromous steelhead populations, mainly from the Cascade Range to the coast. East of the Cascade Range the native rainbow trout evolved from a group of trout Behnke (1981) has called the redbanded trout. Kamloops rainbow trout introduced into Priest Rapids and Wanapum reservoirs 1961-67 are believed to be a redband trout lacking strong migratory tendencies (per. comm. Robert Behnke, CSU). Hatchery rainbow trout commonly stocked in tributaries of the Columbia River have been primarily derived from anadromous stocks with strong migratory tendencies.

Cutthroat trout likewise can be divided into migratory and sedentary stocks; the coastal cutthroat trout (S. clarkis clarki) in which anadromy is well developed, and an interior cutthroat trout comprised of several less distinct subspecies in which anadromy is not well developed (Johnston 1981; Behnke 1976). The Dolly Varden trout is actually two species of char; the bull char (Salvelinus confluentus), an interior freshwater species, and the coastal Dolly Varden char (S. malma), which may migrate between fresh and salt water (Behnke 1980, Cavender 1980).

The highest, most sustained counts of unidentified trout species occurred at Bonneville Dam 1938-69 (annual average 2,960; range 610-9,968) (Figure 9), and doubtless contained a baseline component of anadromous cutthroat trout and Dolly Varden char. Habitat quality of the lower river for resident salmonids is poor compared to the upper river (i.e., warmer water temperatures (Figure 8), heavier siltation, etc.) and high abundance of trout at Bonneville Dam argues against the common precept that the abundance of cold water fishes decreases from the source to the mouth of a river (Hynes 1970, Huet 1959, Pennak 1945) unless mitigated by migrants from the sea. Further, the pattern of annual passage timing of trout counts at Bonneville Dam was the most rhythmic of any of the Columbia River dams (Figure 10). A major peak in passage inevitably occurred in September, which is consistent with fall spawning of Dolly Varden char and winter spawning of anadromous cutthroat trout (Johnston 1981; Wydoski and Whitney 1979). King (1981a) reported that sea-run cutthroat enter the Columbia River July through November, spawn in tributaries primarily below Bonneville Dam, and that the sport catch ranged from 1,400 to 13,600 in years 1969-81.

The upstream McNary Dam averaged only 1.6% (average 48 fish; range 0-383) of the annual average count of trout at Bonneville Dam and trout were least abundant of any of the dams (Figure 9). Several tributaries enter the Columbia River between Bonneville and McNary dams and the missing fish likely turned-off to these rivers.

Counts of trout at Priest Rapids Dam on the mid-Columbia 1960-83 averaged 388 fish annually (range 4 to 1,308). Highest counts occurred

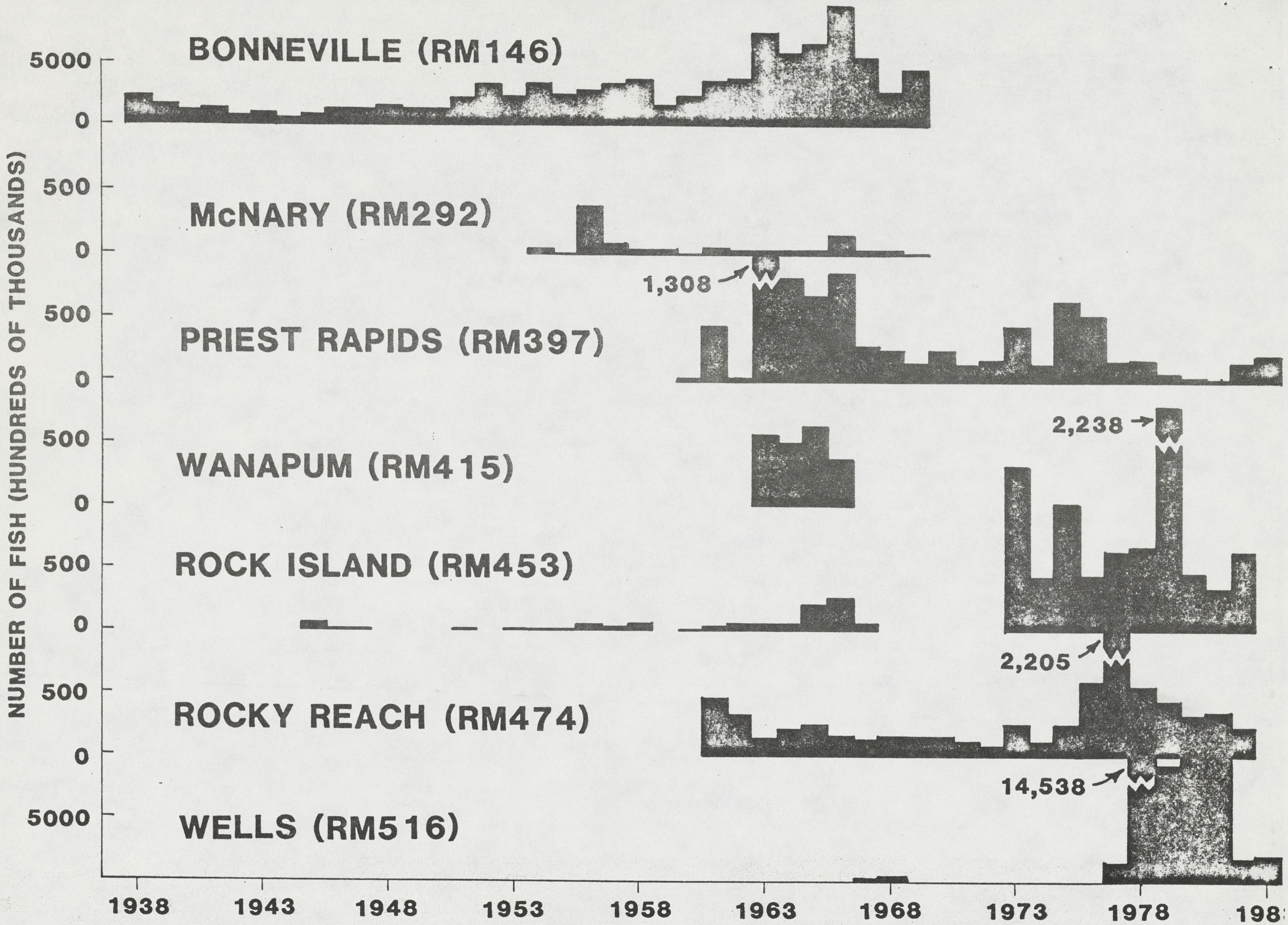

Figure 9. Yearly counts of combined trout species ascending Columbia River dams.

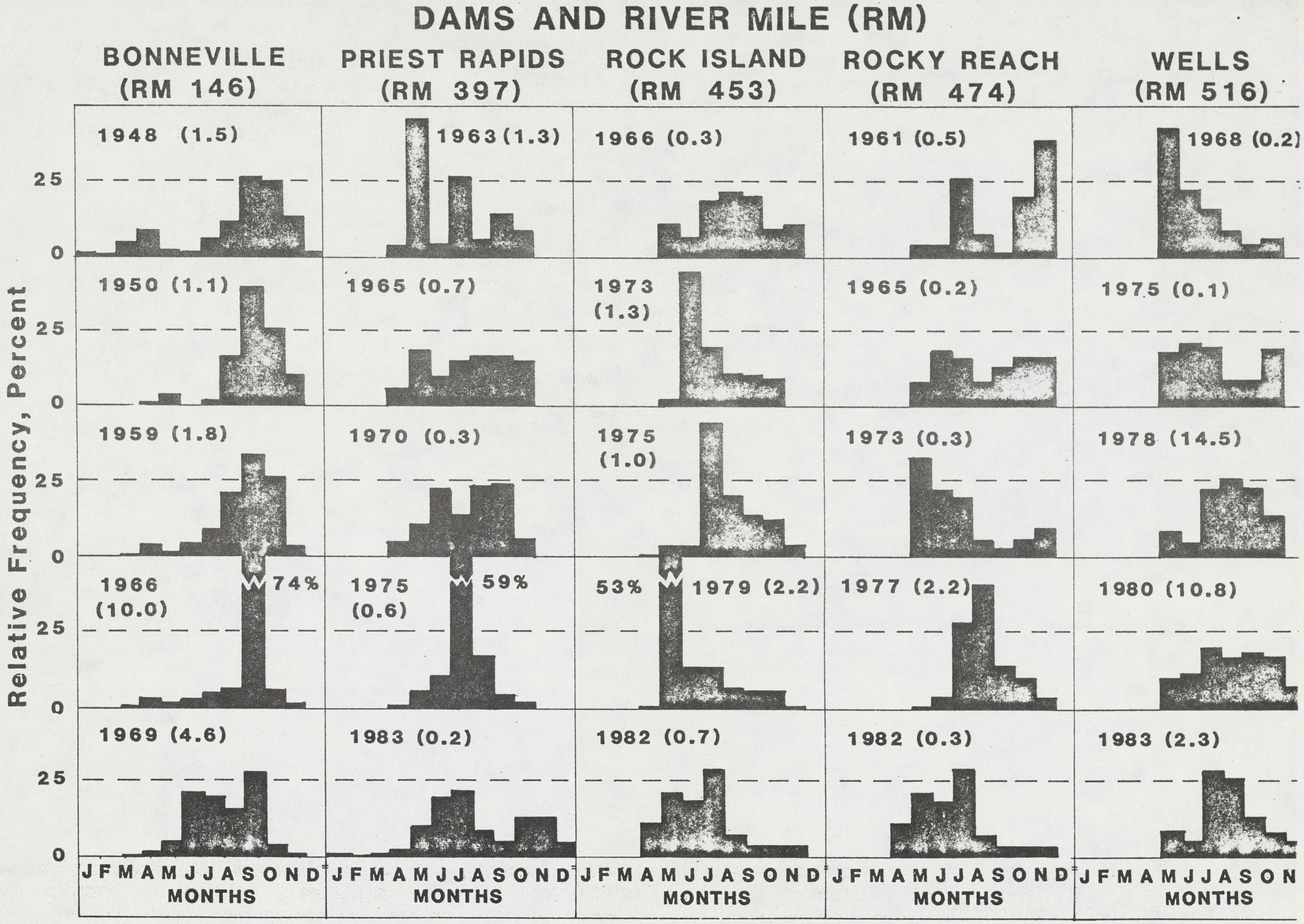

Figure 10. Monthly percent distribution of combined trout species counted passing upstream of Columbia River dams for selected years.

Run size in 1000s of fish ( ).

1963-66 coincidental to the annual stocking of 150,000 Kamloops rainbow trout fingerlings 1961-65 (Figure 9). Similar stocking of Kamloops rainbow trout occurred in the upstream Wanapum Reservoir 1963-67. In 1965 the plants of Kamloops rainbow trout were marked by fin-clipping (Rose 1965). At Priest Rapids Dam 257 of these fish were recorded passing downstream through the fishways and 218 passing upstream; at Wanapum Dam 211 were recorded passing upstream. Movements of this nature qualify as indiscriminate wandering as reported by Hynes (1970).

Trout counts at Priest Rapids and Wanapum dams during the early to mid-1960s were much higher then at the upstream Rock Island and Rocky Reach dams (Figure 9). Much of this difference would seem to be accounted for the introduced Kamloop rainbow trout, particularly considering trophic upsurge and low density of competition species associated with new reservoirs. Other forms of rainbow trout, as well as brown trout (S. trutta), cutthroat trout and "Dolly Varden" were reported (Rose 1965). For year 1965, Rose (op cit) observed that cutthroat trout were more numerous than brown trout at both Priest Rapids and Wanapum dams and that only one Dolly Varden (bull char) was recorded. Brown trout are not common in the mid and upper Columbia River, although they may be locally abundant, and this single report of brown trout in dam counts could be spurious.

Fewer then 70 trout were counted annually at Rock Island Dam 1945-60 and the bulk of these were reported as Dolly Varden trout (bull char) (Figure 9). From 1961 through 1967, when the trouts were last recorded separately, the counts increased to 200-300 trout annually and rainbow trout begin to outnumber bull char. Following suspension of counting in years 1968-72, counts of trout at Rock Island rose to over 800 fish annually (range 464-2,238). This increase in trout numbers at Rock Island Dam beginning in the mid-1960s (Figure 9) doubtless is explained by initiation of major trout stocking in the Wenatchee River in 1965.

To compensate for the loss of the mountain whitefish fishery inundated by Rocky Reach Dam, the Chelan County PUD provided annual funding to the Washington Department of Game for catchable size rainbow trout to be stocked in the Wenatchee and Entiat river drainages. In 1973, for example, 89,400 and 14,900 rainbow trout were stocked in upriver areas of the Wenatchee and Entiat river drainages, respectively. Harvest on the rainbow trout stocked in the Wenatchee drainage was estimated at 69% (Foster 1978), leaving 28,000 fish unaccounted for. The count of trout at Rock Island Dam in 1973 was 1,332, the second highest record, and it is reasonable to assume, considering the meager baseline counts of early years, that at least 1,000 of these fish orginated from the hatchery rainbow trout planted 40-70 miles upstream. Extensive downstream movement of stocked rainbow trout is not unusual (Mullan et al 1976, Mullan 1960). What is unusual in this instance is the evidence for a subsequent reverse upstream movement over Rock Island Dam of a substantial number of trout from an undoubtedly larger number that passed downstream.

Counts of trout at Rocky Reach Dam 1961-82 averaged 356 fish annually (range 127-2,205) (Figure 9) and doubtless reflected similar phenomena described for Rock Island Dam, including upstream movement of hatchery rainbow trout existing the Wenatchee River.

Counts of trout at the furthermost upstream fishways at Wells Dam 1967-76 averaged only 110 fish annually, but increased dramatically to 7,214 fish annually (range 1,841 to 14,538) in years 1978-83. This increase was associated with a vastly refined steelhead and rainbow trout stocking program in the upstream Methow River with fish from Wells Hatchery located immediately below the dam. Examination of otoliths from steelhead broodstock returning to Wells Dam showed a relatively high percentage of fish with two years of freshwater growth. These fish had previously been classified as wild or naturally produced. It is now concluded that they represented hatchery steelhead that did not migrate to the ocean when initially released as large (5/lb) young-of-the-year fish and spent an additional year rearing in Wells Reservoir before smolting (per. comm. Ken William, WDG; Zook 1983). Whether these fish reared an additional year in Wells Reservoir or in the tailwater as well, as indicated in counts, is not as important here as the extensive movement exhibited between reservoir and tailrace (i.e., count of 14,538 trout, 1978).

While it is well known that many fish migrate for great distances through rivers, it is not well known how much less-obvious movement occurs. Stray or wandering hatchery trout which move, perhaps, because of population pressure or because they have unsuitable home territories (Miller 1954, 1952), are numerous enough to be observable as a general phenomenon in the Columbia River.

Zook (op cit) in attempting to reconcile the high rainbow-steelhead trout counts at Wells Dam with only 8 rainbow trout out of 2,431 fish sampled in the reservoir (McGee 1979), speculated that it was likely that a population had taken up residence in and around the stream-like passage facilities at the dam. While such speculation is not without merit at Wells and other dams, the implication of the artifact is that resident populations of trout are static and not transient. Neither dam counts, population sampling (Table 2) or sport fishing (Dobler 1978) indicate that mid-Columbia River reservoirs harbor anything but a sparse population of resident trout. While this may be less true for residualized populations of anadromous salmonids, including steelhead trout as indicated in this report, and for coho salmon (O. kisutch) and sockeye/kokanee (O. nerka) as suggested by Mullan (1984, in press), the overwhelming weight of evidence is that recruitment is from the upstream Lake Roosevelt, tributaries, and hatcheries, and that there is dynamic downstream movement involving upstream incursions. Within this framework the long-term trend of increasing abundance of trout in counts at lowermost Bonneville Dam (1938-69) could have reflected the tremendous expansion in stocking hatchery rainbow trout in upriver areas following World War II (Figure 9).

Chubs

Peamouth chub (Mylocheilus caurinus) and chiselmouth chub (Acrocheilus alutaceus) were generally lumped as chubs if not recorded as miscellaneous species in dam counts. Enumeration at the species level occurred only at Rocky Reach Dam 1961-82 and at Rock Island Dam 1979-82. These latter counts show chiselmouth as the more dominant of the two species (Figure 11); conventional population sampling generally shows the reverse (Table 2).

The distribution of the aptly named chiselmouth chub, readily distinguishable with a hard, straight-edged plate on the lower jaw, may reach a length of 13 inches and an age of six years. It is confined to the Columbia River, the Fraser River system of British Columbia, and the Malheur Lake system of Oregon (Wydoski and Whitney 1979). Scott and Crossman (1973) reported that chiselmouth occur more often in lakes than in rivers in Canada, although lake populations spawned in tributary streams when water temperatures exceeded 62.5F.

The distribution of peamouth chub, which may reach a length of

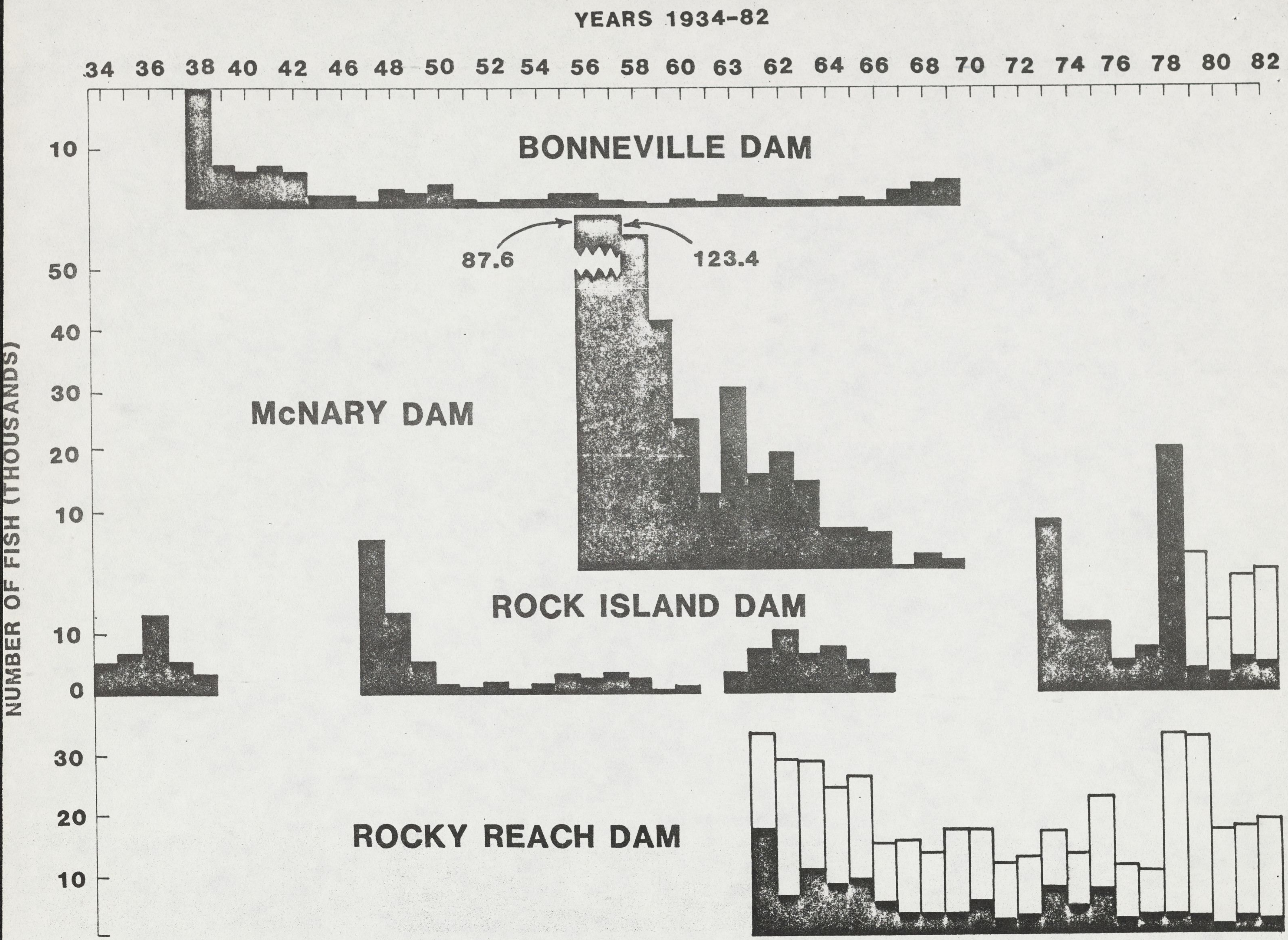

Figure 11. Yearly combined counts of peamouth chub and chiselmouth chub (peamouth distinguished from chiselmouth by shading when the two species were differentiated) at Columbia River dams.

14 inches and an age of 13 years, occurs naturally in lakes and streams of the Columbia River system and in coastal drainages of Washington and British Columbia (Wydoski and Whitney 1979; Scott and Crossman 1973). The peamouth is unusual in that it has been taken in distinctly marine waters in British Columbia and is the second most abundant fresh-water, nonsalmonid species monitored in the Columbia River esturay (Dawley et al. 1984, 1981). Spawning has been reported to occur in both streams and lakes when water temperatures reach about 54F (Wydoski and Whitney 1979; Scott and Crossman 1973).

Daily counts of both chub species at Rock Island and Rocky Reach generally rose to a peak soon after the first arrivals appeared at the dams in late May or June at temperatures of about 56F and then quickly subsided (Figure 12). This passage behavior doubtless exemplified spawning migration. Furthermore, the not uncommon bimodal nature of maxima numbers of chiselmouth chub possibly reflected the earlier passage of ripe males common in spawning migrations of many fish species. On the other hand, the simultaneity of the runs does not confirm slightly earlier spawning of peamouth compared to chiselmouth as suggested by the spawning temperature criteria cited and generalization of time of spawning reported in the literature (Wydoski and Whitney 1979; Scott and Crossman 1973). However, the lack of life history information on chubs precludes rigid generalization on environmental requirements.

