A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

NOAA Technical Report NMFS SSRF-646

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

Dissolved Nitrogen Concentrations in the Columbia and Snake Rivers in 1970 and their Effect on Chinook Salmon and Steelhead Trout

WESLEY J. EBEL

SEATTLE, WA.
August 1971

National Marine Fisheries Service, Special Scientific Report--Fisheries Series

The major responsibilities of the National Marine Fisheries Service (NMFS) are to monitor and assess the abundance and geographic distribution of fishery resources, to understand and predict fluctuations in the quantity and distribution of these resources, and to establish levels for optimum use of the resources. NMFS is also charged with the development and implementation of policies for managing national fishing grounds, development and enforcement of domestic fisheries regulations, surveillance of foreign fishing off United States coastal waters, and the development and enforcement of international fishery agreements and policies. NMFS also assists the fishing industry through marketing service and economic analysis programs, and mortgage insurance and vessel construction subsidies. It collects, analyzes, and publishes statistics on various phases of the industry.

The Special Scientific Report—Fisheries series was established in 1949. The series carries reports on scientific investigations that document long-term continuing programs of NMFS, or intensive scientific reports on studies of restricted scope. The reports may deal with applied fishery problems. The series is also used as a medium for the publication of bibliographies of a specialized scientific nature.

NOAA Technical Reports NMFS SSRF are available free in limited numbers to governmental agencies, both Federal and State. They are also available in exchange for other scientific and technical publications in the marine sciences. Individual copies may be obtained (unless otherwise noted) from NOAA Publications Section, Rockville, Md. 20852. Recent SSRF's are:

586. The Trade Wind Zone Oceanography Pilot Study. Part VII: Observations of sea birds March 1964 to June 1965. By Warren B. King. June 1970, vi + 136 pp., 36 figs., 11 tables.

591. A bibliography of the lobsters, genus *Homarus*. By R. D. Lewis. January 1970, i + 47 pp.

592. Passage of adult salmon and trout through pipes. By Emil Slatick. January 1970, iii + 18 pp., 8 figs., 12 tables.

594. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1967 and 1968. By Kenneth Sherman. July 1970, iii + 8 pp., 6 figs., 3 tables.

595. Size, seasonal abundance, and length-weight relation of some scombrid fishes from southeast Florida. By Grant L. Beardsley, Jr., and William J. Richards. May 1970, iii + 6 pp., 5 figs., 2 tables.

596. Fecundity, multiple spawning, and description of the gonads in *Sebastodes*. By John S. MacGregor. March 1970, iii + 12 pp., 6 figs., 7 tables.

597. Fur seal investigations, 1967. By Bureau of Commercial Fisheries Marine Mammal Biological Laboratory. March 1970, vii + 104 pp., 31 figs., 79 tables.

599 Diagnostic characters of juveniles of the shrimps *Penaeus aztecus aztecus*, *P. duorarum duorarum*, and *P. brasiliensis* (Crustacea, Decapoda, Penaeidae). By Isabel Perez Farfante. February 1970, iii + 26 pp., 25 figs.

600. Birectilinear recruitment curves to assess influence of lake size on survival of sockeye salmon (*Oncorhynchus nerka*) to Bristol Bay and forecast runs. By Ralph P. Silliman. March 1970, iii + 9 pp., 13 figs., 2 tables.

601. Effect of flow on performance and behavior of chinook salmon in fishways. By Clark S. Thompson. March 1970, iii + 11 pp., 8 figs., 3 tables.

602. Biological characteristics of intertidal and freshwater spawning pink salmon at Olsen Creek, Prince William Sound, Alaska, 1962-63. By John H. Helle. May 1970, iii + 19 pp., 11 figs., 5 tables.

603. Distribution and abundance of fish in the Yakima River, Wash., April 1957 to May 1958. By Benjamin G. Patten, Richard B. Thompson, and William D. Gronlund. June 1970, iii + 31 pp., 26 figs., 37 tables.

604. The flora and fauna of a basin in central Florida Bay. By J. Harold Hudson, Donald M. Allen, and T. J. Costello. May 1970, iii + 14 pp., 2 figs., 1 table.