Monthly counts of chiselmouth and peamouth chubs at Rocky Reach Dam following late spring, early summer spawning cohorts frequently showed little passage pattern, particularly in early years (Figure 13). Lack of passage pattern might be ascribed to the instability of fish populations in new reservoirs (Ryder et al 1974; Baranov 1961) except that chubs

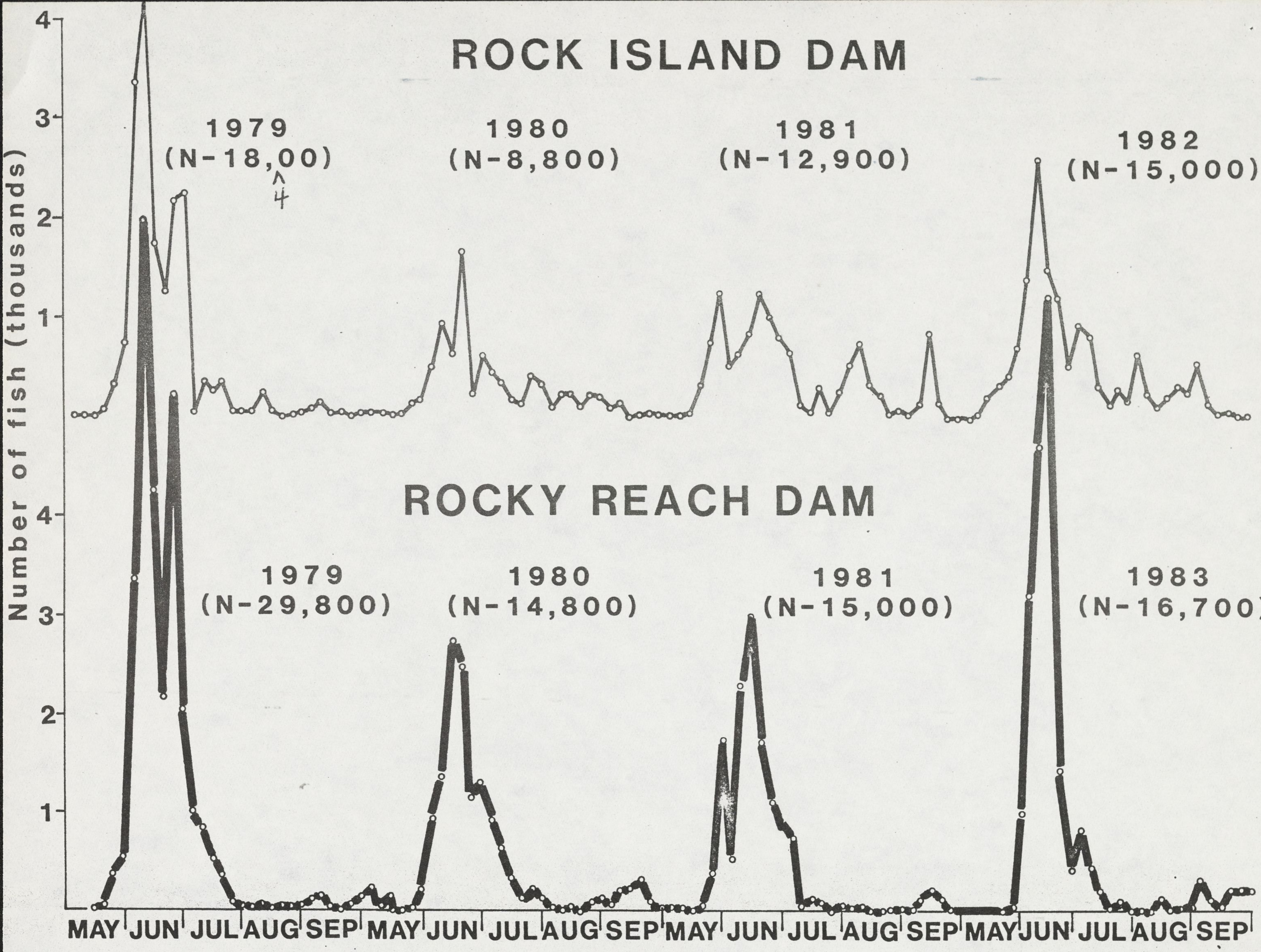

Figure 12. Five day counts of chiselmouth chubs at Rock Island and Rocky Reach dams. May - September (≤3.0% and ≤0.4% of runs occurred October and November), 1979-82.

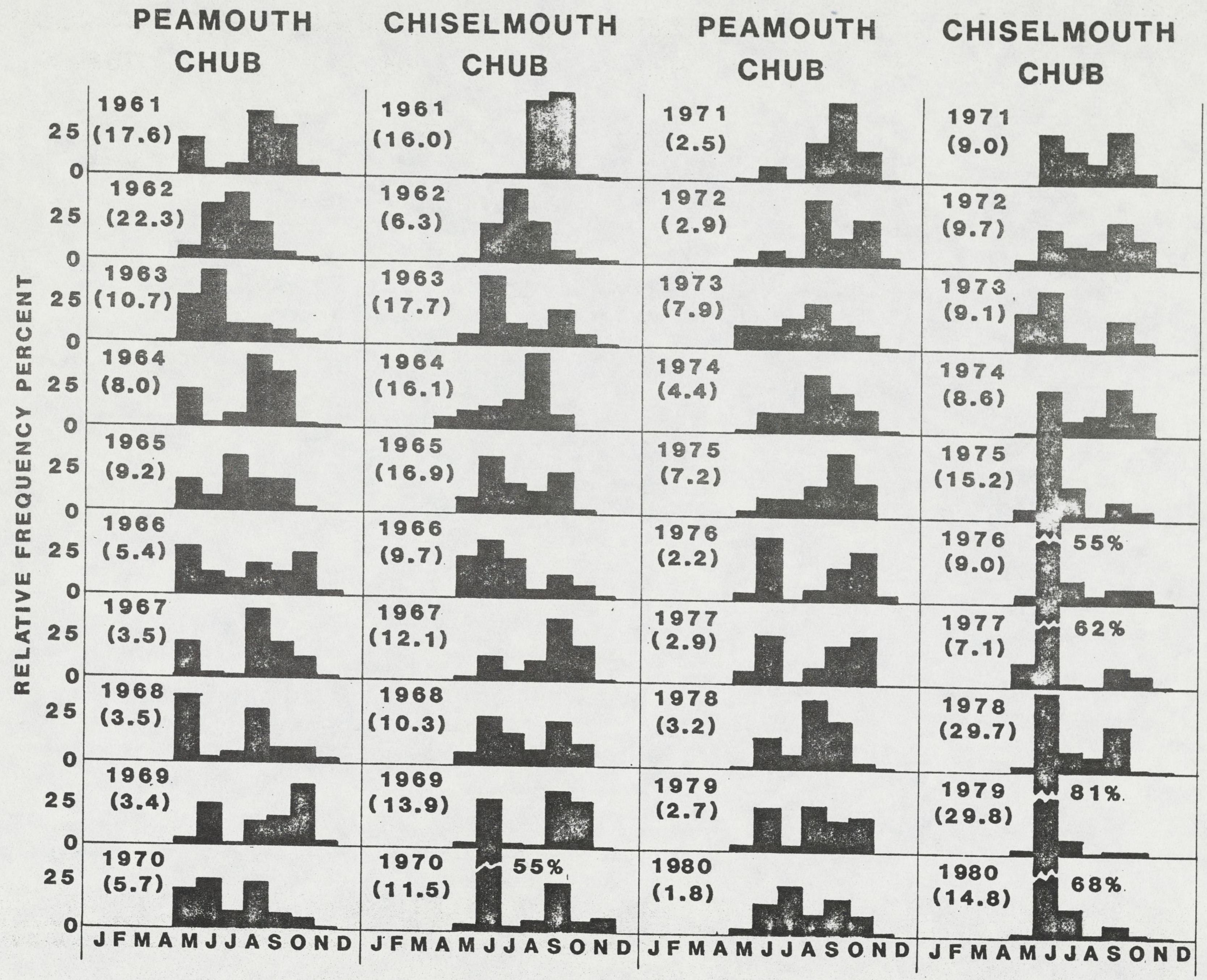

Figure 13. Monthly percent distribution of peamouth and chiselmouth chubs passing upstream at Rocky Reach Dam, 1961-80. Total run size in 1000s of fish (N).

counted passing Rocky Reach Dam in the early 1960s did not originate from the newest upstream reservoir but instead from the oldest downstream reservoir, Rock Island. While it is possible that some irregularity in monthly counts at Rocky Reach may have been the result of sequential upriver passage of chubs through and over one or more downstream reservoirs and dams, the near identical passage timing of chiselmouth at Rock Island and Rocky Reach dams 1979-82 argues against such movement (Figure 12). Fallback, where returning salmon having surmounted a dam are swept back downstream by high flows, is a common phenomenon on the Columbia River and might also be suspected of influencing monthly counts except that most deviant passage occurred in late summer at low or normal flow (Figure 13).

Long-term trends in abundance of chubs are also confused, possibly because of the wide annual fluctuation evident in chiselmouth runs (Figure 11), reflecting an earlier maturing, shorter lived species. Counts at Bonneville Dam show a moderate long-term decline in abundance. Counts at McNary underwent a dramatic decline in the 15 year record from initial completion of the dam. Counts at Rock Island Dam 1934-82 fluctuated widely but with the trend markedly upward in recent years. Rocky Reach Dam counts show a modest long-term decline in peamouth, but with chiselmouth holding their own or increasing (Figure 11).

A six-to-eight week delay in spawning caused by reduced temperatures led to a decline in the reproductive success and numbers of peamouth chub in a Montana tailwater (May and Huston 1979). The reduction in water temperatures during late spring, early summer in the Columbia River tailwater (Figure 14) would not seem ominous to peamouth reproduction, but, then little is known about such species.

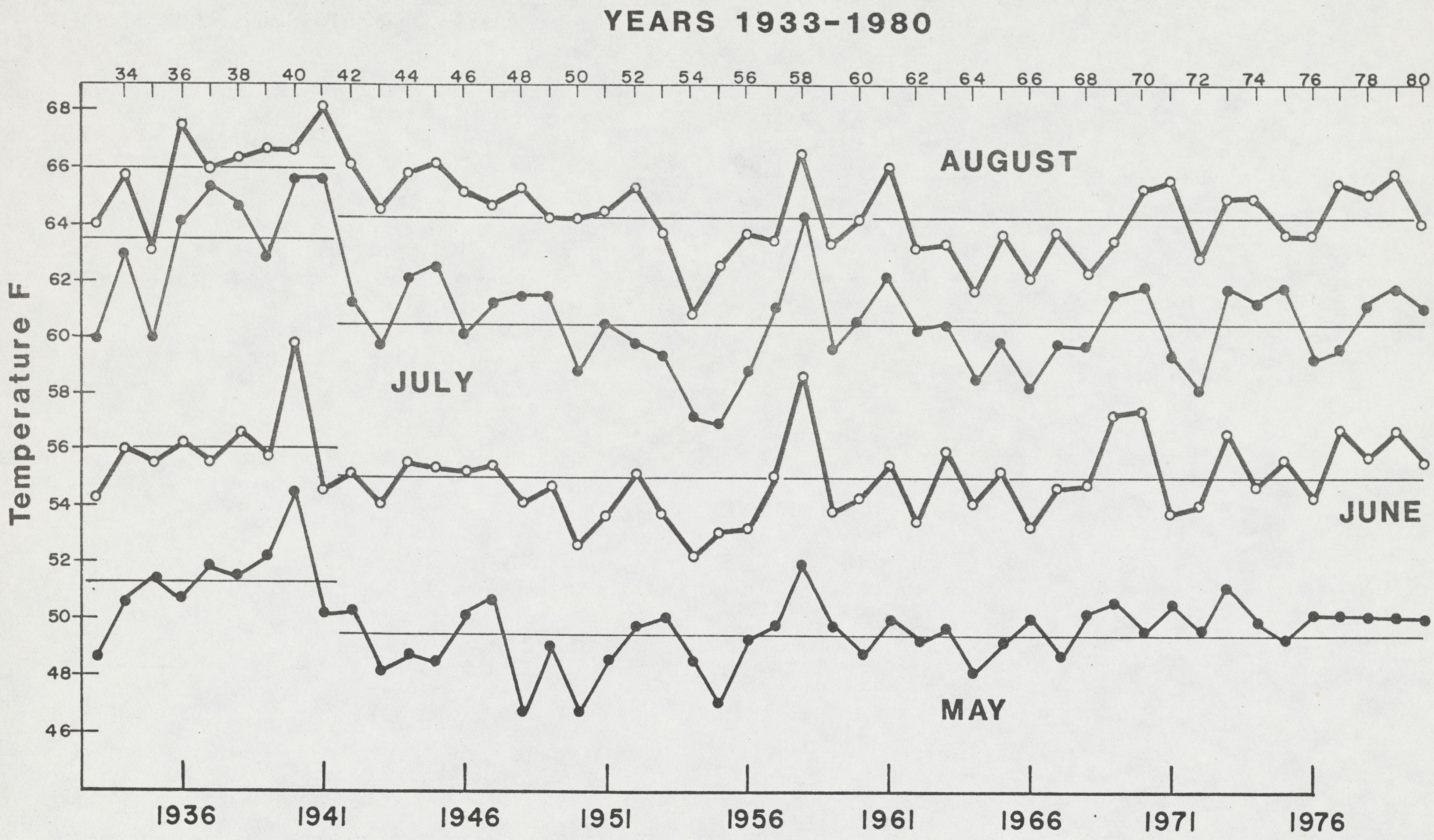

Figure 14. Average May, June, July, and August water temperatures at Rock Island Dam for the years 1933-80. (horizontal line represents the long-term average).

Northern Squawfish

(Ptychucheilus oregonensis)

Northern squawfish have been reported to spawn from May to late July in lakes (Patten and Rodman 1969; Carl et al. 1959) or in tributary streams (Jeppson and Platts 1959) at water temperatures 55-62.5F. In lower Columbia River reservoirs the spawning season extended from June to August (Hjort et al. 1981) and in lower Snake River reservoirs June to early August at water temperatures 57-69F (Bennett et al. 1983). Dam counts of northern squawfish reflect similar spawning phenology (Figure 15).

Virtually no squawfish ascend Columbia River dams from early fall through to late spring. Timing of the onset of upstream movement in spring was apparently not related to annual differences in river discharge but rather to a river temperature of about 52F (Figure 16). Major peak movements in passage were associated with rising water temperatures 54 to 60F, but with increases in movement occurring in spurts. Most temporary decreases in numbers of squawfish migrating up fish ladders occurred on days when there was either a decrease or little change in water temperature. Most decreases in migration associated with increase in temperature followed days on which there had been a marked increase in numbers of squawfish moving upstream. A temporary exhaustion of mature squawfish available to move upstream at the mouths of the fish ladders is suggested. Once water temperatures begin to decline in summer the upstream movement of squawfish fell-off markedly (Figure 16).

Dam counts of squawfish generally declined with aging of the reservoirs (Figure 17). Scott and Crossman (1973), amoung others, characterized the northern squawfish as typically a lake species, preferring still waters to

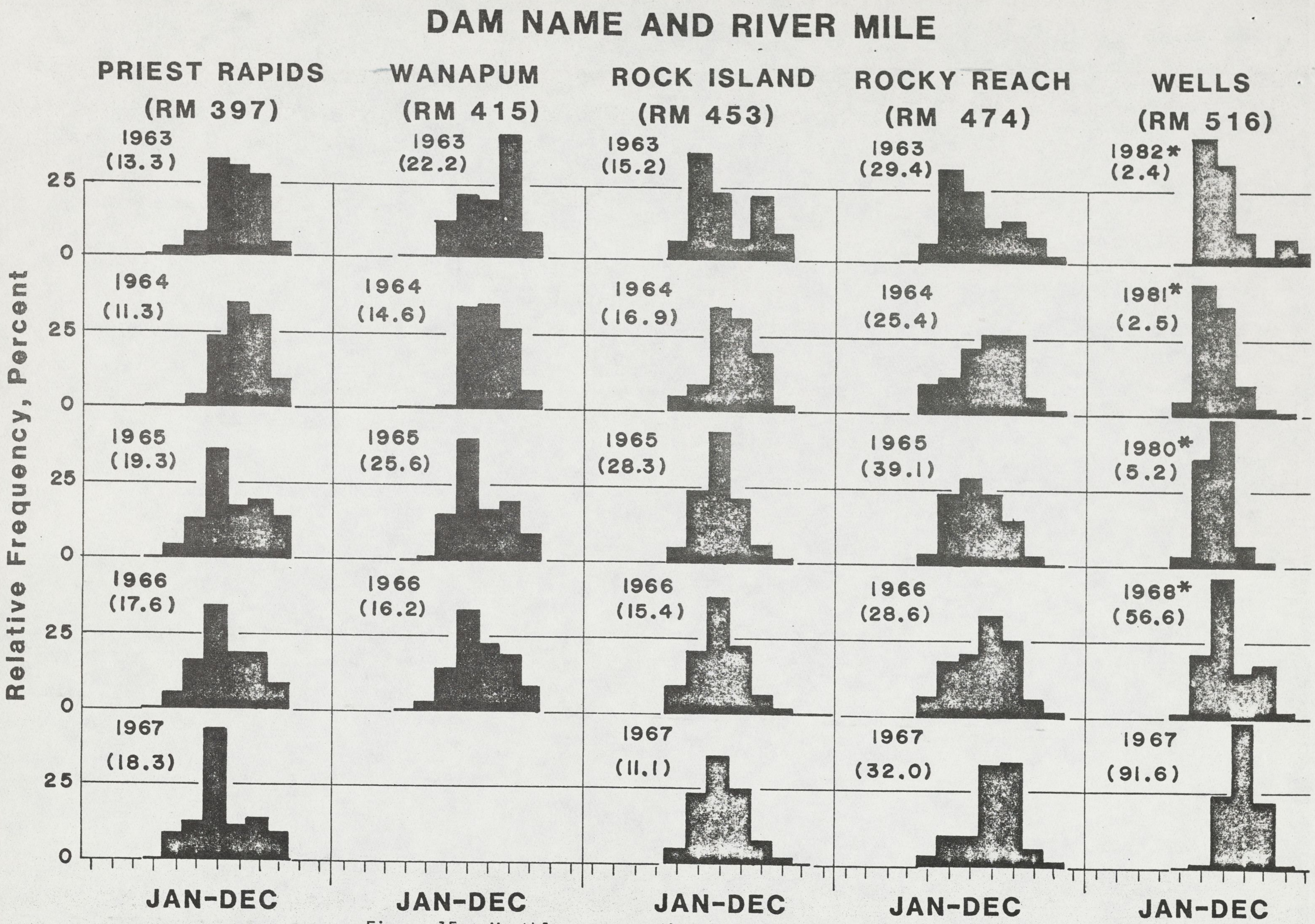

Figure 15. Monthly percent distribution of northern squawfish ascending mid-Columbia River dams for representative years.

Run size in 1000s of fish ( ) and Wells Dam data mostly not in chronological sequence.*

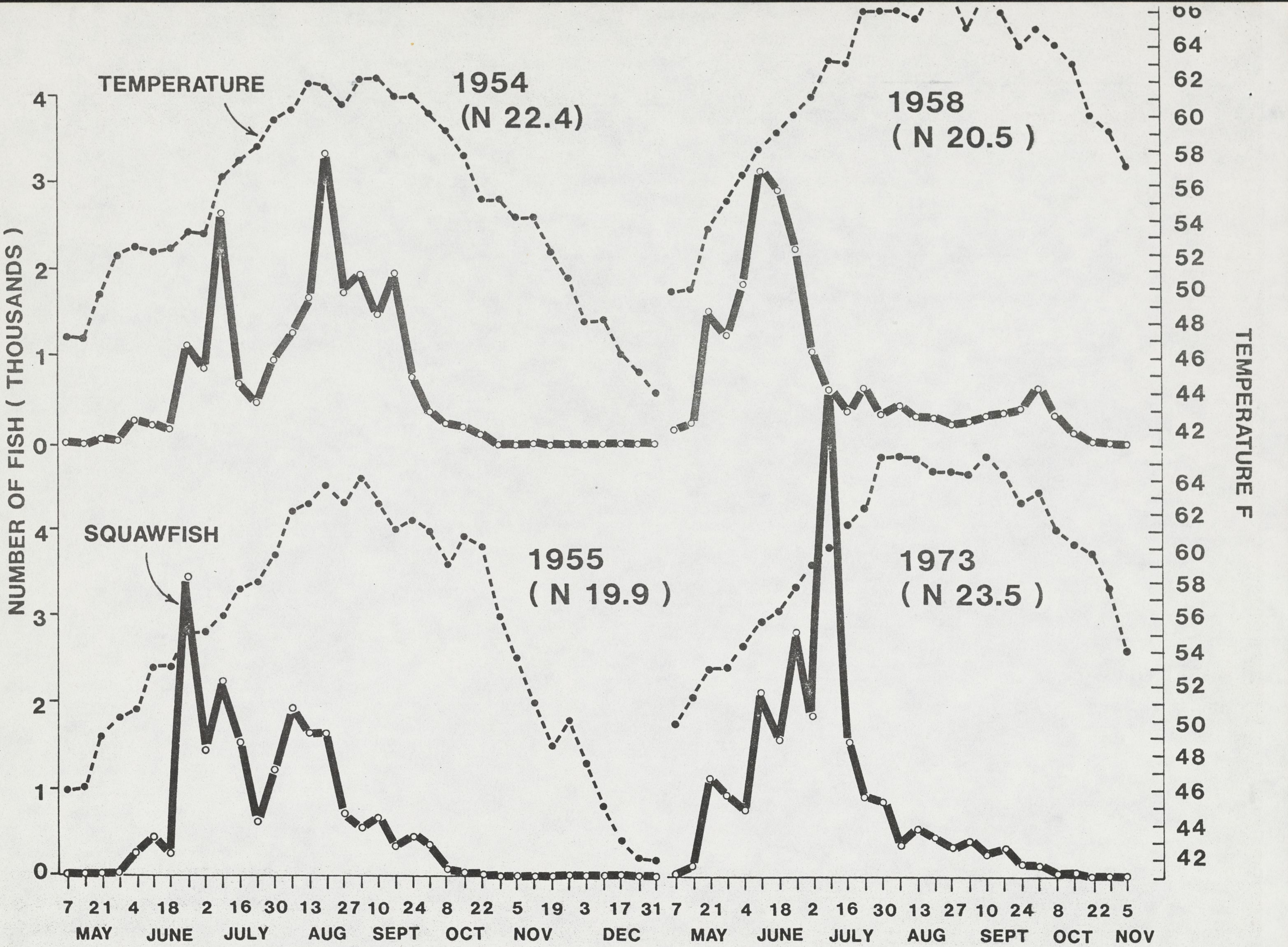

Figure 16. Weekly counts of northern squawfish at Rock Island Dam as related to record or near record low water temperatures and high discharge (left), and record or near record high temperatures and low discharge (right). No squawfish were counted January 1 through May 14, 1955.

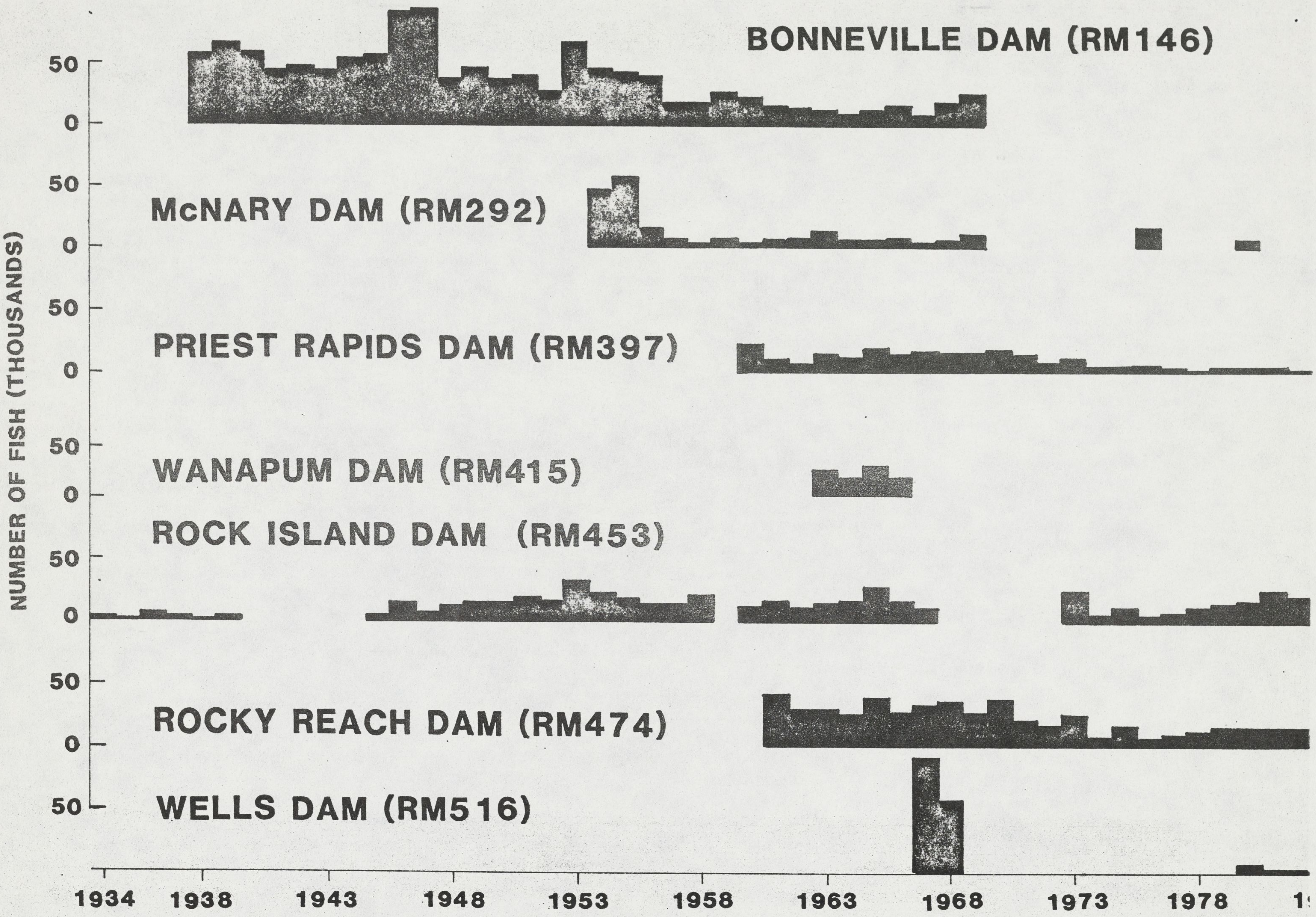

Figure 17. Yearly counts of squawfish at Columbia River dams.

swift streams. The Rock Island Dam counts suggest positive response to impoundment. The northern squawfish is widely recognized as a slow growing, long-lived, late maturing species (Wydoski and Whitney 1979; Scott and Crossman 1973; Carlander 1969) and the response time of the population to impoundment was slow (Figure 17).

Wydoski and Whitney (1979) have also characterized the northern squawfish as preferentially a warm water species (≥70F), a preference reflected in greater abundance in dam counts from the warmer, lower river (Figure 17). This species also appears to do well in most cold tailwaters as well (Walburg et al. 1981). However, a decrease in temperature and resultant 6-to-8 week delay in spawning is believed responsible for a reduction in northern squawfish numbers in a Montana tailwater (May and Huston 1979). Temperature reduction has also had a devastating impact on the related Colorado River squawfish (*P. lucius*) (Mullan et al. 1976; Vanicek et al. 1970; Vanicek and Kramer 1969).

Whether northern squawfish are a mobil or a sedentary species is not clear. Post-spawning tagging suggested little movement in the Columbia River (Zimmer 1967). Regular capture of substantial numbers of northern squawfish in passive fishing gears indicate at least nominal movement spring through fall (Table 9). Sims et al (1974-77) reported squawfish concentrated below dams on the Snake River, i.e., 75,000 and 45,000 in tailraces of Little Goose and Lower Granite dams, May, 1977. Aggregations of squawfish below dams in spring doubtless represented spawning migrations. Studies of the Colorado River squawfish suggest that spawning migrations are not necessarily very long in length or necessary for survival (Joseph et al. 1977). Passage timing of squawfish at Columbia River dams suggest that upstream migrants largely originate in the immediate downstream habitat (Figure 15).

Carp

(*Cyprinus carpio*)

Introduced carp are very tolerant of adverse environmental conditions; nevertheless, the extensive literature clearly shows that they are most suited to warmwater (≥70F) streams and lakes (Carlander 1969). The following temperature preferences for carp were given by Pitt et al. (1956):

acclimated at ^{o}F	50	59	68	77	86	95
preferred ^{o}F	63	77	81	88	88	89

Spawning starts at water temperatures of 58 to 63F but is most active at 65 to 68F and may be spread over a considerable time period (Sigler 1958).

Carp are not considered migratory, but some individuals move for long distances (Walburg et al. 1981). Carp movement in dam fish ladders was virtually nonexistent at water temperatures under 56-57F and was most active at maximum summer temperatures during July and August.

Highest counts occurred at McNary Dam and reflected an upsurge in numbers during initial impoundment, followed by decline (Figure 17). Counts at Priest Rapids, Wanapum, Rock Island, and Rocky Reach dams suggest the same relationship even though the magnitude of annual counts decreased dramatically in an upstream direction (Figure 17). The discrepancy in carp abundance between McNary and upstream dams is all the more accentuated considering that carp do take up residency in fish ladders and resident carp may unduly inflate the size of small runs.

Counts at lowermost Bonneville Dam were appreciably higher then middle river dams, but lower then McNary and did not reflect trophic upsurge in initial years of impoundment (Figure 17). A commercial fishery for carp occurred in sloughs of the lower Columbia River in the late 1930s (Wydoski and Whitney 1979). Whether the harvest - 126,700 pounds in 1937, 90,800 in 1938, and 104,500 pounds in 1939 - masked initial trophic upsurge at Bonneville is probmatical.

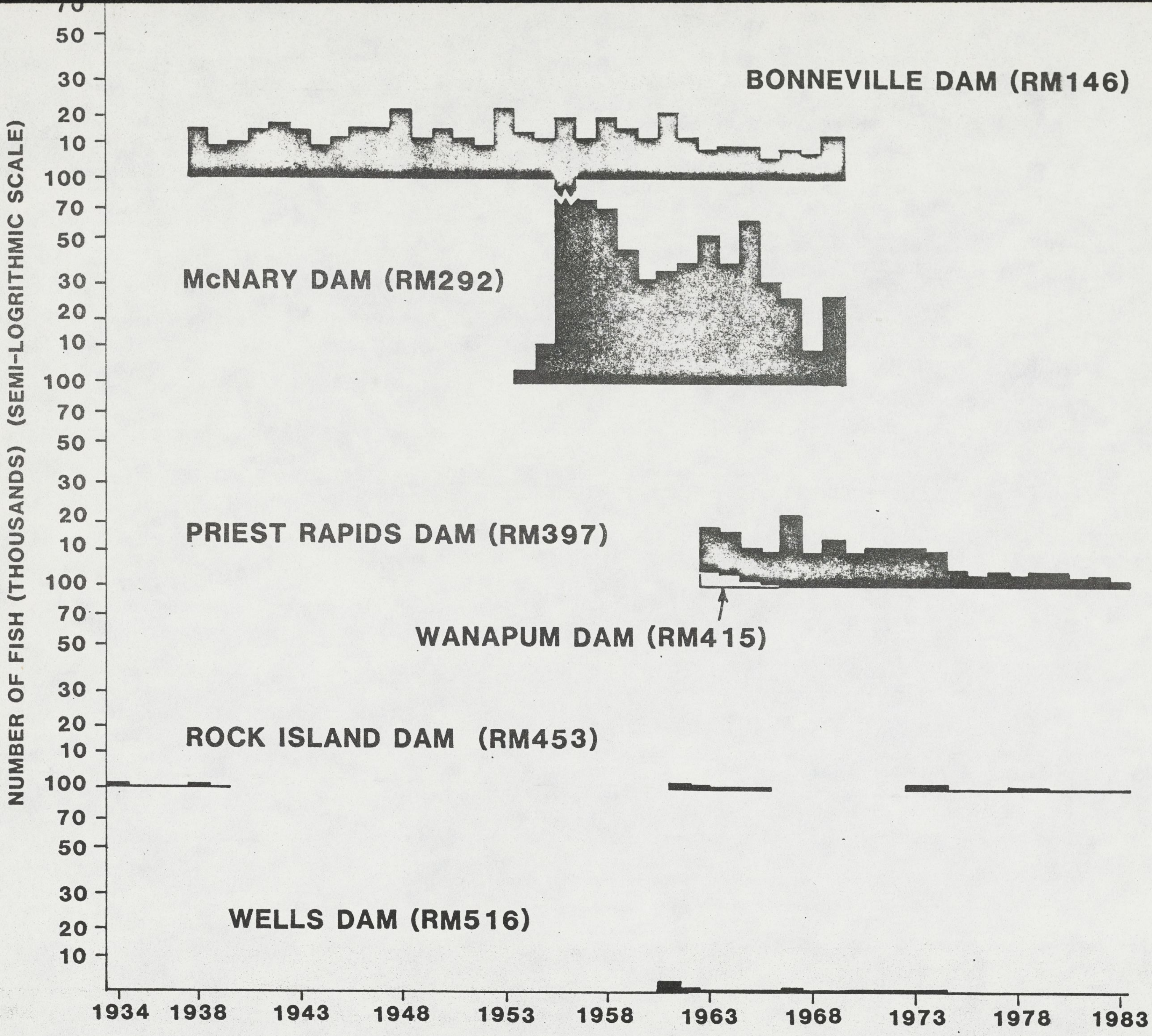

Figure 18. Yearly counts of carp at Columbia River dams.

Other Minnows

(Cyprinidae)

The minnow family is the largest of all fish families. Most members are small, but some like the carp, squawfish and chubs attain comparative large size. The smaller minnow species were recorded only to genera or catergorized as miscellaneous species in dam fish counts.

Shiners are the most abundant species within the Cyprinidae. They are a diverse group and the various species have a wide variety of habitat preferences. The only shiner species currently common in the Columbia River is the redside shiner (Richardsonius balteatus) (Bennett et al. 1983; Hjort et al. 1981; McGee 1979; Erickson et al. 1977; Dell et al. 1975). The redside shiner thrives in both warm and cold rivers and tailwaters (Walburg et al. 1981).

Annual counts of shiners at Bonneville Dam (1938-69) ranged from 207 to 14,603 and show no trend. Counts at McNary Dam (1954-69) declined precipitously after the first three years of impoundment from 12-14,000 to fewer then 100 shiners annually. Annual counts of shiners ranged from 3 to 2,269 at Rock Island Dam (1934-38; 1980-82) and from 338 to 10,291 at Rocky Reach Dam (1961-70; 1980-82), and also declined following initial impoundment.

Several genera of cyprinids are referred to by the common name dace. The speckled dace (Rhinichthy osculus) is the only dace commonly reported from the Columbia River (Bennett et al. 1983; McGee 1979; Erickson et al. 1977; Dell et al. 1975). Generally they were reported in small numbers in fish counts as miscellaneous species. Only at Bonneville Dam (1938-69) were they reported as dace. Here the maximum counts of 1,844 occurred in the first year of impoundment (1938) with only an occassional specimen recorded in following years. Speckled dace are recognized as a cold water stream species (Walburg et al. 1981; Wydoski and Whitney 1979).

The only other cyprinid in dam fish count was an occassional tench (Tinca tinca). This large introduced minnow, with an affinity for warm pond or lake habitat (Wydoski and Whitney 1979), is not common in fish population samples from the Columbia River (Table 2).

Suckers

Sucker species in dam fish counts were categorized only as suckers. Four species of suckers occur naturally in the Columbia River; longnose (Catostomus catostomus) largescale (C. macrocheilus) bridgelip (C. columbianus), and mountain (C. platyrhynchus) (Wydoski and Whitney 1979). The mountain sucker primarily inhabits tributary streams. Largescale are the most common and longnose the least common of the three sucker species regularly found in the mid-Columbia River (McGee 1979, Erickson et al 1977, Gray and Dauble 1977, Dell et al 1975, Dauble 1980).

Suckers are ubiquitous in the Columbia River and appear to have increased with impoundment, but with abundance declining with aging of the reservoirs except for Rock Island, and increasing spatially in a downstream direction (Figure 19).

A great many riverine fish species move upstream to spawn, doubtless to prevent net downstream movement of the species as a whole, and this is especially characteristic of suckers (Hynes 1970). Fewer then 25,000 suckers were recorded annually passing from the downstream riverine habitat to the upstream lacustrine-like habitat at Rock Island when this was the only dam on the river. With the addition of the upstream Grand Coulee Dam in the early 1940s, annual counts of suckers at

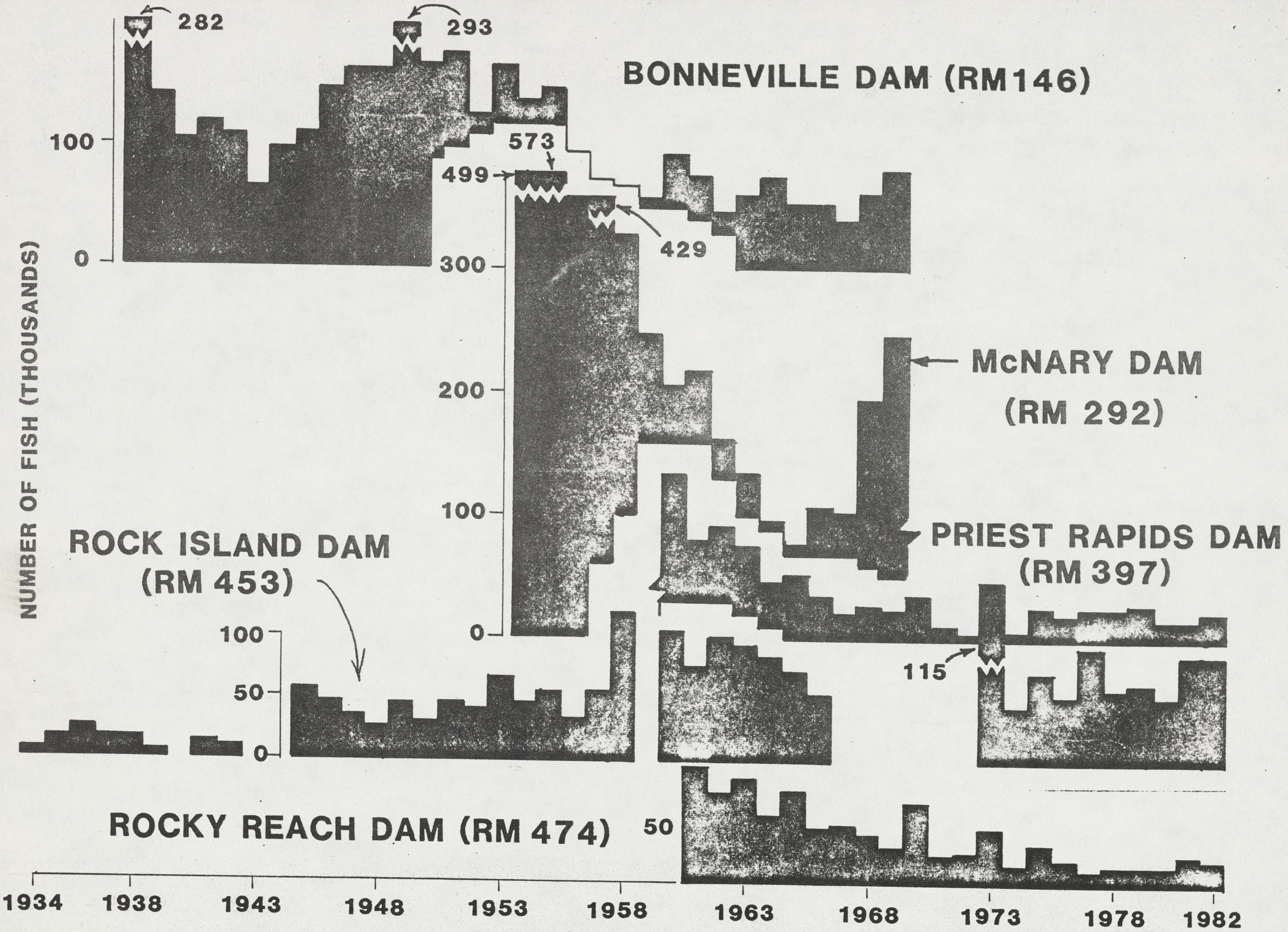

Figure 19. Yearly counts of combined sucker species at Columbia River dams.

Rock Island Dam increased two-fold or more, and, then two decades later, with the construction of Priest Rapids and Wanapum dams, attained a still higher plateau of abundance (Figure 19). This inverse trend in overall temporal abundance of suckers in the Columbia River can be vaguely related to the infrastructure of the habitat.

Largescale and longnose suckers are usually depicted as slow growing, long-lived (10-25 years), and late maturing (4-7 years) (Edwards 1983; Varley and Schullery 1983; Scott and Crossman 1973; Carlander 1969). The same generalization emerges from the single detailed life history of the bridgelip sucker reported from the Hanford reach of the Columbia River (Dauble 1980).

Slow growing, long-lived, late maturing species have sacrificed early reproduction maturity for longevity of the adults. Persistence of the species is provided by the long reproductive life of the adults. The latter circumstance assures that at least a few spawnings will occur during environmental conditions favorable to larval survival. Even during favorable conditions, however, the response time of the population to changing conditions is slow. Rock Island Dam counts of suckers broadly depict this survival strategy (Figure 19).

Largescale suckers have been reported to spawn from late April to late June in British Columbia (Scott and Crossman 1973), mid to late June in Idaho (MacPhee 1960), early May to early August, with a peak in late June or early July, in lower Columbia River reservoirs (Hjort et al. 1981), and May and June in lower Snake River reservoirs (Figure 1) (Bennett et al. 1983). Spawning of longnose sucker, which has a much more widespread distribution in northern North America, ranges from mid-April to early July (Edwards 1983). Bridgelip suckers, whose distribution is confined to the Columbia and Fraser River systems, has been reported to spawn in late spring in British Columbia (Scott and Crossman 1973), mid April to mid June in the Hanford reach of the Columbia River (Dauble 1980), March to June, with most spawning occurring during April, in lower Columbia River reservoirs (Hjort et al. 1981), and April and May in lower Snake River reservoirs (Bennett et al. 1983). Counts of suckers at dams confirms major movement during late spring, early summer reflecting spawning migration, but counts also show, at least in some years, substantial movement of fish in late summer, early fall (Figure 20). Year-round dam counts show only a comparative handful of suckers passing through dam fishways from late fall through to the spring pulse in movement.

Walton (1980) found that initial upstream movement of longnose sucker in spring related to water temperature, while the rate of movement was influenced by fluctuations in discharge. Barton (1980) found that both water temperature and discharge played a role in the initiation of spawning migration of longnose sucker, depending on which condition was limiting in spring. Scott and Crossman (1973) reported spawning movement begins at 41F for longnose sucker and 46-48F for largescale sucker.