605. Contributions to the life histories of several penaeid shrimps (Penaeidae) along the south Atlantic Coast of the United States. By William W. Anderson. May 1970, iii + 24 pp., 15 figs., 12 tables.

606. Annotated references on the Pacific saury, *Cololabis saira*. By Steven E. Hughes. June 1970, iii + 12 pp.

607. Studies on continuous transmission frequency modulated sonar. Edited by Frank J. Hester. June 1970, iii + 26 pp. 1st paper, Sonar target classification experiments with a continuous-transmission Doppler sonar, by Frank J. Hester, pp. 1-20, 14 figs., 4 tables; 2d paper, Acoustic target strength of several species of fish, by H. W. Volberg, pp. 21-26, 10 figs.

608. Preliminary designs of traveling screens to collect juvenile fish. July 1970, v + 15 pp. 1st paper, Traveling screens for collection of juvenile

Continued on inside back cover.

U.S. DEPARTMENT OF COMMERCE
Maurice H. Stans, Secretary
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator
NATIONAL MARINE FISHERIES SERVICE
Philip M. Roedel, Director

NOAA Technical Report NMFS SSRF-646

Dissolved Nitrogen Concentrations in the Columbia and Snake Rivers in 1970 and their Effect on Chinook Salmon and Steelhead Trout

WESLEY J. EBEL

SEATTLE, WA.
August 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. - Price 20 cents Stock number 0320-0020

CONTENTS

Dissolved Nitrogen Concentrations in the Columbia and Snake Rivers in 1970 and Their Effect on Chinook Salmon and Steelhead Trout

By

WESLEY J. EBEL, Fishery Biologist
National Marine Fisheries Service, Biological Laboratory
Seattle, Washington 98102

ABSTRACT

Concentrations of dissolved nitrogen gas varied widely in 1970 but were generally lower in the Columbia River than in 1968-69. Concentrations were high, however, in some areas of the Snake River in the spring and early summer, mainly because of spilling of water at Little Goose Dam. Symptoms of gas bubble disease were widespread in Snake River juvenile and adult chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*). There were substantial losses of fish, particularly juveniles, during periods of high concentration of dissolved nitrogen gas.

INTRODUCTION

Continued evidence of the supersaturation of dissolved nitrogen gas associated with spilling of water at dams in the Columbia River Basin has prompted the U.S. Army Corps of Engineers to undertake studies to develop a mathematical model for prediction of concentrations of dissolved nitrogen and to examine means of designing spillways that do not supersaturate the water. It was hoped that information from the development of the model would also enable the Corps to modify present spillway operations to reduce nitrogen gas concentrations in the Columbia and Snake Rivers.

This report summarizes the water sampling data provided by the National Marine Fisheries Service for the model and briefly reviews some studies of the effects of supersaturation of dissolved nitrogen on some salmonids. Concentrations of dissolved nitrogen gas were measured twice a month from April to August 1970 in the lower 200 km of the Snake River and the lower 640 km of the Columbia River. The effects (unusual mortality and symptoms of gas bubble disease) of the concentrations were examined among various populations of juvenile and adult chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*).

METHODS

Dissolved Nitrogen Concentrations

Stations from the forebay of Little Goose Dam to Astoria, Oreg., were reached by aircraft and sampled semimonthly from 7 April to 18 August 1970 (Figure 1 and Table 1). On some trips, the aircraft could not land at all stations because of high winds near some sampling sites. Each set of samples was obtained in a single day, usually on the second and fourth Tuesday of the month. Samples from forebay stations were taken at the surface and at 10 m; samples from tailrace stations were taken at the surface only. Data were collected on dissolved nitrogen, dissolved oxygen, and related water temperatures. The sampling techniques and analytical procedures

were identical to those described by Ebel (1969) and by Beiningen and Ebel (1970). The argon fraction in the air is included in the listed nitrogen data.