The two highest counts of suckers at Rock Island Dam in 1958 and 1973 (Figure 19) were associated with record or near record high water temperatures (Figure 21) and low discharge. Record or near record low water temperatures and high discharge in 1954 and 1955 were associated with more average run size for the period (Figures 19 and 21). Initiation of upstream movement was related to temperature preferendum cited for largescale sucker (46-48F) irrespective of year, while rate of movement appeared most influenced by increase in temperature. Geen et al (1966) reported parallel response of longnose sucker to temperature. Surges in movement during the seasonal rate of temperature increase tended to be

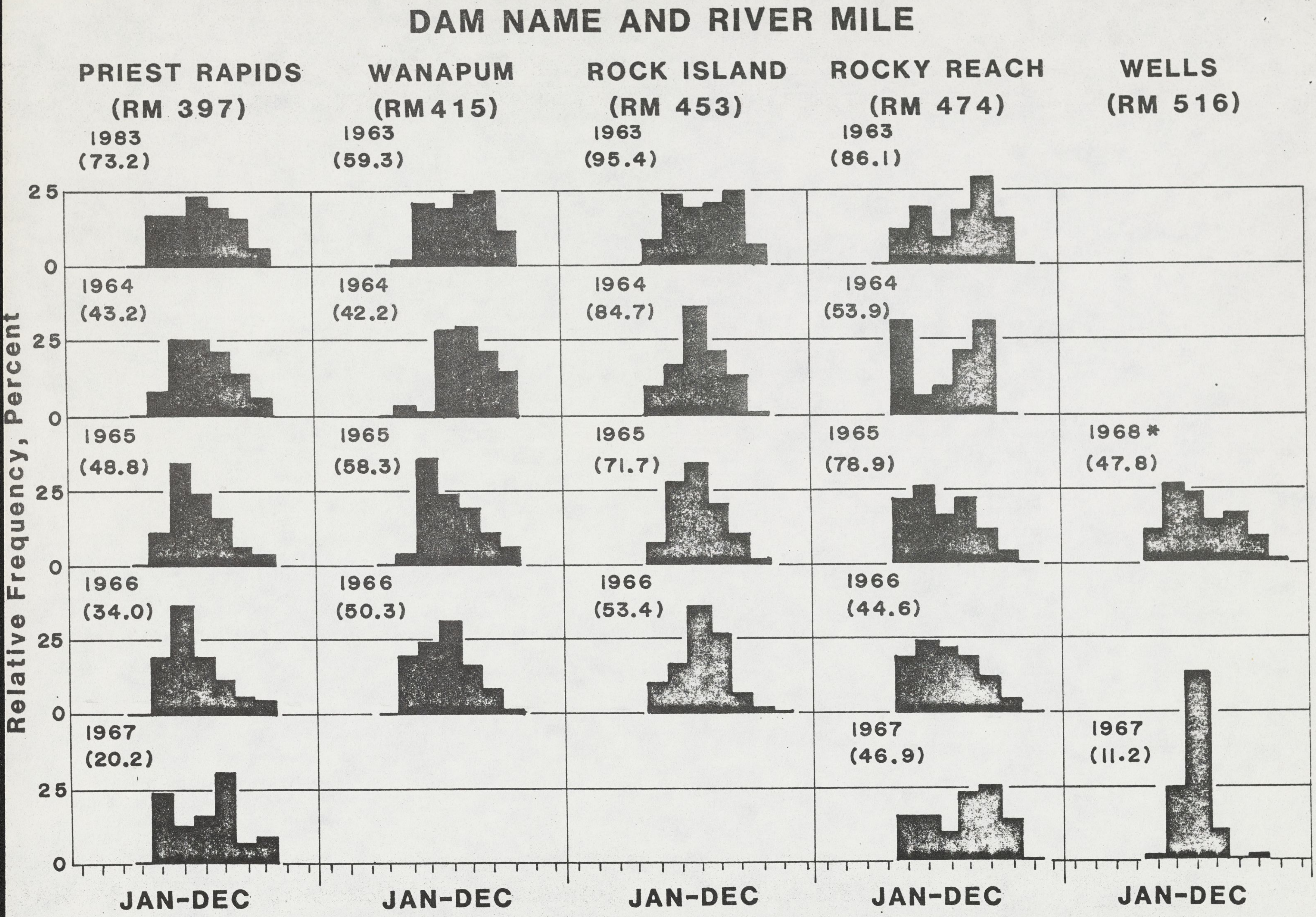

Figure 20. Monthly percent distribution of suckers ascending mid-Columbia dams 1963-67.

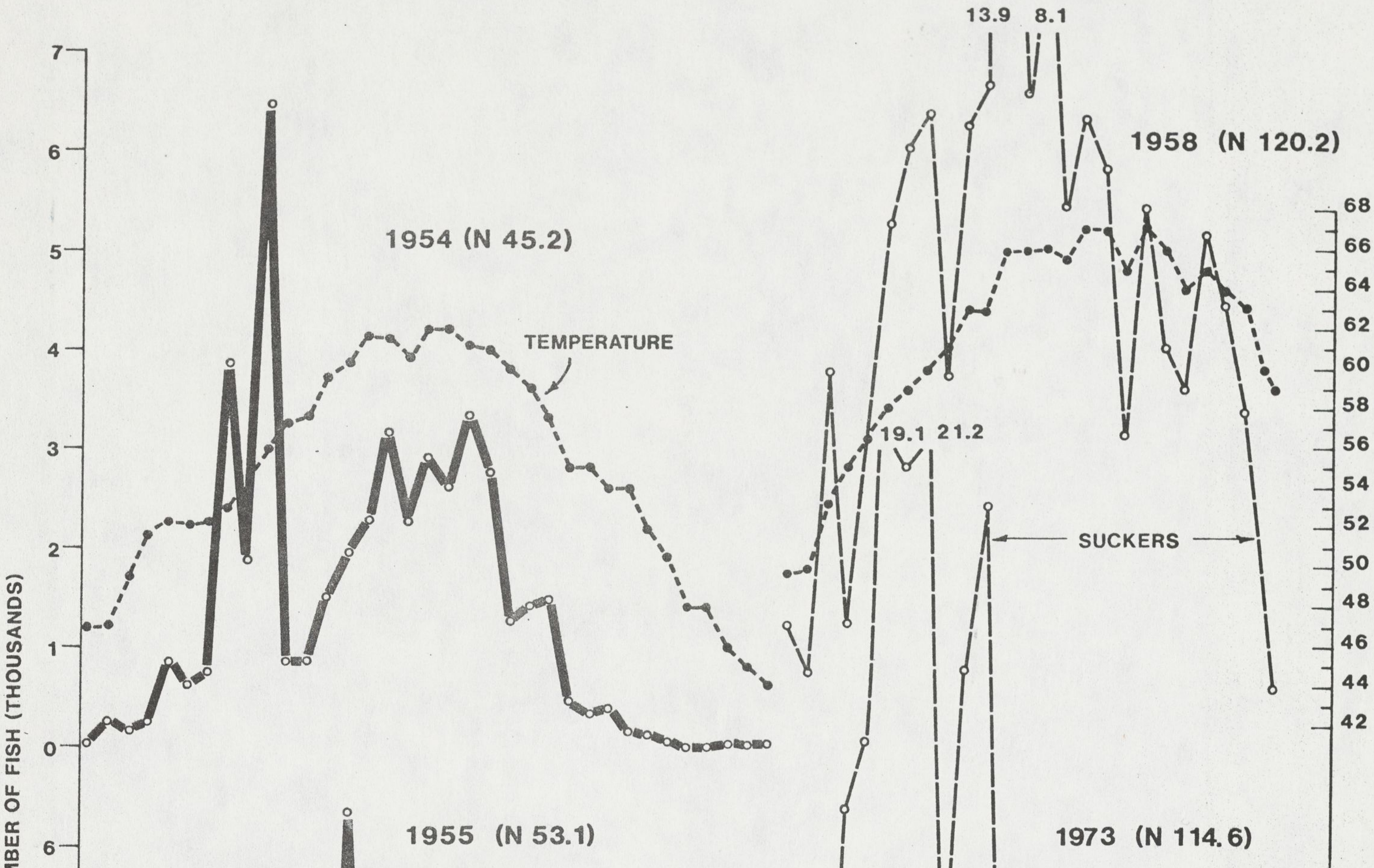

Figure 21. Weekly counts of suckers at Rock Island Dam as related to record or near record low water temperatures and high discharges 1954-55 (left), and record or near record high temperatures and low discharges 1958 and 1973 (right). The 1958 and 1973 counts were the maximum number of suckers recorded 1934-82.

bimodal and to involve four peaks (Figure 21). The first peak of the season occurred at temperatures of 53-55F, the second at 56-60F, and the remainder at 61-67F.

Spawning itself has been reported to occur at about 50-59F in longnose sucker, with all fish usually spent at 59F (Walton 1980; Harris 1962; Rawson and Elsey 1948); at about 54-61F in largescale sucker (Bennett et al. 1983; Hjort et al. 1981), and at about 46-55F in bridgelip sucker (Bennett et al op cit; Hjort et al op cit; Dauble 1980). Logically, the first bimodal peak in sucker movement at Rock Island Dam primarily involved bridgelip and the second, largescale sucker. More minor surges in movement associated with temperatures 61-67F in late summer, early fall would not seem related to spawning migration, barring dysfunction of thermal-photoperiod reproductive preferences or requirements. May and Huston (1979) reported that reduction in water temperatures in a Montana tailwater delayed reproduction six to eight weeks for both the largescale and longnose sucker. May, June, July and August water temperatures at Rock Island Dam now average 49.5F, 55.1F, 60.5 and 64.3 versus 51.3F, 56.1F, 63.5F and 66.0F prior to Grand Coulee Dam becoming operational in 1941 (Figure 14).

Co-occurrence of several old year classes of mature suckers does not assure that all individuals or age classes spawn every year. Geen et al (1966) reported many longnose suckers spawned several years in a row while others skipped a season or two. Irregularity of fish spawning generally denotes a harsh, cold environment (i.e. Miller and Brannon 1981) or unfavorable cold temperature regime imposed by man (i.e., Walburg et al. 1981; Eschmeyer and Smith 1943). Diviant phenology of movement (i.e., Rocky Reach Dam 1963, 1964, Figure 20) could be related to such phenomea, or capriciousness. Scott and Crossman (1973) have described white suckers

(C. commersoni) moving into tributaries at spawning time but actually spawning in the lake of origin rather than in the streams. Moreover, suckers are commonly recognized as mobil and not sedentary species because of their extreme susceptability of capture in passive net gears.

The eggs of sucker species are broadcast in riffle areas in streams or along wave-swept shorelines in lakes or reservoirs. Largescale sucker eggs hatch in about two weeks. Fry remain in the gravel or on the surface of the substrate for the first few weeks until the yolk sac is absorbed. At this point, the mouth is terminal and they become pelagic. They remain so until the mouth moves to the ventral position at a little over ½ inch in length and they then become associated with the bottom in still water (Scott and Crossman 1973).

Sucker species are characterized by very high potential fecundity, counterbalanced by very high mortality rates in the larval and juvenile stages (i.e. Geen et al. 1966).

Wanapum Reservoir provides more backwaters and quiet shallows favorable to survival of larval and juvenile stages of suckers then the Rock Island Reservoir. Rocky Reach Dam counts of suckers declined over time while counts at Rock Island Dam remained stabler and higher (Figure 18). The same comparative relationship holds for sucker counts at Priest Rapids Dam where the spawning population originates in the more hazardous free-flowing Hanford reach of the Columbia River.

Higher abundance of suckers in counts at the downstream Bonneville and McNary dams is more enigmatic considering the weight of species anticological evidence. Scott and Crossman (1973) describe the longnose sucker as the most successful and widespread sucker in the north of

Canada, occurring almost everywhere in clear, cold water in moderately large numbers. In the south of Canada, these authors reported occurrence as more sporadic, in more restricted environments (the deeper areas only of lakes), and in fewer numbers. While the biology of the largescale sucker is not so well documented, it too appears to have an affinity for cold oligotrophic waters and are often found in the same general habitat as longnose sucker (Scott and Crossman op cit). While the dominance of largescale sucker over longnose sucker in the mid-Columbia River is logical, with the former occupying the focus and the latter the periphery of natural distribution, the seemingly oligotrophic habitat requirements of both species is inconsistent with high abundance in the more eutrophic or mesotrophic habitat of the lower Columbia River.

Taken as a group, suckers compose a significant segment of the fish population in most rivers and tailwaters, both warm and cold water (Walburg et al. 1981). While some species display a very narrow range of environment tolerance (i.e. the endangered razorback sucker of the Colorado River *Xyrauchen texanus*), other species are more plastic. White suckers, for example, characteristic of headwater streams, may achieve high abundance in streams, lakes and reservoirs with low and high temperatures, low and high turbidities, and fast and slow currents (Walburg et al. 1981). Although the biology of the longnose sucker is not so well documented, more information is available than for most other species, and it too appears to represent a relatively versatile species, but only in cool or cold water (≤70F) (Edwards 1983). On the other hand, largescale suckers are extremely abundant below Dorena Dam, Fern Ridge Reservoir, Lookout Point Dam, and Dexter Dam on the Willamette River, apparently thriving in the 70-80F termperatures commonly attained in these warmwater tailwaters tributary to the Columbia River (Hutchinson et al. 1966). Recent studies also show largescale sucker thriving, as well as the less dominant bridgelip sucker, in McNary and Dalles Reservoir on the lower Columbia River (Hjort et al 1981) as well as in the still warmer (Figure 8) reservoirs on the lower Snake River (Bennett et al. 1983). Thus, it only can be concluded that largescale sucker and bridgelip sucker are adaptive generalists fully capable of playing either unstable, short-lived or stable, long-lived roles suggested in this scenario of population dynamics of suckers in the Columbia River.

Sunfishes (Centrarchidae)

The black basses, "true sunfishes", and crappie of this family are found in nearly all types of cool or warm waters. Their life histories are similar, differing only in detail. None are endemic to the Columbia River.

Centrarchids were never sufficiently abundant in mid-Columbia River dam fish counts to warrant tabulation other then as miscellaneous species. Annual counts of black basses at Bonneville Dam (1938-69) ranged from 0 to 1,983, with an increasing trend cumulating in peak members in 1969. Annual counts of black basses at McNary Dam (1954-69) ranged from 0 to 2,308 and show an inverse trend with maximum numbers recorded in the third year of impoundment. Only a few true sunfishes were ever recorded at either dam. Annual counts of crappie ranged from 0 to 1,054 at McNary and from 0 to 397 at Bonneville, with the maximum counts occurring in the fourth and second years of impoundment, respectively, followed by declines.

Centrarchids migrate little; most remain in the same stretch of stream or shoreline throughout life (Walburg et al. 1981). What little movement does occur is from deep to shallow water for feeding or spawning. Lateral movement of this nature would not be expected to be indexed to any degree in dam counts requiring upstream movement unless provoked by unusual circumstances. Chemical irritants (i.e., Tompkins and Bridges 1958), tags or tagging (i.e., Wydoski and Emery 1983), environmental instability, and excessive population densities are generally recognized as causing behavioral changes.

Population sampling indicates that relative abundance of centrarchids in the lower Columbia River (6-8%) is currently many-folds greater then in the colder middle river (≤1%), while many-fold less than the still warmer Snake River (30%) (Table 2). The 14.7% centrarchid composition of total catch exception reported by McGee (1979) for Wells Reservoir (Table 2) reinforces the correlation that centrarchid abundance in the mid-Columbia is temperature limited, phenomena repeatedly reported for cold tailwaters (Walburg et al. 1981).

The Okanogan River joins the mid-Columbia River in Wells Reservoir and the atypical high summer water temperatures (≥80F) of this major tributary (Figure 1) are well documented (Allen and Meekin 1980; Major and Mighell 1965). Less well known is the flourishing population of smallmouth bass (Micropterus dolomieui) and pumpkinseed sunfish (Lepomis gibbosus), along with a more minor population of black crappie (Pomoxis nigromaculatus), which McGee (1979) sampled in Wells Reservoir largely near or in the river's confluence. It is hardly coincidental that the only other smallmouth bass population of any renown in the mid-Columbia exist in the free-flowing Hanford reach (Henderson and Foster 1956). Variable spawning success is achieved in atypical warm backwaters depending on seasonal water regimes and climate (Montgomery et al. 1980).

Catfishes (Ictaluridae)

Generally less then 100 catfishes were recorded in annual dam fish counts. Temperature relationships of these warm water exotics in the Columbia River are similar to those of the centrarchids, differing only in detail and magnitude. Seven species have been identified. Brown bullhead (*Ictalurus nebulosus*), black bullhead (*I. melas*) and channel catfish (*I. punctatus*) are the most common. Channel catfish are restricted to the lower Columbia and Snake Rivers where they provide the only concerted sport fishing for members of this family.

Perches (Percidae)

Walleye (*Stizostedion vitreum*) have been in the Columbia River since at least the early 1950s even though the origin of the introduction is clouded (Zook 1983; Mullan 1980). This voracious predator elicited widespread interest by sport fish enthusiasts, while generating foreboding among officials responsible for salmon and steelhead beginning in the late 1970s. Only 19 walleye were ever recorded in dam fish counts and this occurred in 1969 at lowermost Bonneville Dam.

Whatever the origin, it seems certain that walleye first became established in Lake Roosevelt with subsequent dispersal downstream (Zook 1983). Walburg et al. (1981) provides numerous examples of the export of walleys from reservoirs to the river below. Walleye tagged in Lake Roosevelt have been recovered from Chief Joseph Reservoir (Nigro et al. 1982; Harper et al. 1981).

Walleye also undergo extensive upstream migrations (Walburg et al. 1981), although they have not been reported from Snake River reservoirs (Bennett et al. 1981; Sims et al. 1976), and would appear highly vulnerable to monitoring in dam fish counts. On the other hand, major movement occurs in winter-early spring, very possibly at night due to the species being highly sensitive to light, when monitoring of fish ladders is minimal or non existent. Typically, however, sport fisheries have targeted on spawning runs below dams in winter-early spring. All evidence indicates that viable reproduction in the mid-Columbia River has not occurred (Zook 1983).

Spawning occurs at water temperatures 42-52F; however, survival of larval walleye and production of zooplankton food is poor below 50F (Hokanson 1977). The threshold for larval survival (50F) must also be increasingly exceeded for successive early life phases, followed by a growing season for young-of-the-year in which at least 50 percent of the maximum growth potential is realized by mid-summer. Otherwise, low winter temperatures may limit survival of smaller individuals directly or indirectly (Hokanson op cit.).

Water temperatures in the mid-Columbia River now, as a result of flow regulation, reach 50F only in late May-early June and require an additional four and eight weeks to reach temperatures of 55F and 60F, respectively (Figure 14). Maximum seasonal water temperature of a little over 64F is not reached until August and is well below the 73F physiological optimum for walleye (Hokanson 1977). Limited direct observations suggest that zooplankton food is sparse, peaks in July, and that drifting insects are not numerically important components of the zooplankton community (Neitzel and Page 1982). Indirectly, a large literature shows that crustacean zooplankton needed as food for larval walleyes are always unimportant in streams except for backwaters (Hynes 1970).

Proof that low water temperatures and high water exchange limits walleye reproduction in the mid-Columbia is shown by confirmation of reproduction only in the atypical warm Spokane Arm of Lake Roosevelt (Nigro et al. 1982; Harper et al. 1981) and in backwaters of the John Day and McNary reservoirs in the lower river (Hjort et al. 1981).

Only a scattering of yellow perch (*Perca flavescens*) were recorded in dam fish counts. Abundance of this exotic is also spatially correlated with highest water temperatures and lowest water exchange (Table 2).

Sturgeon

Sturgeon are rarely seen in fishways. The 4,663 sturgeon recorded at Bonneville Dam 1938-69 were primarily counted passing upstream through the navigational locks. Only 6 and 26 sturgeon were counted in fish ladders at McNary and Priest Rapids dams 1954-69 and 1960-83.

The white (*A. transmontanus*) and the green (*A. medirostus*) sturgeon are endemic to the Columbia River. Both species are diadromous and long-lived, with the white sturgeon possibly attaining a maximum weight and length of 1,800 pounds and 20 feet in 100 years (Scott and Crossman 1973). Green sturgeon are much less common, smaller (to 350 pounds), and rarely found in fresh water (Stockley 1981; Carl et al. 1967).

Prior to the construction of dams on the Columbia and Snake rivers sturgeon had free access up and down the rivers and to the ocean. White sturgeon were commonly found 1,000 miles inland (Coon et al. 1977; Carl et al. 1967). Bajkov (1951) reported white sturgeon moving as much as 100 miles upstream in the fall and downstream in the spring to the mouth of the Columbia River. Even though the extent of movement by sturgeon before the construction of dams was not determined, variable residencies and extensive movement is suggested by studies after construction of dams (Stockley 1981; Haynes et al. 1978; Coon et al. 1977). Coon et al. (1977) observed that extensive up and downstream movements in the Columbia and

Snake rivers were apparently not obligatory for survival of the sturgeon populations.

When white men arrived on the Columbia River, sturgeon were abundant (Craig and Hacker 1940). At some locations they were so numerous that they caused damage to the gill nets used by salmon fishermen. For years the smaller sturgeon (under 50 pounds) caught by salmon fishermen were killed, and in a few places, special efforts were made to eradicate them. The peak commercial harvest of 5.5 million pounds was reached in 1892 and fell rapidly therafter. From the turn-of-the-century until the early 1940s the annual harvest in the lower river hovered at 100,000 to 200,000 pounds, after which it gradually increased to around one million pounds by the late 1970s (Stockley 1981). In recent years the catch has been shared increasingly by sport fishermen (King 1981a, 1981b).

An average of 15,410 white sturgeon were taken annually by sport fishermen below lowermost Bonneville Dam 1969-81 (King 1981a). In 1981, during the months of June and July, 6,700 white sturgeons were caught at a rate of 0.23 fish per angler trip. Catch rates in the upstream Bonneville, Dalles, and John Day reservoirs during the same months and year were 0.25, 0.23, and 0.12 sturgeon per angler trip, respectively (King 1981a). Malm (1981) also found a large population of white sturgeon in Bonneville Reservoir, similar to that reported below the dam (Stockley 1981), but a much reduced abundance in John Day Reservoir. Reproduction has only been confirmed for below Bonneville Dam (Stockley 1981).

White sturgeon are also not uncommon in the upstream McNary Reservoir (Hjort et al. 1981; Nelson 1981), but it is not clear whether this and downstream reservoir populations are sustained by recruitment from the viable population remaining in the free-flowing Hanford Reach of the Columbia River (Haynes et al. 1978). There appears to only be remnant numbers of sturgeon above Priest Rapids Dam, ~~surviving from pre-impoundment~~. Lanmeyer (1972) captured two (39 inches and 12.0 pounds and 30 inches and 5.0 lbs) and Erickson et al. (1977) captured one (no size given) in Chief Joseph Reservoir 17 and 22 years after impoundment (Table 2). In 1982 a ten-foot, two-inch white sturgeon was found dead at Wells Dam. It is likely that the age (Coon et al. 1977) of this fish pre-dated construction of all dams on the river.

In contrast to the mid-Columbia River, Coon et al. (1977) estimated 8,000-12,000 white sturgeon inhabiting the free-flowing Snake River from Lower Granite Dam upstream to Hells Canyon Dam during the period 1973-75. Although hardly a pristine population, due to man the predator and habitat despoiler, the estimate of 66 to 98 predators per mile, averaging about 37 pounds each, is an eye-opener to pre-dam abundance throughout the Columbia River.

Miscellaneous Other Species

An occassional sandroller (Percopsis transmontana) was recorded in dam fish counts. This endemic species is not uncommon in mid-Columbia River reservoirs (Dell et al. 1975) as well as in the free-flowing Hanford reach (Gray and Dauble 1979).

Threespine sticklebacks (Gasterosteus aculeatus) are abundant in mid-Columbia reservoirs (Dell et al. 1975) and fish ladders. Due to small size (1-3 inches) and abundance they were ignored in fish counts. They apparently are not common in Snake River reservoirs (Bennett et al. 1983) nor in lower Columbia River reservoirs despite being the most common non salmonid species found in the esturary (Dawly et al. 1981, 1984). Sculpin (Cottus asper mainly), also were ignored in dam fish counts although common in the entire river.

A few eulachon (Thaleichthys pacificus), were noted in Bonneville Dam fish counts. During winter millions of these smelt-like fish enter the Columbia River but spawn in tributaries below Bonneville Dam (Wydoski and Whitney 1979; Pruter 1966).

Burbot (Lolta lota) and lake whitefish were infrequent migrants in all fish ladders; an occurrence paralleling that reported in fish sampling (Table 2) and suggesting downstream despersal from upriver habitats (i.e., lake whitefish from Lake Roosevelt).

Other Environmental Perturbations

Gas Bubble Disease: Dam induced nitrogen supersaturation has been cited as the primary cause of mortalities ranging from 40% to 95% of all juvenile salmon and steelhead emigrating from the Snake River during high flow years 1965-75 (Ebel 1971; Ebel et al. 1975; Ebel and Raymond 1976). Meekin and Allen (1974) reported similar mortality of adult sockeye and chinook salmon on the mid-Columbia River in the late 1960s. Although no direct mortalities were ever noted, Dell et al. (1975) reported the incidence of gas bubble disease symptoms in mid-Columbia River resident fishes as: suckers, 25.4%; peamouth chub, 12.1%; squawfish, 11.8%; mountain whitefish, 10.9%; chiselmouth chub, 7.6%, yellow perch, 6.4%; pumpkinseed, 5.7%; and carp, redside shiner, sculpin, dace, stickleback,sandrollers, tench, 0.8-4.4%.

Even though problems of gas bubble disease were not noted until the end of the dam-building era, destabilizing and possibly selective effects of gas supersaturation on resident fishes cannot be ruled out in earlier year (Weitkamp and Katz 1980; Bouck 1980; Crunkilton et al. 1980; Montgomery and Becker 1980; Nebeker et al. 1980). Grand Coulee Dam was most responsible for air entrainment as a result of spill beginning in 1941. Gas supersaturation did not become widely manifest until hydroelectric generation began at the downstream Chief Joseph Dam in 1955, however, because the entrapped gas was readily released back to the atmosphere in the turbulent tailwater prior to impoundment. In recent years, the problem of gas bubble disease in high flow years has been alleviated via expanded generating capacity at existing dams, completion of upstream Canadian storage reservoirs allowing greater regulation of flows, and installation of spillway deflectors at some Snake River dams so as to avoid critical air entrainment as a result of the deep plunging action of spill.

Toxic pollution: Gould and Wedemeyer (1981) observed that surprisingly incomplete information exists on current toxic contaminant levels in Columbia River waters or on what biological impacts they are having. It is known that salmon and sturgeon populations now carry body burdens of PCBs and chlorinated hydrocarbon pesticides, presumably because of widespread use in agriculture (Gould and Wedemeyer 1981; Stockley 1981). Gould and Wedemeyer conclude, however, with all due deference to the possibilities of chronic sub-lethal water pollution, that safe limits for water quality alterations are not presently being exceeded in the Columbia River and, with the exception of gas saturation, probably were not exceeded in the past.

Biogenous pollution: Less clear are the impacts from untreated wastes formerly discharged to flow-through reservoirs of the Columbia River from cities and towns along its course. One reason for this is that although there has been a dramatic decrease in untreated municipal and industrial wastes entering the Columbia River since 1945, there was no overall accounting until after 1977, when most pollution abatement facilities were operational, as mandated in the Federal Clean Water Act of 1972 (per. comm. Donald Moos, Wa. Dept. of Ecology).

In 1971 it was estimated that municipalities and industries produced organic wastes equivalent to those from a population of 2.04 million people, with only the equivalent of the wastes of 68,500 people actually reaching waterways in the mid-Columbia subregion. This did not include wastes from rural populations, irrigated farming, domestic livestock, and other non-point sources suspected of contributing high nitrate-nitrogen concentrations in some reaches of the Columbia River (Pacific Northwest River Basins Commission 1971). Within this prospectus it is not unreasonable to estimate a waste effluent to the mid-Columbia during the 1950s that was the equivalent of the domestic sewage from one million people. Figuring 3.3 pounds per capita-year phosphorus supply (Johnson and Owen 1971, as reported in Dillon and Rigler, remembering that legislation to reduce the phosphorus content of laundry detergents had not occurred in the 1950s) Mullan (in press) estimated that 3.3 million pounds of phosphorus entered the mid-Columbia River annually.

By way of reference this is 500 times the elemented phosphorus used in the annual fertilization (33 tons elemental N and P with an atomic ratio of 10:1) of Great Central Lake, British Columbia, that so spectacularly increased sockeye salmon production (Le Brasseur et al. 1978). Proportional increase in fish production could not be expected in impoundments of the Columbia River, due to tremendous discharge and short water retention time (De Angelis 1980), and especially considering that Great Central Lake has a water retention time of 34 years (Costella et al. 1979). By the same token, appreciable, if unknown, biological impact could not be avoided considering the magnitude of phosphorus and inferred nitrogen enrichment, even if only a small portion was haltingly sequestered and cycled in food webs over 365 linear miles before leaving the system. Adding to probable impact was that hydroelectric generation was more sporadic in early years than now, allowing nutrients, especially in summer, early fall, greater transit time. However, it should be noted that waste treatment removes very little P and N but does change these biogenous substances into a more solvable form, so that actual enrichment of the Columbia River may have increased over time.

Water Exchange: Rate of water exchange has increased dramatically over the years as the result of the incessant demand for electrical energy and expanded generating capacity at existing dams. As ever increasing volume of available flow has been put through turbines, particularly during drought years, downstream migrants have had little recourse but to pass through turbines where many are killed outright and others injured or stunned and left vulnerable to predation. This turbine/predator related mortality has been variously demonstrated to range from 7 to 30 percent per dam for anadromous salmonid smolts (Olson and Kaczynski 1980; Long and Ossiander 1974; Long 1968; Oligher and Donaldson 1966;Schoeneman et al. 1961). Perhaps of greater ecological consequence than that of turbine/predator mortality for resident fish passing downstream of only one dam, is the effect increasing water exchange has had on food production and conversion to resident fish biomass. Hatchery trout in one Utah tailwater realized a net annual gain of about 100 pounds per acre under circumstances of sporadic discharge, allowing inchannel warming of the water, but production declined to a pittance under condition of sustained hydroelectric generation and rapid water exchange (Mullan et al. 1976).

Increase in species: "Niche" concerns the role of a species in its community and its interaction with its environment. "Habitat" is the physical component of the environment that provides certain combinations of conditions that result in required living areas for a given species. When two or more species coexist in an area, equilibria between species are different than if only one species were present. An important outcome of niche theory is that the sum of two or more realized niches is greater than the sum of one potential niche, although realization of the latter provides more biomass of an individual species. Within this framework it is logical that the abundance of endemic species in the Columbia River would have decreased with the introduction of exotic species. Compounding the problem is that while impoundment has created more backwater and slow water areas that are utilized by exotic species and many of the native species, it apparently has reduced the usable spawning area of the native fishes as well as shad and carp (Hjort et al. 1981).

Conclusions and Discussion

Dam counts of resident fishes afford unparallel insight into the fish populations of the Columbia River despite much imponderability. Populations of mountain whitefish, sucker species, chub species, and squawfish clearly used fish ladders to return to spawn in the same general upstream area as is universal in salmon, steelhead, shad, and lamprey. While the movement or lack of movement of other fish species was more vague, indexing in dam counts was nonetheless revealing.

Structure of an aquatic ecosystem is usually based on "critter counts," which reflect how the basic building blocks of aquatic communities (i.e., species) are arrayed. Functional attributes of an aquatic community center on nutrient or energy transfer. Food gathering, and the morphological-behavioral adaptions that form its basis, is therefore considered the paramount animal function in river ecosystems (Cummins 1972).

Zonation schemes, characterized by differences in physical habitat and the organization of the food chain, essentially consists of: 1) an erosional zone 2) a downstream depositional zone, and, 3) in between, an intermediate or transitional zone (White 1973; Hynes 1970). Salmonids depend heavily on the erosional and intermediate zones containing gravel for egg deposition and incubation (White 1973). In addition to the salmonids, whitefish, dace, darter, sculpin, sucker and cyrinid species are acknowledged erosional inhabitatants with a wider variety of genera encountered in larger rivers (Cummins 1972).

Proceeding downstream form erosional to depositional, the trophic structure becomes more complex. Both systems depend to a large degree on detritus as an energy source. The erosional zone receives vegetable debris from the land and the depositional zone receives the debris and dissolved organic matter from the erosional zone as well as from the land. Additions to the complexity of depositonal over the erosional zone include major plankton populations. Fish eating species may be present in either system, but plankton eating species provide an additional food source for fish predators allowing piscivorous fish to proliferate (Campbell 1979). Typical fish of depositional sections are cyprinids, centrarchids, catfishes, and planktivorous fishes such as shad.

These zones are not necessarily discrete communities of co-evolved species (Moyle and Li 1979). Instead, they are broad regions where the distribution patterns of the characteristic species coincide because of similar physiological responses to environmental characteristics such as water velocity, temperature and substrate. Thus, species characteristic of upstream zones are often found in lower zones as well, because of the increased diversity of habitats in the lower zones or because of dispersal from upstream.

The picture that emerges from dam fish counts and other fish sampling closely corresponds to the oversimplified zonation described, but with important exception. Indigenous salmonids and piscivorous species are almost non-existent in the mid-Columbia River above Priest Rapids Dam.

The abundance of individual species in the Columbia River has been radically altered with change from erosional river to flow-through reservoirs. According to Miller and Brannon (1981), the original high gradient, infertile North Pacific streams, like the Columbia River, with their frequent floods would have been highly unpredictable and relatively inhospitable habitats for resident salmonids, whereas spring and fall freshets provide a relatively predictable vehicle for emergence and outmigration of young and spawning migration of adult anadromous salmonids. Inundation of spawning grounds above Priest Rapids Dam has virtually eliminated indigenious anadromous salmonid reproduction along with that of lamprey and sturgeon. White sturgeon larger than 19 inches in length are primarily fish eaters (Scott and Crossman 1973), although the food that may be eaten is extremely variable (Carlander 1969).

Dam fish counts indicate that response of mountain whitefish, chubs, suckers, squawfish, carp, shiner, dace, shad, centrarchids and walleye to initial impoundment was positive, and that abundance of mountain whitefish, chubs, suckers, and squawfish subsequently experienced long-term decline except for instances to the contrary above Priest Rapids Dam.

Only Rock Island Dam dam counts of squawfish indicate achievement of static equilibrium following impoundment (Figure 18). Thompson's (1959) evaluation of the stomach contents of 3,546 squawfish collected from the Columbia River clearly shows this cyprinid qualifying as a trophic generalist, "eating anything available that is palatable", but with fish constituting the most important food. However, the effectiveness of this omnivore as a predator can be questioned. The population irruption of shad in Bonneville and McNary did not prevent decline in squawfish abundance in those reservoirs nor did squawfish preclude contrary increases of sucker and chub species at Rock Island Dam.

We can never know, of course, how virgin predator and prey populations may have affected each others abundance and/or production, but we can be assured that interactions, including cannibalism and mutual competition shaped a fish community different in structure and function than existing today. Nor can we possibly unravel the interaction of multiple environmental perturbations imposed by man. Recognizing that we usually are forced to manage fish stocks only on the grossest of terms, however, management for the unfilled species niche in mid-Columbia River reservoirs would seem to boil down to the following options, which may and may not be mutually exclusive.

(1) Sturgeon would seem to be well suited to put-and-grow management. They are a noncontroversial native species, even though highly piscivorous, unique, long-lived, large-sized, and highly esteemed as a sport fish. Moreover, they have an established track-record and wild stock might be available from the lower Columbia River, but, in any case, sturgeon are amenable to artificial propagation (Folz et al 1983; Flagg 1981).

The only disconcerting consideration is that the majority of the introduced sturgeon might be prone to move downstream past the dams and not return. Coon et al. (1977) found only 4% of the sturgeon in the Snake River consisting of fish 3 to 6 feet in length and attributed this to either overexploitation or the tendency of small fish to move downstream. One of the most successful local sturgeon sport fisherman claims that he catches many sturgeon 10 to 12 feet in length from the free-flowing Hanford reach, but seldom catches 3-6 foot (legal size) keepers (per. comm. Larry Brown, WDF).

(2) Walleye have many of the same desirable attributes described for sturgeon, except that their piscivorous nature is viewed as a threat to hatchery or wild tributary salmon smolts that migrate through the reservoirs. Gross examination of stomach contents from angler-caught walleye from Wells Reservoir indicated that sculpin, suckers, chubs, and other cyprinids constituted the major food (Zook 1983). Food habit studies in John Day Reservoir indicate that non-game species made up 80% of walleye diets 1980-81 (Maule 1982). Hjort et al. (1981) observed that walleye in the same reservoir doubtless qualified as a "keystone predator" (Paine 1966), tending to reduce competitive interaction at lower trophic levels by holding competitor population in check (Meachum and Clark 1979).

Walleye are currently recruited to the mid-Columbia from Lake Roosevelt and abundance steadily declines downstream (Zook 1983, Table 2). Exceptional growth (Brown and Williams 1983) and catches of primarily trophy size fish (5-16 pounds) from Chief Joseph Dam downstream suggest low overall population densities. Managers who might expect large gains in abundance by fine-tuning sport fisheries harvest in Lake Roosevelt, so as to increase recruitment to the tailwater, will find little encouragement in the exhaustive study of walleye in Oneida Lake, New York (Forney 1980). Frequent changes in the vulnerability of the walleye to angling reduced the effectiveness of angling regulations, and hopes of increasing recruitment were frustrated by evidence that there were few surplus prey to support a larger predator population.

Possibly walleye could be increased in the mid-Columbia by the stocking of relatively large-size juveniles, but the long generation times of species available as prey argues against any surfiet of food to sustain a large population. Considering that walleye are most abundant in lakes as compared to rivers, that Lake Roosevelt walleye are subject to an intense annual exploitation of 25% of fish over 12 inches in length, and that yield amounts to a little under one pound per acre (Nigro et al. 1982, Harper et al. 1981), we perhaps can safely conclude that walleye potential in the mid-Columbia is represented in the lower quartile of biomass values (1 to 5 pounds/acre) reported by Carlander (1977).

(3) Management for production of salmonid smolts also has precendences, both as reported in this report for steelhead trout and mountain whitefish and by Mullan (in press, 1984) for coho and sockeye salmon, as well as on an evolutionary and historical basis. With change in abiotic conditions, harvests, or both, virgin ecosystems inevitably change and become based on a whole new group of species (Larkin 1979). The theoretical and empirical evidence show that such stresses tend to deform a community toward dominance by small to medium sized trophic generalists (i.e., sticklebacks, cyprinids, percids, clupeids, osmerids) and away from large piscivorous and specialist benthivores (McIntyre 1980; Regier et al. 1979; Spangle et al. 1977; Regier and Loftus 1972). This is exactly what appears to have

happened to the fish community of the mid-Columbia River to the deteriment of anadromous salmonid smolt production.

Mullan (in press) presents a large body of circumstantial, but irrefutable evidence that some sockeye salmon introduced and relocated to tributaries of the mid-Columbia under the Grand Coulee Fish Maintenance Project in the late 1930s, early 1940s established viable stocks that used the impoundments as nursery lakes. Annual production of up to 1.4 million smolts was estimated, based on a 2% survival to adults, but declined drastically with aging of the reservoir. Had this happenstance of man and nature been planned, as in the case of chemical renovation of lakes for trout, it could be cited as a phenominal management success.

Up until this point we have inferred that competitive interaction between species in mid-Columbia reservoirs might be desirably controlled by establishment of acknowledged predator species. However, it should not be overlooked that the dams and their fish ladders are a means to the same end as demonstrated in the interception and relocation phase of the Grand Coulee Fish Maintenance Project described in the beginning of this paper (i.e., Other Prologue).

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DESCRIPTION, DISTRIBUTION, FISH, FISH-rare, FOOD HABITS, HISTORY, LIFE HISTORY, RIVER-Colorado

Gives aspects of the life history, distribution, habitat requirements, and historical accounts of fish species occurring in the state of Arizona, including many found in the upper basin of the Colorado River.

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Five species of fishes, *Pantosteus clarki*, *Catostomus insignis*, *Xyrauchen texanus*, *Gila r. robusta*, and *Ptychocheilus lucius* were identified from an archaeological site of Pueblo Indians near Perkinsville, Yavapai County, Arizona. Discussed the ecological requirements of each fish. Three of the species still occur in the Verde River near Perkinsville and two are no longer present. Probable historic changes of the river are outlined.

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DISTRIBUTION, FISH, FISH-rare, HISTORY, RIVER-Colorado

Declines in the populations of native fishes in the American Southwest are largely due to habitat changes associated with man's modification of various aquatic environments. The diversion and impoundment of rivers, arroyo cutting, lowering of water tables through use of subsurface water for irrigation, eutrophication, and introduction of exotic species have been responsible for reductions in the native fish fauna.

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ABUNDANCE, DISTRIBUTION, MANAGEMENT, PLAN, RIVER-Colorado and tributaries

Gives a review of the literature available concerning the razorback (humpback) sucker and a description of the original and present distribution of this rare fish. The main emphasis of the plan is to outline a course of action that will prevent the extinction of this unique fish.

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FISH, SALINITY, WATER QUALITY

To Dr. Behnke, with compliments from Harold Mundie. [1986]

Predictability of the Consequences of the Kemano Hydroelectric Proposal for Natural Salmon Populations[1]

J.H. Mundie[2] and R. Bell-Irving[3]

Abstract:
The Aluminum Company of Canada, Limited (Alcan) has proposed completion of its hydroelectric developments to increase aluminum smelting capacity in north-central B.C. The project was started in 1950 and included the Kenney Dam on the Nechako River in the Fraser catchment area, the creation of the Nechako Reservoir, and the construction of facilities for generating power at the Kemano River on the west coast. Completion of development (Kemano Completion Proposal), at a cost of over $2 billion, would divert 84 percent of the initial mean annual discharge of the Nechako River, and 62 percent of the mean annual discharge of the Nanika River in the Skeena catchment area, to the Kemano River. The proposal offers discharges that are intended to protect Pacific salmon stocks, or, where this is not possible, mitigation of losses. This paper identifies the more obvious effects of abstraction and regulation on salmon populations and their habitat. These include interference with migration of adults, changes in the quality of spawning gravel, imposition of stress on all stages of the fish from high total gas pressures and from alterations in ambient temperature, changes in the composition of the total fish community, changes in the production and availability of food, stranding of fish, weakening or loss of cues for homing, and increased exposure to predation from fish and birds. A major difficulty in trying to relate effects to salmon populations lies in distinguishing fish numbers as determined by habitat effects, from numbers determined by the level of recruitment to the rivers as a result of exploitation by the fishery. Three approaches to the problem are: experimental design of impact assessment, modelling changes of discharge and salmon habitat, and analysis of case histories of regulated discharge. The last seems to be the most instructive per unit of effort required. As an approximation to obtaining replication of treatment effects, and to judge the reliability of prediction of effects of flow regulation, case histories of regulated salmonid rivers were examined. It was found that negative effects outnumbered positive ones, that prediction was usually incorrect, and that, even where flow regulation was implemented with the express intention of increasing numbers of salmonids the results fell short of expectations. On this evidence it appears that the outcome of a development as demanding of water as Kemano Completion is difficult to predict in precise quantitative terms and carries some risk for natural populations.

[1]This paper was presented at the Canadian Waters: The State of the Resource. A National Symposium held at the Royal York Hotel, Toronto, Ontario, May 26-29, 1985 and sponsored by The Rawson Academy of Aquatic Science.

[2]Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, British Columbia.

[3]Department of Fisheries and Oceans, Habitat Management Division, 1090 West Pender Street, Vancouver, British Columbia.

Résumé:
La Compagnie Aluminium du Canada Limitée (Alcan) a proposé la réalisation de ses aménagements hydro-électriques dans le but d'accroître la capacité de fusion de l'aluminium dans le centre nord de la Colombie-Britannique. Le projet a été mis en oeuvre en 1950 et comprenait le barrage Kenney sur la rivière Nechako dans le bassin d'alimentation du fleuve Fraser, la création du réservoir Nechako et la construction d'installations de production d'énergie électrique relatives à la rivière Kemano sur la côte ouest. La réalisation de l'aménagement (proposition de Kemano), au coût de plus de 2 milliards de dollars, détournerait 84 p. 100 du débit initial annuel et moyen de la rivière Nechako et 62 p. 100 du débit annuel moyen de la rivière Nanika dans le bassin d'alimentation de Skeena vers la rivière Kemano. La proposition présente des débits visant à protéger les stocks de saumons du Pacifique ou à minimiser les pertes. Le texte indique les effets les plus évidents de la dérivation et de la régularisation sur les populations de saumons et sur leur habitat; ce qui comprend la perturbation de la migration des adultes, des changements touchant la qualité du gravier de frai, des contraintes à tous les stades pour les poissons, depuis les pressions de gaz élevées, les changements dans la température ambiante, dans la composition de la communauté de poissons, la production et l'accessibilité de la nourriture, l'échouage de poissons, la diminution ou la perte de repères pour la remontée, jusqu'aux risques accrus de servir d'appâts à d'autres poissons et à des oiseaux. Une importante difficulté, lorsqu'on essaie de déterminer les effets d'un projet sur les populations de saumons, réside dans la distinction à établir entre le nombre de poissons en rapport avec les effets sur l'habitat et le nombre venant de la mer à la suite de l'exploitation des lieux de pêche. On peut aborder ce problème de trois manières: par l'étude expérimentale de l'évaluation de l'impact, par la modélisation des changements apportés au débit et à l'habitat des saumons, et enfin par l'analyse d'histoires de cas de débits régularisés. Cette troisième approche semble être la plus instructive en termes d'efforts nécessaires. Pour se faire une idée des effets et juger de la fiabilité des prévisions des conséquences qu'aurait la régularisation des débits, on a examiné des cas de rivières de salmonidés comprenant des ouvrages de régularisation, et l'on a découvert que les effets négatifs dépassaient les effets positifs, que les prévisions étaient généralement incorrectes et que, même lorsque la régularisation du débit était faite dans l'intention expresse d'accroître le nombre de salmonidés, les résultats ne répondaient pas aux attentes. En ce qui concerne un aménagement aussi exigeant en matière d'eau que celui de Kemano, il ressort de ce qui précède qu'il est difficile de prévoir les résultats en termes quantitatifs précis et que cet aménagement comporte des risques pour les populations naturelles.

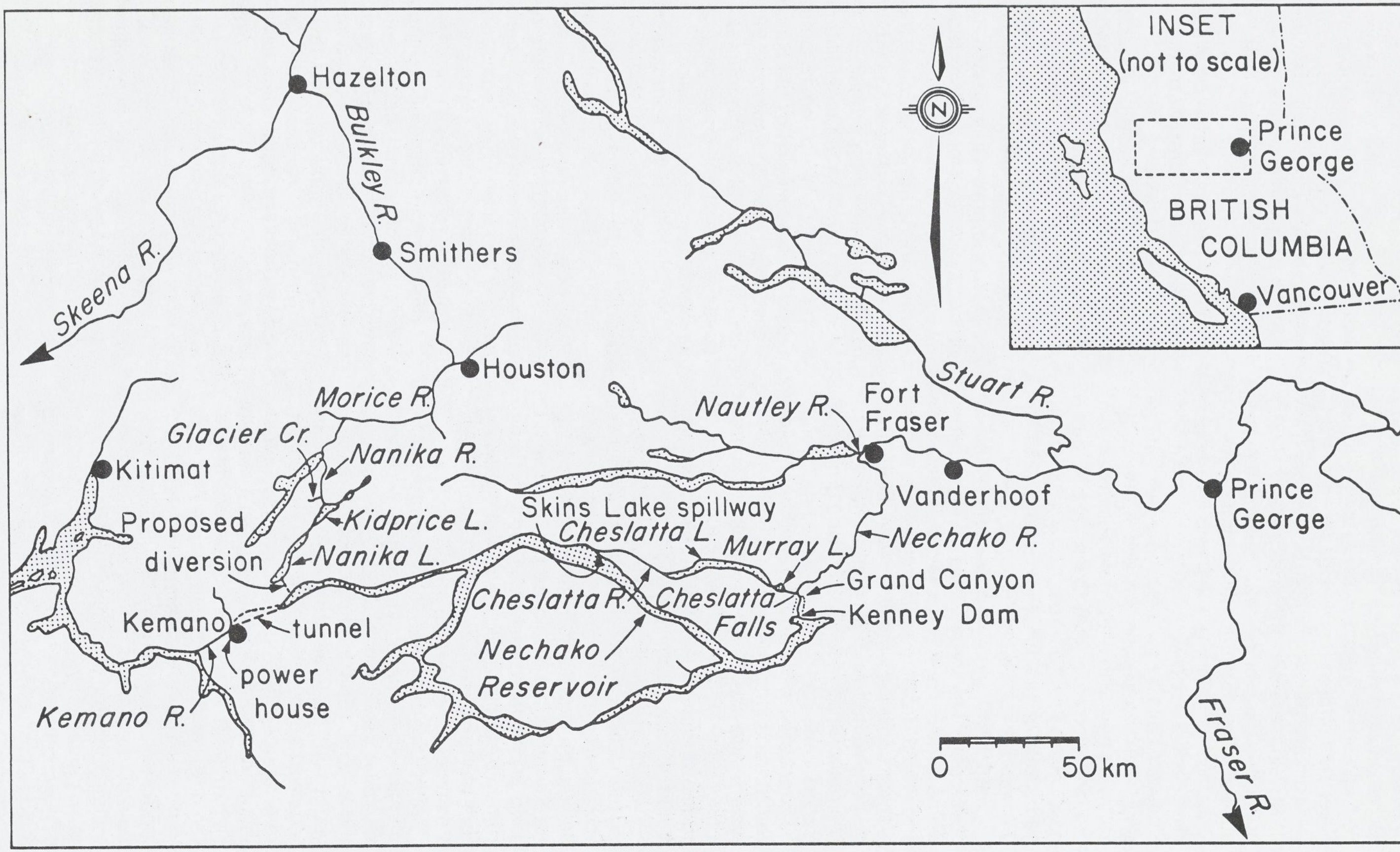
Introduction

The objectives of this paper are to describe a major proposal to regulate the discharge of some rivers in British Columbia, to point out the difficulties in the way of predicting the consequences of this proposal for salmon populations, to comment on current methods for assessing such consequences, and to judge the probable outcome from available evidence.

The Kemano Completion Proposal

The Kemano Completion Proposal of the Aluminum Company of Canada, Limited (Alcan) is the second stage of a hydroelectric development that was begun in 1950. Under an Agreement with the Province of British Columbia Alcan was given permission to divert water of the Nechako River and Nanika River catchment areas to supply the electrical needs of an aluminum smelter at Kitimat. The first phase of the development was operational by 1957. It consists essentially (Fisheries and Oceans 1984) of the Kenney Dam, on the Nechako River, that impounds an 890km² reservoir. Water is diverted from the west end of this reservoir via a 16km tunnel through the coastal mountains to the power plant at Kemano near the coast (Fig. 1). Transmission lines convey power to the smelter at Kitimat.

FIGURE 1: Sketch Map of the Nechako Reservoir and Features of the Kemano Completion Proposal



The reservoir has generally been regulated to store water during the spring snow-melt period, with releases of water to the Nechako River during the remainder of the year. There is no discharge of water from the Kenney Dam itself; releases are made from the Skins Lake spillway from which water passes through several lakes to enter the Nechako River at Cheslatta Falls (Fig. 1). The former riverbed of the Nechako between Kenney Dam and Cheslatta Falls is now almost dry. Discharges prior to this development and in the years following the filling of the reservoir are shown in Fig. 2. Releases from Skins Lake spillway have averaged 130m³/s since 1956, with peak flows occasionally exceeding 425m³/s (Fisheries and Oceans 1984).

The second, and final, phase of the Kemano development (Fisheries and Oceans 1984) would provide power for two new smelters and would draw upon the unused potential granted under the water license. A dam would be constructed on the Nanika River (Fig.1). The reservoir formed (52km²) would contain Nanika Lake and Kidprice Lake, and would be connected to the existing Nechako Reservoir (thus linking the waters of the Skeena system and the Fraser system) by a new tunnel—the Nanika tunnel—6.8km long. In addition, unused Nechako River capacity would be drawn upon and a further 16km tunnel would be constructed parallel to the existing tunnel from the Nechako Reservoir to the powerhouse at Kemano. To permit cooling water to be passed down the Nechako River the Kenney Dam would be provided with a deep cold water release structure. Cold water from this source could be mixed with water from Murray Lake, below Cheslatta Lake, to provide cooling flows of up to 170m³/s.

After very extensive studies and environmental assessments Alcan has proposed regulated flow regimes (Figs. 2, 3; Fisheries and Oceans 1984) for the affected rivers, and would take measures to mitigate predicted negative impacts on salmon stocks resulting from reduced habitat. The proposed mean annual discharge for the regulated Nanika River (Fig. 3) would be 38 percent of pre-Kemano, i.e., natural, flows, and releases of 75m³/s for 4 days every three years have been suggested as flushing flows to disperse accumulated sediments. The proposed mean annual discharge of the Nechako River would be 16 percent of the original river (currently it is 31 percent). Here the cooling flows would serve as flushing flows. The Kemano River, to which the water is directed would have an approximately two-fold increase in discharge.

The cost of Kemano Completion would exceed $2 billion. In October 1984 Alcan withdrew the proposal owing to a fall in the market value of aluminum, claiming, however, that the proposal would be re-opened when economic conditions improved.

Environmental Impact Assessment and Kemano Completion

Numbers of Fish

Prior to the first phase of development the maximum escapements of chinook salmon (*Oncorhynchus tshawytscha*) in the Nechako River averaged 3500. Following the development, concerns for the salmon runs (Fisheries and Marine Service and International Pacific Salmon Fisheries Commission 1979) have related to the need for sufficient flows to allow migration of chinook salmon to spawning grounds in the upper Nachako River, and of sockeye salmon (*O. nerka*) to tributary rivers. The sockeye salmon production from tributaries and lakes in the Nechako catchment area currently contributes 18 percent of the Fraser River sockeye run (International Pacific Salmon Fisheries Commission 1983). There is also concern over high temperatures and the possible loss of spawning area for chinook salmon in the upper Nechako.

The Nanika River currently supports a significant run of sockeye salmon and smaller populations of chinook salmon and coho salmon (*O. kisutch*). It flows to the Morice River which has runs of chinook, coho and pink salmon (*O. gorbuscha*). Here the chinook stock currently amounts to 20 percent of the total Skeena River chinook escapement. The Kemano River contains these four species and also chum salmon (*O. keta*).

The Kemano Completion Proposal is of such magnitude that it can be viewed as an environmental impact and its effects on these salmon stocks can be assessed accordingly. Environmental impact can be defined as any change in an environment that is caused by a human activity or circumstance (Ward 1978). The changes that result from flow regulation and water abstraction impinge on many features of river systems and on many resources and values. The Department of Fisheries and Oceans, however, by virtue of its mandate, is concerned only with effects on salmonid stocks and with the economic and social consequences of changes in stocks, and therefore with predicting the consequences in terms of numbers of fish. Nevertheless, it is frequently very difficult to relate

FIGURE 2: The Nechako River Discharge Regime
(a) prior to construction of Kenney Dam, and
(b) in the years following the formation of the Nechako Reservoir Fisheries and Oceans 1984).

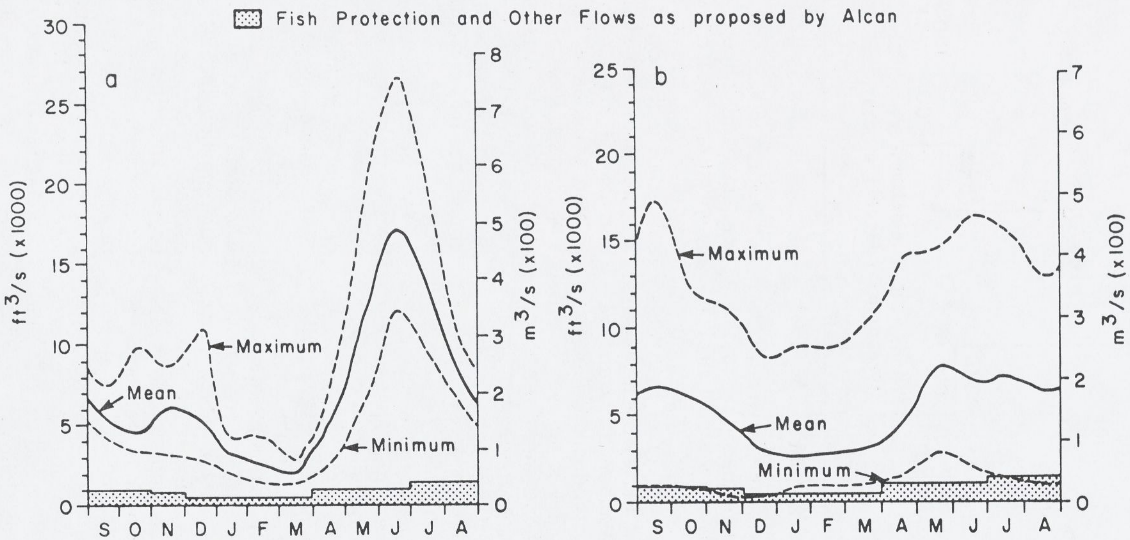
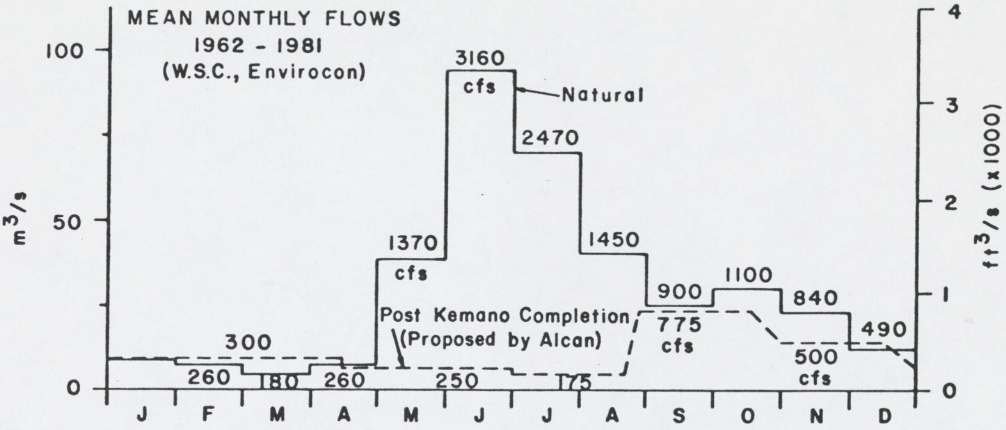


FIGURE 3: Natural and Proposed Discharge Regime for the Nanika River (Fisheries and Oceans 1984).



changes in discharge to even the limited concern of fish numbers. One reason for this difficulty is the substantial natural annual variation in numbers of eggs, alevins, juveniles and adults caused by factors other than discharge, e.g. predation, disease, ocean conditions. This makes numbers an insensitive measure of survival or production in relation to a single variable. This is so even when estimates of populations are known to be unbiased—an exceptional state of affairs. In consequence, the most likely error in trying to detect changes in fish numbers in response to changes in conditions would be a Type II statistical error, i.e., accepting the null hypothesis of no difference in numbers when in fact a change had occurred (Pella and Myren 1974).

The difficulty presented by natural variation is made even greater by the effects of fisheries that introduce an additional source of variation in escapements. Fishery exploitation rates, of course, vary annually themselves. It is noteworthy that over the years in which records have been kept there has been at least a 70-fold difference between the smallest and largest escapements of sockeye salmon to the Nanika River; in recent years 10-fold differences have been common (Fisheries and Marine Service and International Pacific Salmon Fisheries Commission 1979). Five-fold differences in annual escapements of chinook salmon to the Morice River and to the Kemano River, and 10-fold differences to the Nechako River have been recorded (Fisheries and Oceans 1984). These are attributable to a combination of natural and man-imposed influences. They make the quantitative evaluation, with reasonable precision, of changes in salmon production caused by regulation of discharge perhaps an intractable problem. It is shown by Pella and Myren (1974) for a hypothetical study of salmon abundance (five years before and after impact) that, given the variance observed in some Alaskan streams, a t-test would show no difference in salmon numbers in three of four cases in which the average abundance had in fact been reduced by 50 percent.

Yet a further difficulty in relating fish numbers to discharge is that numbers do not necessarily reflect the upper limits of capacity of habitat. For example under-seeding (as a consequence, say, of heavy exploitation by the fishery) or under-recruitment by juveniles (as a consequence, say, of severe winter conditions) may result in fish occupying habitat in numbers that are well below productive capacity. It is necessary, therefore, to distinguish fishery management effects, density-independent environmental effects, and density-dependent effects. The major independent effects (a comprehensive list is provided by Stalnaker 1980) for the rivers affected by Kemano Completion include changes in water quality (temperature, dissolved substances, dissolved oxygen, total gas pressure, and turbidity) and changes resulting from altered discharge regime, i.e. changes in depth, velocity, cover, and in characteristics of gravel, including its movement, permeability and compaction. The major density-dependent effects operate through changes in food supply, territory for spawners and juveniles, and survival of offspring per spawner. It should be noted that density-independent and density-dependent effects are not necessarily unrelated. For example, at times of high spawner density fish may be compelled to spawn in less preferred areas (a density-dependent effect). In the event of changes in discharge the eggs in these areas may be subject to high mortality rates (a density-independent effect).

These in-stream effects, in their negative aspects, may cause difficulties for migrating adults, elevate mortality rates for eggs and alevins, impose stresses to all stages of fish from high total gas pressures and extremes of temperature, increase the occurrence of disease, reduce the production and availability of food, leave fish stranded, weaken the cues used for homing, augment predation from fish and birds, and bring about changes in the total fish community. The proposals of Alcan are intended to protect fish from such effects, or to offer mitigation where they might occur.

Detecting Changes: The Tools at Our Disposal

In general, assessment of the effects of an environmental change on fish populations can be approached via experimental design, modelling, and analysis of case histories.

Experimental designs for impact assessment

To make quantitative comparisons of fish numbers that would allow conclusions to be drawn with reasonable precision it would be necessary to have recourse to formal experimental design. The classical scientific approach to measuring differences between two entities (e.g. fish numbers with and without water abstraction) requires many measurements of the degree to which the entities vary within themselves. The array of experimental designs for providing this is: intensive (one river) and extensive (several rivers) studies before and after regulation; and intensive and extensive studies after regulation but with concurrent comparisons with unregulated rivers (controls). Each of these designs has severe limitations, both of theory and logistics (Hall et al. 1978) and there seems to be no simple and powerful way of dealing with the problem. To design and implement a program for assessing, precisely, the consequences of flow regulation on salmon numbers would be a major undertaking.

Modelling

In their comprehensive overview of environmental impact assessment Beanlands and Duinker (1983) stress the usefulness of conceptual and quantitative modelling for making predictions. Conceptual models, however, although they may be attractive, are no more than speculations and are of little value until they are expressed quantitatively. Quantitative models may be indispensable; the modelling of temperature/discharge relations in the Nechako River, for example, is necessary for reaching decisions on management of the river for salmon. For biological systems, however, whose properties can alter so that the initial system no longer exists, modelling carries no predictive power. For example, the amount of usable fish habitat, as defined by depth, velocity, and physical substrate, might be predicted for a change in discharge regime of the Nechako River. If, however, as a consequence of the change, extensive growths of rooted vegetation were to develop across much of the bed of the river, then the model would have no applicability because the system would have been altered fundamentally.

Attempts to provide a mathematical description of the relationship between discharge and fish habitat have been a major concern in North America in the past two decades because of the economic importance of making water allocations that protect fisheries. Some 20 different approaches have been developed (summarized by Stalnaker and Arnette 1976). The most recent of these try to determine, over a range of carefully selected discharges of a river, the amount of usable or most frequented habitat for each stage of the life history of the commercially important species. The preferred habitat for salmon is usually defined by three criteria—depth, velocity and substrate—and the fishes' preference for these variables is established either by direct observation or from data available in the literature. The usable width of river is calculated for different discharges; this, of course, differs among spawning, over-wintering, rearing and migrating populations. These are *threshold* approaches, i.e. fish populations will not be harmed unless stream flows drop below a minimum value, and the hydrograph can remain flat but must be appropriate to each life stage. Although these methods are helpful, especially for assessing the requirements of spawning fish, the assumptions underlying them are erroneous or suspect (see Smith 1979). Firstly, depth, velocity and substrate are considered to be not only necessary *but sufficient*, to describe fish habitat. Secondly, these factors are regarded as independent of each other and fish are considered to select them on an independent basis. Thirdly, the morphometric features of the stream channel are assumed not to alter with change in discharge regime. The last assumption is the most misleading. Fluvial geomorphology is replete with examples of the dependence of stream physical pattern on dominant discharge. A change in discharge generates changes in morphometry, and therefore in features of salmonid habitat, e.g. stream width, frequency of riffles and pools, depths of pools, and gravel composition. It is remarkable that the pursuit of instream models has continued without acknowledgement of this fact. The current methods can have application only where moderate changes are being contemplated for short periods, say ±30 percent, or less, of mean natural flows for the season in question.

Other assumptions of instream flow models are that water quality will not change, that predatory relations, i.e. numbers of fish and birds, will not change, and that the fish community will not change. These assumptions are questionable, and the methods cannot answer the question: how many fish will be lost if discharge is reduced by a certain amount?

The subject of change within a river system after reservoir construction is so important that it calls for fuller comment. Petts (1980) recognizes three orders of impact. The first-order impacts following dam construction are major changes of flood magnitude and frequency, and of the quantity and quality of sediment loads. These lead to second-order impacts on the stream that involve changes in morphology. "The processes operating within regulated river-channels will not simply reflect the changes of sediment loads alone, but will be the resultant of the interactions between the changed sediment-loads and the altered flow-regime. The elimination of flood events, for example, may effectively prevent channel-bed erosion. Indeed, the total sediment transport capacity of an impounded river to alter local configuration may be reduced by 75 percent, depending on the relative transport characteristics of the controlled releases and the normal flows... Thus it is becoming increasingly apparent that induced erosion below dams may not be as problematical, nor as simple, as was previously thought, while the severity of the environmental problems arising from long-term sedimentation induced by flow-regulation are only now appreciated." The second-order adjustments are not likely to proceed uniformly nor to follow a simple negative exponential path, but will probably be "stepped" with alternating phases of erosion and deposition and will culminate in a reduction of cross-sectional area and in increased meandering. The third-order impacts are the long-term adjustments of channel morphology and ecology, involving macrophytes, invertebrates and fishes. These impacts may require 100 years to attain equilibrium. The outcome would be a diminished river (Petts 1980).

It might be argued that a diminished river would be more productive of salmonids than a pre-impacted river. Small streams are more productive, per unit area, as rearing habitats than large ones, and some small tributaries of the Nechako River have higher densities of juvenile chinook salmon than has the mainstream (Russell et al. 1983). A small stream, however, would not have the spawning gravels required by adult chinook salmon, and it should be noted that after emergence the bulk of the chinook fry in the upper Nechako River move downstream and spend their juvenile lives in the lower mainstream or elsewhere.

It is apparent, therefore, from the nature of change within a disturbed river that neither the short-term fluctuations of discharge, which are essential for the maintenance of the stream ecosystem, nor the long-term consequences of man-induced change, are accommodated by present models of the habitat requirements of salmonids. A ... "facet of the aquatic-riparian stream system which present methods do not address is the cumulative effects of permanent reductions or augmentations in flows. Long-term changes may be expected from cumulative effects on the following components of the system: 1) sediment transport and depositional patterns; 2) intro-gravel permeability and percolation rates; 3) nutrient flow through the system and deposition of detrital materials determining microbe production rates and spatial distributions; 4) extent and time frame for vegetational changes, including emergents, the encroachment of herbaceous and woody riparian plants, and the effects of major plants (trees and shrubs) providing cover and shade; 5) intimately tied to the above *and perhaps most important* are changes in primary and secondary production which ultimately affect the production of fishes in a particular stream (assuming other life needs are not limiting, i.e. reproduction, cover, water quality, space)" (Stalnaker and Arnette 1976, p.132).

Case Histories

There may be no powerful means of predicting the effects of flow control on fish numbers, but there remains the lesson to be learned from retrospective studies, i.e. examination of case histories of comparable impacts. These are surprisingly neglected (see Larkin 1984, p. 1126), and poorly documented, perhaps because, once a decision has been made for a project to go ahead and once the project is irreversibly completed, interest is lost, and incentive to spend monies to assess the consequences is low. It can also be argued that each case is site-specific and unique so comparison is invalid or weak at best. There remain positive aspects, however. A case history does integrate all components and interactions of effects and consequences in a system; cases span different periods of time; if sufficient cases can be found a probable outcome for a new example can be suggested; finally, a review of histories should help to identify all possible effects and the possible *ranges* of these effects. That effects may be overlooked must constantly be borne in mind. An example of failure to anticipate a major effect is the W.A.C. Bennett dam on the Peace River. This caused unforeseen changes in water level of the Peace-Athabasca delta with ensuing serious deterioration of one of the most important habitats for North American migrating waterfowl (see Blench 1972, for a discussion). The suspicion, of course, that there may be unidentified impacts is not a sufficient reason for rejecting a project; it does, however, give added importance to the examination of case histories.

Evidence From Case Histories

A review of the effects of about 60 flow regulation projects in N.W. America and Canada (Burt and Mundie, in prep.) shows that if regulation is looked at in its broadest application there is less than a 40 percent likelihood of natural salmonid stocks being maintained or improved in the regulated system (Table 1a). When 18 cases most applicable to the Kemano Completion project are extracted i.e. cases of substantial change of discharge, or cases with effects that might prove to be of consequence in Kemano Completion, it is found, with three exceptions, that salmonid stocks have been reduced. Two of the exceptions (Duck Valley irrigation project, Idaho and Montpelier Creek, Idaho; Nelson et al. 1976; case studies) gave improved production of salmon but were projects where flows had been *augmented* (Table 1b). The third exception was the Big Qualicum River, British Columbia. This is an example of regulation implemented with the purpose of increasing salmon production. The project maintained, but did not increase, coho and chinook salmon although it has increased chum salmon (Fraser, Perry and Lightly 1983). Another case of regulation intended to increase salmon is the Rogue River, Oregon. This did not succeed for chinook salmon (Satterthwaite 1982).

The explanations of the negative results of flow regulation all appertain to effects that are recognized to be of possible consequence in Kemano Completion, i.e. no unexpected explanations presented themselves. In the sample these explanations of negative results (more than one may be of consequence in a case) are distributed as follows:

Reduced flows resulting in diminished spawning area and rearing capacity	9
Fluctuating flows, e.g. power-peaking	6
Altered water temperatures	5
Sedimentation and deterioration of gravel	3
Pollution	1
Gas supersaturation	1

For the first item, above, it is not possible to say whether diminished rearing capacity resulted through loss of wetted area, of available food, or of territory for juveniles.

In terms of predictability, the effects that offer most difficulty are those of sedimentation and deterioration of gravel, with their attendant long-term influences on stream morphology. Sedimentation affects both the quality of spawning gravel and the production of food organisms. Even where there are no tributaries carrying loads into a regulated river and where some attempt may be made to release flushing flows, e.g. the Big Qualicum River, the accumulation of sands from the banks of the river may impair riffle areas. For the Big Qualicum River this necessitates mechanical scarification to disperse settled material. Such maintenance is not usually envisaged when regulation is planned.

Conclusion

A survey of present methods of assessing the effects of changes of discharge on fishes shows that there is no single powerful way of

TABLE 1: Case Histories of Flow Regulation; Based on Fraser, Perry and Lightly 1983; Hazel et al. 1976; Nelson et al. 1976 case studies and final report; Satterthwaite 1982.

(a) Status of natural salmonid stocks after flow regulation of all kinds.

	Projects	Improved	Maintained	Reduced
Idaho	8	2	0	6
Oregon	18	1	5	12
Washington	4	0	0	4
California	31	4	10	17
British Columbia	1	1	0	0
	62	8	15	39
	100%	13%	24%	63%

(b) Status of natural stocks after flow regulation; from case histories applicable to Kemano Completion

	Projects	Improved	Maintained	Reduced
Idaho	6	2	0	4
Oregon	9	0	0	9
Washington	2	0	0	2
British Columbia	1	1	0	0
	18	3	0	15
	100%	17%	0%	83%

predicting, in precise quantitative terms, the outcome of projects such as Kemano Completion on natural salmonid populations. This is partly because of the confounding of effects of man-induced alterations of discharge with effects of exploitation by fisheries, partly because of the complexity of ecological consequences of altered discharge on habitat and its fish populations, and partly because the responses that will occur will themselves fluctuate, until, after many years, some ecological equilibrium emerges. Predictions and judgements, however, should be based on facts as far as is possible. For these, intensive study of the pre-impacted rivers is necessary to identify the variables of importance and to try to define their acceptable limits. Concurrently, a review of the outcome of comparable completed projects can serve as a guide to possible outcome. From such case history analysis it appears, on the evidence to date, that the Kemano Completion project carries risk for the salmonid populations of the affected rivers.

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Dispute about dams and trout still spilling over

By ELLEN HADDOW
Associated Press Writer

Part four of five

MONTROSE — Barry Nehring, a fish biologist with the Colorado Division of Wildlife, is considered a heretic in some circles.

He doesn't think dams are necessarily bad for fish. In some cases, he thinks fishing may improve when a dam is built.

Nehring, who once raised trout for the Shah of Iran, is stationed here. He is a well-known researcher and advocate for "catch-and-release fishing," which he says improves both the individual size and number of trout in state rivers.

Mark Pearson of the Sierra Club in Grand Junction agrees the term "heretic" could be used to describe Nehring. Many environmentalists think "there are more values to rivers than putting imported fish in them," Pearson said.

TROUT, PEARSON says, shouldn't be the first priority of wildlife managers in rivers where they historically didn't flourish until stocking became widespread.

Environmentalists, he said, generally oppose dams, particularly on main rivers, and also in cases in which certain fish species could be endangered by damming a river.

Nehring believes that if a dam is built with care, it doesn't have to destroy the intrinsic values of a river. With proper management of water releases, stretches of rivers can be made into excellent trout streams, Nehring said.

"Take Blue Mesa," he said. "It destroyed 30 miles of premier stream fishing, but created a fishery that's as good if not better."

Below Blue Mesa Dam, the Gunnison Gorge is one of the state's best trout streams — good enough that Rep. Mike Strang, R-Colo., introduced legislation to protect the gorge under the federal wild and scenic rivers program.

"THE GUNNISON wasn't much of a trout fishery below the Black Canyon before the dams went in because it was too warm," Nehring said. Water released from dams — because it comes from the bottom of reservoirs — is colder and therefore better for trout, he said.

Before dams like Blue Mesa on the Gunnison and like Reudi on the Fryingpan River were built, he said, water temperature was higher and thus didn't produce vast numbers of trout.

"If dams are constructed right and operated right, fishing can be more productive," Nehring said. "The problem is controlling the (federal) agencies and whether they'll manage their operations well."

FISH EGGS have been washed away from the banks of the Gunnison by huge releases from the Blue Mesa dams at the wrong times, he noted.

"Little fish are weak swimmers. They like about two inches of slow water, so a heavy release of water and silt can kill them," he said.

Nehring is a trout expert who spent several years in Iran researching and later stocking a trout population for the Shah.

> "If dams are constructed right and operated right, fishing can be more productive. The problem is controlling the (federal) agencies — and whether they'll manage their operations well."
>
> **Barry Nehring, wildlife biologist**

Some of the things that he did in Iran were better than others, he said. He recalled once having to shock and kill thousands of trout for a single banquet ordered by the Shah.

Today, Nehring points with pride to the increasing numbers of trophy-size trout in the Gunnison and other rivers where the wildlife division has put restrictions on its Gold Medal trout steams.

The division's Gold Medal program involves limiting anglers to the use of artificial flies and lures only, and requires fish to be carefully returned to the water. Nehring said the result is more big trout for Colorado fishermen.

Pearson and other environmentalists, however, say dams have altered the river to the extent that imported trout have taken over.

MEANWHILE, ENDANGERED species like the humpback chub and squawfish, which thrived in the warmer Colorado River before the dams were built, are chased out and further threatened, environmentalists say.

Although fishermen call them trash or junk fish, the squawfish and chub "have some intrinsic value to them," Pearson said.

Environmentalists don't oppose all dams, he said, "If they make some sense for some useful purpose, and not just paranoia of water flowing out of the state.

TOMORROW: Colorado can move into the 1990s with enough water for its needs if there is adequate planning — but planning may be the biggest problem of all, says the state's director of the Department of Natural Resources.

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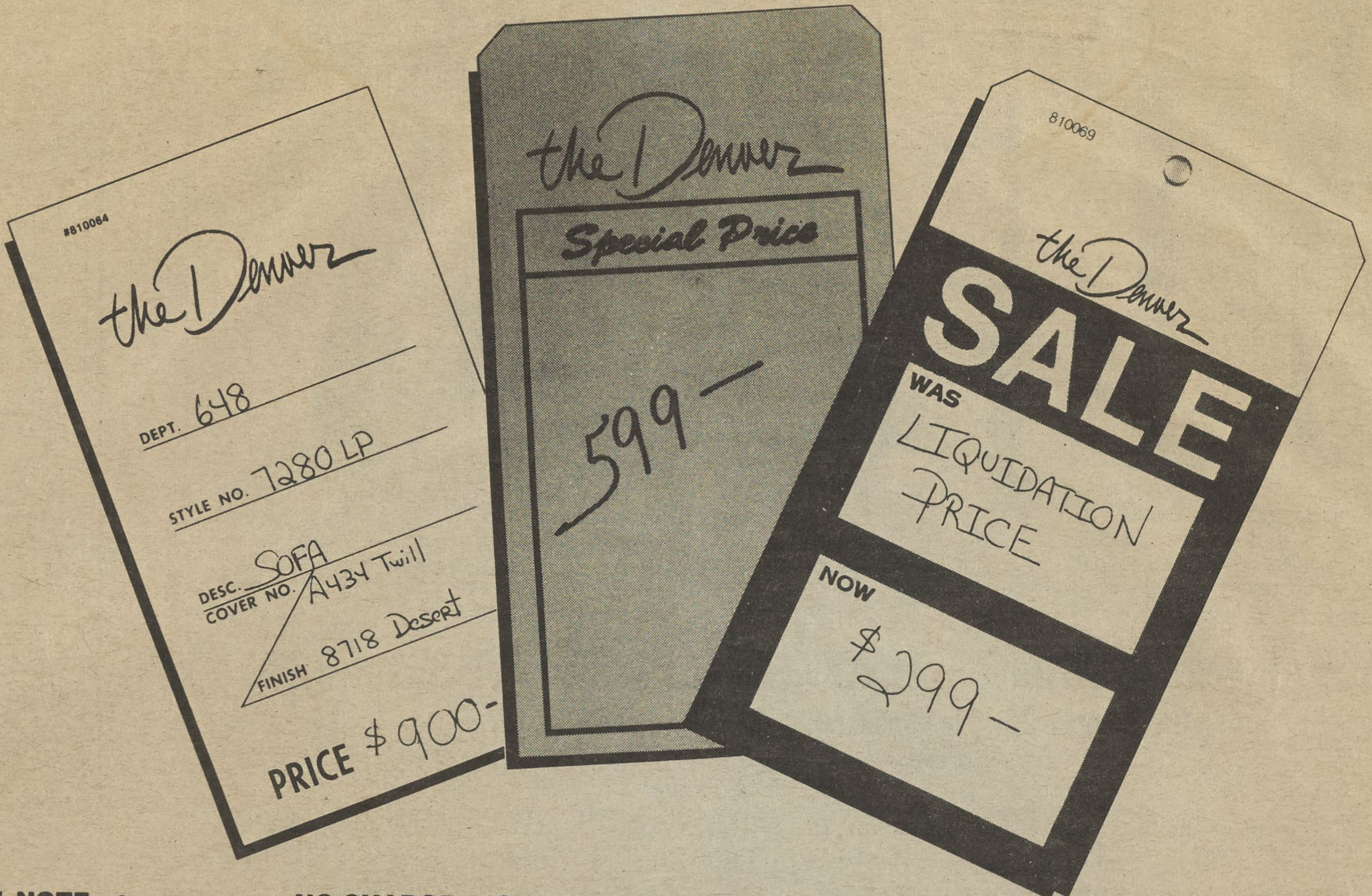

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Energy Budgets for Juvenile Rainbow Trout at Various Oxygen Concentrations

CHRISTIAN LENTZ PEDERSEN

Danish Trout Culture Research Station, Broens Moellevej 7, Broens, DK-6780 Skaerbaek (Denmark)

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ABSTRACT

Pedersen, C.L., 1987. Energy budgets for juvenile rainbow trout at various oxygen concentrations. *Aquaculture*, 62: 289-298.

Growth experiments with rainbow trout, *Salmo gairdneri*, weighing 100 g/fish were carried out at 15°C at the oxygen concentrations 4, 5, 6, 7, 8.5, 10 and 12 mg O_2/l. The diet was dry pellets. Food consumption, growth rate, faeces production and NH_3 excretion were determined directly and transformed to the energy unit kcal. The concomitant metabolic rate was found by difference. Oxygen acted as a limiting factor in relation to food consumption, growth rate and food conversion efficiency. The critical level of oxygen for food consumption was about 6 mg O_2/l and the critical level for both growth rate and food conversion efficiency was about 7 mg O_2/l for fish fed the maximum ration. The experiments did not reveal any relation between assimilation and oxygen concentration or between NH_3 excretion and oxygen concentration.

INTRODUCTION

In the light of the work of Fry (1971), Brett (1979) defined a limiting factor as an environmental factor which restricts the supply or removal of metabolites, involved in the chain of metabolism (e.g. oxygen, light (as in photosynthesis)). Limiting factors become operational at a particular level of the factor, involving dependent and independent states (see also Shepard, 1955; Winberg, 1960). The critical level of oxygen is often correlated with the metabolic rate of the fish (Winberg, 1960; Doudoroff and Shumway, 1970).

Brett and Blackburn (1981) concluded from their own experiments and those reported in Herrman et al. (1962), Chiba (1966) and Stewart et al. (1967) that oxygen acts as a limiting factor in relation to growth rate and food conversion efficiency of fish. These studies were based on wet and/or dry weight measurements. But since body composition and energy content of the fish are influenced markedly by the ration size (Brett et al., 1969; Niimi, 1972; Elliott,

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1976a; From and Rasmussen, 1984), growth is better expressed by the increased energy content of the fish.

This study was carried out in order to examine the influence of oxygen concentration on the appetite, growth rate, food conversion efficiency, assimilation and NH_3-N excretion of rainbow trout.

MATERIAL AND METHODS

The energy budget equation

The experiments were carried out in accordance with Davis and Warren (1971), Cho et al. (1982) and From and Rasmussen (1984). For each experiment an energy budget was drawn up by using the equation:

$$C = \Delta B + F_1 + F_2 + U_1 + U_2 + R_1 + R_2$$

where

C = energy value of food consumed
ΔB = change in energy value of body (growth)
F_1 = fecal energy of metabolic origin: determined approximately as the energy value of the faeces excreted by a fasting fish
F_2 = energy value of non-assimilated food
U_1 = energy value of endogenous nitrogen excretion: determined approximately as the energy value of nitrogen-containing compounds excreted by a fasting fish
U_2 = energy value of exogenous nitrogen excretion (total excretion $- U_1$)
R_1 = energy of metabolism of a fasting fish (routine metabolism)
R_2 = additional energy released as a consequence of feeding (the feeding procedure itself and the following apparent specific dynamic action; Beamish, 1974).

C, ΔB, F_1, F_2, U_1, U_2 (only NH_3 excretion) were determined directly and R_1 and R_2 were calculated as differences. The absolute values of C, ΔB, F_1, F_2, U_1, U_2, R_1, R_2 were converted to rate terms A (Warren and Davis, 1967; Averett, 1969; Warren and Doudoroff, 1971).

$A = Q/(W^x \cdot t)$ where

t = time in days
W = mean energy value of the fish
$W = (W_t + W_0)/2$ (W_t, W_0 = final and initial energy values of the fish).

x = some mean power of W

$Q = C, \Delta B, F_1, F_2, U_1, U_2, R_1, R_2$.

As the fish used in all the experiments were of almost the same size (see below), $x = 1$ was chosen, which is in accordance with Averett (1969).

Consumption (C)
In this study consumption was expressed by the feeding level f ($0 \leq f \leq 1$) which is the ratio between the actual consumption and the maximum consumption C_{max}.

Growth rate
The constant instantaneous rate of growth G was calculated as $G\% = [(\ln W_t - \ln W_0)/t] \times 100\%$ (Ricker, 1979). For each oxygen concentration a (f, $G\%$) curve was drawn from which values of $G\%$ at $f = 1.0, 0.8, 0.6, 0.4, 0.2, 0$ were read.

Food conversion efficiency
The food conversion efficiency was calculated as $\Delta B/(f \cdot C_{max})$.

Assimilation
For each oxygen concentration a (f, $(F_1 + F_2)$) curve was drawn from which values of F_2 = at $f = 1.0, 0.8, 0.6, 0.4, 0.2$ were read. The assimilation was calculated as $(C - F_2)/C$.

Excretion ($U = U_1 + U_2$)
For each oxygen concentration a (f, U) curve was drawn from which values of U at $f = 1.0, 0.8, 0.6, 0.4, 0.2, 0$ were read. $U/C\%$ and $U_2/C\%$ were calculated.

Respiration ($R = R_1 + R_2$)
The metabolic rates were calculated by means of the oxycalorific coefficient 3.24 kcal/g O_2 (Elliot and Davison, 1975; see also Brafield and Solomon, 1972).

Experimental conditions

The experiments were performed at the Danish Trout Culture Research Station. At each of the oxygen concentrations 5, 6, 7, 8.5, 10 and 12 mg O_2/l experiments with $f = 1$, $f \simeq 0.7$, $f \simeq 0.4$ and $f = 0$ were carried out; at 4 mg O_2/l a single experiment with $f = 1$ was carried out.

Water from the river Broens was percolated through a sand filter and led to a fibreglass basin where heating or cooling took place. The water was then led by a manifold system to seven identical glass aquaria (120 l/aquarium), and water flows were determined every day at 9 a.m. and 7 p.m. The water was not recirculated. Temperatures in the aquaria were checked every day to be within ±0.2°C of 15.0°C.

The aquaria had bottom outlets through which the faeces which settled were collected daily and kept in a deep-freezer. Peristaltic water pumps placed at the inlets and outlets of the aquaria sampled continuously about 2 l/day. The sample container was emptied every day. The NH_3 content of one subsample was determined immediately and another subsample was deep-frozen and its organic matter content was determined (as g COD) at the end of the experiment (all the analyses in this study were carried out in accordance with From and Rasmussen, 1984). The total amounts were determined as "outlet — inlet" multiplied by the waterflow. The conversion factors 3.42 kcal/g COD (Davis and Warren, 1971; Ostapenya, 1971) and 5.94 kcal/g NH^3-N (Elliott and Davison, 1975) were used.

The oxygen controlling system of each aquarium consisted of an "oxygen controller" connected to a TOX 40 oxygen transmitter. The "oxygen controller" contained two magnetic valves connected to an oxygen source and a nitrogen source, respectively. According to the output from the oxygen transmitter, oxygen or nitrogen was added to the aquarium by means of an air diffuser. In order to avoid oxygen gradients, two water pumps (4 l/min each) were placed in the aquarium. The oxygen concentration in each aquarium was checked by Winkler titration every day at 8 a.m., 12 noon, 4 p.m., 8 p.m., and 12 midnight to be within ±0.3 mg O_2/l of the prescribed value. The oxygen concentrations were also continuously registered on printers.

Fish and experimental procedures

The experiments were performed with juvenile rainbow trout of the same strain delivered by the hatchery connected to the Danish Trout Culture Research Station. The fish were acclimated to the experimental conditions (15°C, a 12L–12D photoperiod and the various oxygen concentrations) over a period of 3 weeks during which they were fed to satiation every day. At the end of the acclimation period the trout were starved 3 days for gastric evacuation (From and Rasmussen, 1984). The trout were then anaesthetized with chlorbutolum, blotted using a wet cloth and weighed one by one to the nearest 0.1 g. In each experiment the fish did not vary more than ±5 g from the mean. All the experimental fish were in the size range 85 g$<W_0<$115 g. Mean initial weight for all the experiments was 100.4 g±8.5 g (±S.D.). Out of the 40–45 fish acclimated in each aquarium, 10–20 were used as experimental fish and 4–10 fish of the same size as the experimental fish were analysed for dry matter % and kcal/g. At the end of the experiment (t=14 in all the experiments), the trout were starved for 3 days, weighed one by one to the nearest 0.1 g and analysed.

The diet was dry pellets (Table 1). At f=1 the fish were fed hourly during the light period; feeding was stopped when 2–3 pellets were refused. These pellets were either picked up again or registered as part of the faeces if they dropped into the faeces collector. The $f \simeq 0.7$ ration was fed in two fractions and the $f \simeq 0.4$ ration was fed at one time in order to obtain an even distribution to all the fish.

TABLE 1

Composition of dry pellets

	Mean	Range
Dry matter (%)[a]	91.07	89.47–92.87
Energetic value (kcal/g d.w.)[a]	5.19	4.77– 5.64
Crude protein (% of d.w.)[b]	52.8	52.2–53.8
Lipid (% of d.w.)[b]	13.8	13.3–14.1
Crude fiber (% of d.w.)[b]	2.0	1.7– 2.3
Ash (% of d.w.)[b]	9.0	8.0–10.6

[a]From [illegible] separate analyses.
[b]From 3 separate analyses.
All analyses were carried out in accordance with From and Rasmussen, 1984.

RESULTS

It can be seen from Table 2 that C_{max} is reduced at oxygen concentrations below 6 mg O_2/l. At oxygen concentrations above 6 mg O_2/l C_{max} is independent of the oxygen concentration.

At f=1 the growth rate decreases when the oxygen concentration is lower than 7 mg O_2/l whereas the growth rate is independent of oxygen concentrations above 7 mg O_2/l. At f=0.2 the growth rate is seen to be independent of oxygen concentrations above 5 mg O_2/l (Table 2).

At all feeding levels the food conversion efficiency is dependent on the oxygen concentration when this is below 7 mg O_2/l (Table 2).

The data reveal neither a clear relation between the assimilation and the oxygen concentration nor between the NH_3 excretion rate and the oxygen concentration.

At 12, 10, 8.5, 7, 6, 5 mg O_2/l the metabolic rate of a fasting fish is calculated to be 554, 529, 485, 178, 447, 422 mg O_2/100 g fish•day^{-1}.

TABLE 2

Energy budgets for rainbow trout (100 g/fish) at 15°C at various oxygen concentrations

f	Oxygen concentration (mg O_2/l)						
	12	10	8.5	7	6	5	4
1.0 C_{max} (cal/kcal fish·day^{-1})	104	100	90	88	96	73	24
1.0 G%	4.05	4.00	3.90	4.00	2.90	2.00	−0.05
1.0 $\Delta B/(f\cdot C_{max})$	0.40	0.41	0.40	0.47	0.30	0.28	−0.02
1.0 $(C-F_2)/C$%	86	84	80	88	79	85	x
1.0 U/C%	2.8	1.5	1.3	3.7	1.5	2.3	3.2
1.0 U_2/C%	2.7	1.5	1.3	3.4	1.4	2.1	x
1.0 R_2/C%	31.7	30.8	23.4	34.3	38.1	40.8	x
0.8 C (cal/kcal fish·day^{-1})	83	80	72	70	77	58	19
0.8 G%	3.40	3.25	3.25	3.25	2.35	1.50	x
0.8 $\Delta B(f\cdot C_{max})$	0.42	0.41	0.46	0.47	0.31	0.26	x
0.8 $(C-F_2)/C$%	83	79	80	82	77	84	x
0.8 U/C%	3.1	2.1	2.8	3.3	1.7	2.1	x
0.8 U_2/C%	3.0	2.1	2.8	3.0	1.6	1.9	x
0.8 R_2/C%	22.5	22.0	17.0	26.5	32.9	38.3	x
0.6 C (cal/kcal fish·day^{-1})	62	60	54	53	58	44	14
0.6 G%	2.65	2.40	2.35	2.45	1.70	0.95	x
0.6 $\Delta B/(f\cdot C_{max})$	0.43	0.40	0.44	0.47	0.30	0.22	x
0.6 $(C-F_2)/C$%	80	81	75	78	75	84	x
0.6 U/C%	3.6	2.0	3.1	3.0	2.0	1.7	x
0.6 U_2/C%	3.5	2.0	3.0	2.6	1.8	1.4	x
0.6 R_2/C%	12.6	21.1	9.1	21.9	28.2	36.5	x
0.4 C (cal/kcal fish·day^{-1})	42	40	36	35	38	29	10
0.4 G%	1.65	1.45	1.30	1.55	0.95	0.15	x
0.4 $\Delta B/(f\cdot C_{max})$	0.40	0.36	0.36	0.45	0.25	0.10	x
0.4 $(C-F_2)/C$%	78	85	68	78	68	82	x
0.4 U/C%	4.2	1.9	2.7	3.0	2.3	4.3	x
0.4 U_2/C%	4.0	1.9	2.6	2.4	2.0	3.8	x
0.4 R_2/C%	4.4	18.1	1.2	19.8	15.7	31.2	x
0.1 C (cal/kcal fish·day^{-1})	21	20	18	18	19	15	5
0.2 G%	0.30	0.30	0.15	0.60	0.15	−0.35	x
0.2 $\Delta B/(f\cdot C_{max})$	0.14	0.15	0.08	0.34	0.08	−0.24	x
0.2 $(C-F_2)/C$%	75	85	68	79	69	82	x
0.2 U/C%	4.5	1.8	2.8	3.3	2.5	4.7	x
0.2 U_2/C%	4.0	1.9	2.6	2.4	2.0	3.8	x
0.2 R_2/C%	−2.8	13.2	−1.1	24.4	9.4	29.6	x

DISCUSSION

Consumption, growth and food conversion efficiency

The results confirm the effect of oxygen as a limiting factor in relation to C_{max}, G% and $\Delta B(f\cdot C_{max})$ because obvious zones of dependency and independency of the oxygen concentration were revealed. As mentioned above, this is in accordance with the results of Brett and Blackburn (1981) concerning coho salmon *Oncorhynchus kisutch*, sockeye salmon *Oncorhynchus nerka*, largemouth bass *Micropterus salmoides*, and carp *Cyprinus carpio*. However, for all four species the critical levels of oxygen in relation to food consumption, growth rate and food conversion efficiency were reported to be about 4–5 mg O_2/l which is lower than the critical levels for rainbow trout found in this study. Andrews et al. (1973) found that channel catfish, *Ictalarus punctatus*, under ad libitum feeding consumed about 3.3% of their body weight at 8 mg O_2/l, whereas the consumption declined to 2.9% and 2.1% at 4.8 mg O_2/l and 2.9 mg O_2/l respectively. Likewise, growth rate and food conversion efficiency were markedly reduced only at the lowest oxygen concentration (2.9 mg O_2/l).

However, Adelman and Smith (1970) found for northern pike, *Esox lucius*, a gradual decrease in food consumption and growth rate when the oxygen concentration was reduced to 3–4 mg O_2/l and a sharp decline in food consumption and growth rate with a further reduction of the oxygen concentration. The food conversion efficiency, on the contrary, was found to be independent of oxygen concentrations above 3–4 mg O_2/l. For this species, oxygen seems to act as a limiting factor only in relation to food conversion efficiency.

Assimilation

Assimilation was found to be independent of the oxygen concentration and it has not been possible to find any data in the literature which allow examination of this result.

The assimilation was 68–88% which is in accordance with values found in the literature, e.g. Brocksen et al. (1968) found that cut-throat trout, *Salmo clarki* assimilated 85.6% of the food; Cho et al. (1982) concluded that salmonids assimilated 60–90% of commercially formulated diets; and From and Rasmussen (1984) found that rainbow trout assimilated 70–90% of the food.

Excretion

Brett and Zalá (1975) found that NH_3 contributed 87% to the daily NH_3 and urea nitrogen excretion in fed sockeye salmon and approximately 79% in fasting sockeye salmon. Elliott (1976b) found that NH_3 always contributed over [illegible]% to the total energy value of NH_3 and urea excretion in brown trout, *Salmo trutta*. Therefore the error introduced by measuring only NH_3 excretion can be considered rather small.

The NH_3 excretion rate was found to be independent of the oxygen concentration and it has not been possible to find any data in the literature which allow examination of this result. The energy excreted as NH_3 accounted for 1.5–4.7% of the energy consumed, which is in accordance with values found in the literature. Elliott (1976b) found, for brown trout fed *Gammarus pulex*, that generally 4–12% of the energy consumed was excreted as urine (the protein content of *Gammarus pulex* was approximately 75% of the dry matter (calculated from the data given by Elliott, 1976b)). From the models given by From and Rasmussen (1984) the corresponding values of $U/C\%$ and $U_2C\%$ for a rainbow trout (100 g wet weight $\simeq$ 37.5 g COD) can be calculated; at 15°C and f=1.0, 0.8, 0.6, 0.4, 0.2, $U/C\%$ values are 3.6, 2.9, 2.5, 2.6, 3.3 and $U_2/C\%$ values are 3.2, 2.4, 1.8, 1.5, 1.2. The diet in From and Rasmussen (1984) contained, like the diet used in the present study, approximately 53% protein.

Respiration

By using the models in From and Rasmussen (1984), the metabolic rate of a fasting trout of 100 g wet weight can be calculated to be 279 or 291 mg O_2/100 g fish•day^{-1} depending on the model used. Brett and Groves (1979) concluded that the apparent specific dynamic action normally accounted for 12–16% of the energy consumed. From and Rasmussen (1984) found that the apparent specific dynamic action at maximum accounted for 15–16% of the energy consumed.

The metabolic rates found in the present study were higher than corresponding values reported in the literature, which, according to Winberg (1960), could be the reason for the relatively high critical oxygen concentrations found in this study. However, no specific reason for the relatively high metabolic rates can be given in as much as the water circulation within the aquaria was very modest and the level of activity seemed to be "normal". Furthermore, the fish were all in good health.

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Influence of Acclimation Temperature on Interrenal and Carbohydrate Stress Responses in Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*)*

BRUCE A. BARTON[1] and CARL B. SCHRECK

Oregon Cooperative Fishery Research Unit[2], Oregon State University, Corvallis, OR 97331 (U.S.A.)

[1]Present address: Utah Division of Wildlife Resources, Fisheries Experiment Station, 1465 West 200 North, Logan, UT 84321 (U.S.A.)

[2]Cooperators are Oregon State University, U.S. Fish and Wildlife Service, and Oregon Department of Fish and Wildlife.

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ABSTRACT

Barton, B.A. and Schreck, C.B., 1987. Influence of acclimation temperature on interrenal and carbohydrate stress responses in juvenile chinook salmon (*Oncorhynchus tshawytscha*). *Aquaculture*, 62: 299–310.

In juvenile chinook salmon (*Oncorhynchus tshawytscha*), acclimated to 7.5, 12.5 and 21.0°C and subjected to a 30-s handling stress, cortisol elevations were similar in all groups but the return to resting levels was slowest in the fish acclimated to 7.5°C. Glucose increases in response to handling were much greater in the fish acclimated to 21.0°C than in those of the other two groups. Among chinook salmon subjected to continuous confinement, plasma cortisol rose most quickly in fish acclimated to 21.0°C, but peak levels were similar in all three groups. For plasma glucose, both resting levels and elevations induced by confinement stress were highest in fish acclimated to the high temperature. Confinement-induced mortality was also highest in fish acclimated and confined at 21.0°C; mortality was low in fish held at 12.5°C and nil in those held at 7.5°C. Liver glycogen declined in all confined fish, but this decline was smallest in those acclimated to the low temperature.

INTRODUCTION

Among both researchers and managers, there is a growing interest in the detrimental effects of stress in fish (see Pickering, 1981). This trend is particularly evident in fish culture where managers are concerned with the stress associated with physical disturbances such as handling, crowding, or transport.

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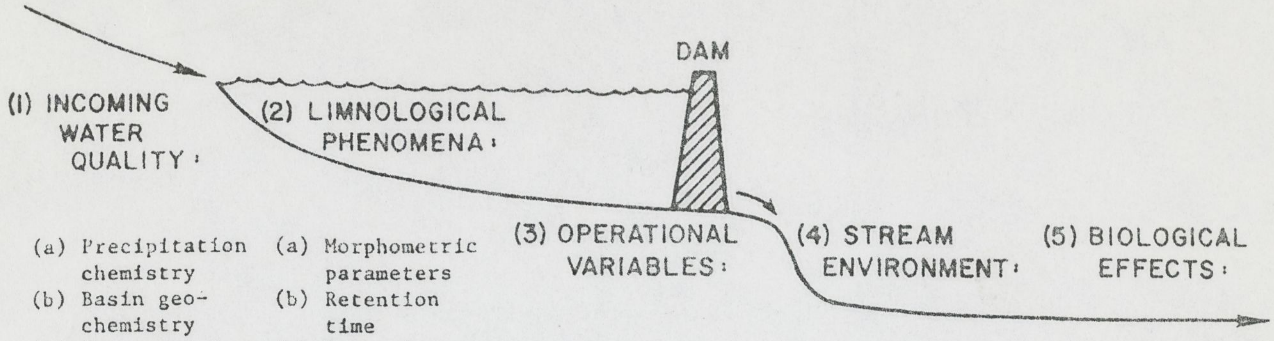

(1) Incoming water quality:

(a) Precipitation chemistry
(b) Basin geo-chemistry
(c) Terrestrial vegetation
(d) Climatic conditions
(e) Anthropogenic impacts

(2) Limnological phenomena:

(a) Morphometric parameters
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(c) Impoundment age
(d) Turbidity currents
(e) Drawdown extent
(f) Thermal stratification
(g) Chemical stratification
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(3) Operational variables:

(a) Discharge pattern
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(4) Stream environment:

(a) Thermal regime
(b) Flow regime
(c) Nutrient levels
(d) Substrate type
(e) Water clarity
(f) Lentic plankton
(g) Dissolved salts
(h) Dissolved gases
(i) Organic detritus

(5) Biological effects:

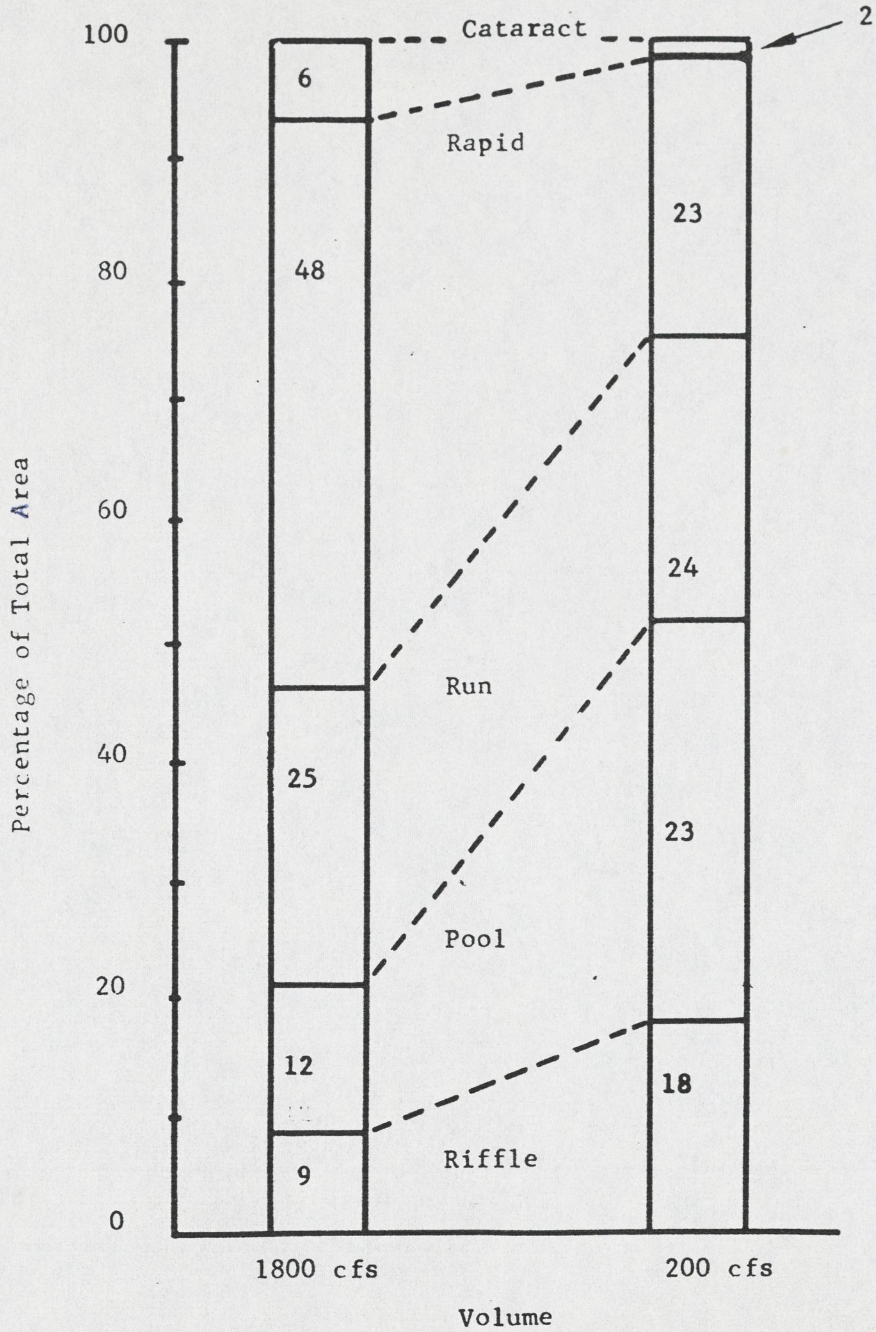
(a) Riparian vegetation
(b) Aquatic vegetation
(c) Ecological diversity
(d) Biotic productivity
(e) Migratory movements
(f) Species composition
(g) Life-cycle phenomena
(h) Trophic structure

Figure 1. Major factors and phenomena influencing the stream environment below dams and resultant effects on stream biota.

Table 4. Frequency of occurrence (number of sites present/number of sites sampled) and abundance (+ = 1-10/m^2, ++ = 11-100/m^2, +++ = 101-1000/m^2, ++++ = >1000/m^2) of each taxon, for all drainage basins combined.

Taxon	Upstream Frequency	Upstream Abundance	Downstream Frequency	Downstream Abundance
Plecoptera				
Alloperla (s.l.) spp.	.92	++	.31	+++
Claasenia sabulosa	.25	++	.00	-
Isogenoides elongatus	.25	+	.08	++
Isoperla quinquepunctata	.17	++	.15	++
Perlesta placida	.25	+	.00	-
Pteronarcella badia	.42	++	.00	-
Zapada oregonensis	.08	++	.00	-
Ephemeroptera				
Baetis bicaudatus	.74	+++	.62	+++
Baetis insignificans	.17	++	.00	-
Baetis tricaudatus	.58	+++	.23	+++
Cinygmula sp.	.50	++	.00	-
Drunella doddsi	.25	+	.00	-
Drunella grandis	.08	++	.00	-
Drunella coloradensis	.08	++	.00	-
Epeorus alberta	.08	+	.00	-
Epeorus deceptivus	.50	++	.08	+
Epeorus longimanus	.33	++	.00	-
Ephemerella inermis	.25	++	.31	++
Ephemerella infrequens	.08	+++	.08	++
Ephemerella tibialis	.17	++	.00	-
Heptagenia sp.	.17	++	.00	-
Paraleptophlebia packi	.00	-	.08	++
Paraleptophlebia sp. A	.42	++	.23	++
Rhithrogena hageni	.75	++	.00	-
Timpanoga hecuba	.08	+	.08	+
Tricorythodes minutus	.17	++	.15	+++
Odonata				
Omphigomphus sp.	.00	-	.08	++
Trichoptera				
Agapetus sp.	.17	++	.08	++
Agraylea sp.	.08	++	.00	-
Anagapetus sp.	.08	+	.00	-
Arctopsyche grandis	.50	++	.08	+
Brachycentrus sp.	.75	++	.08	++
Cheumatopsyche sp.	.17	++	.15	+
Glossosoma sp.	.25	+	.00	-
Hesperophylax sp.	.17	++	.00	-
Hydropsyche sp.	.33	++	.31	+++
Hydroptila sp.	.08	++	.08	+++
Lepidostoma sp.	.08	+++	.00	-
Rhyacophila sp.	.50	++	.00	-
Wormaldia sp.	.25	++	.00	-

Taxon	Upstream		Downstream	
	Frequency	Abundance	Frequency	Abundance
Coleoptera				
Agabus sp.	.08	++	.08	++
Heterlimnius corpulentus	.75	++	.31	+++
Optioservus sp.	.17	++	.23	++
Zaitzevia parvula	.25	++	.15	++
Diptera				
Atherix pachypus	.17	++	.31	++
Chelifera sp.	.08	+	.00	-
Dicranota sp.	.17	+	.08	++
Euparyphus sp.	.00	-	.08	++
Hemerodromia sp.	.17	+	.00	-
Hexatoma sp.	.75	++	.15	++
Hydrella sp.	.08	+	.00	-
Limnophora sp.	.08	+	.08	+
Pericoma sp.	.08	+	.00	-
Probezzia sp.	.17	+	.00	-
Psychoda sp.	.00	-	.08	+
Simulium sp.	.83	+++	.69	++++
Tipula sp.	.17	+	.00	-
Cardiocladius sp.	.17	+++	.23	++
Cricotopus sp.	.67	+++	.85	+++
Diamesia sp.	.25	+++	.31	+++
Eukiefferiella sp.	1.00	+++	.85	+++
Heterotrissocladius sp.	.00	-	.08	+
Orthocladius sp.	.67	+++	.70	+++
Polypedilum fallax	.08	+++	.31	++
Procladius sp.	.42	++	.38	+++
Pseudodiamesa sp.	.17	+++	.15	++
Rheotanytarsus sp.	.50	++	.23	++
Thienemanniella sp.	.08	++	.00	-
Amphipoda				
Crangonyx sp.	.00	-	.08	+
Gammarus lacustris	.00	-	.15	+++
Hyallela azteca	.00	-	.15	++
Miscellaneous				
Polycelis coronata	.25	++	.15	++
Eiseniella tetraedra	.08	+	.15	++
Limnodrilus hoffmeisteri	.00	-	.15	++
Nais sp.	.00	-	.15	++++
Tubifex tubifex	.08	+++	.08	+++
Helobdella stagnalis	.00	-	.08	++
Lymnaea sp.	.00	-	.08	++
Sperchon sp.	.08	+	.00	-



[illegible] River habitat [illegible] of the [illegible]