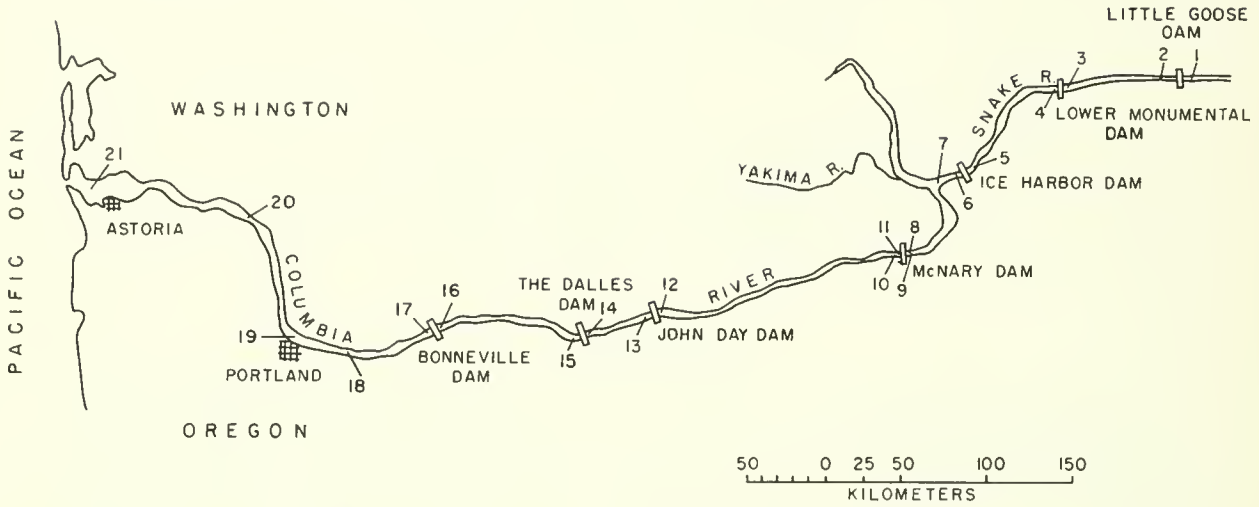

Figure 1.—Location of sampling stations (station code numbers from 1 through 21) on the Columbia and Snake Rivers, 1970.

Table 1.—Location of sampling sites in the Columbia and Snake Rivers; representative sampling sites are shown by number in Figure 1.

Station code number	Sampling site	River kilometers from Columbia River mouth
	Snake River	
1	Little Goose Dam—Forebay	696.1
2	Little Goose Dam—Tailrace	695.1
3	Lower Monumental Dam—Forebay	597.8
4	Lower Monumental Dam—Tailrace (Spillway side)	596.8
5	Ice Harbor Dam—Forebay	538.2
6	Ice Harbor Dam—Tailrace (Spillway side)	537.2
	Columbia River	
7	Columbia River—above Snake River mouth	521.7
8	McNary Dam—Forebay (Spillway side)	470.6
9	McNary Dam—Forebay (Powerhouse side)	470.6
10	McNary Dam—Tailrace (Powerhouse side)	469.6
11	McNary Dam—Tailrace (Spillway side)	469.6
12	John Day Dam—Forebay	347.6
13	John Day Dam—Tailrace (Spillway side)	346.6
14	The Dalles Dam—Forebay	308.8
15	The Dalles Dam—Tailrace (Spillway side)	307.8
16	Bonneville Dam—Forebay	235.7
17	Bonneville Dam—Tailrace (Spillway side)	234.7
18	Columbia River at Washougal	195.9
19	Columbia River above month of Willamette	171.5
20	Columbia River near Prescott	109.0
21	Columbia River at Harrington Point (Astoria)	37.8

Effect of Dissolved Nitrogen on Fish

Wild and hatchery stocks of juvenile fall chinook salmon and wild spring chinook salmon were held in cages at various depths in the forebay of Ice Harbor Dam and were inspected for numbers of dead fish and symptoms of gas bubble disease. Fifty fish were placed in each cage and observed for 7 days. In each of these tests the deep cage, or the enclosure with fish held at 3 to 4 m, was designated as the control cage because at these depths concentrations of dissolved nitrogen up to about 135% of saturation would be compensated for by the hydrostatic pressure. Concentrations of dissolved nitrogen and water temperatures were recorded at the beginning and end of each test. Numbers of survivors with and without gas bubble disease symptoms were also recorded at the termination of each test.

Samples of juvenile chinook salmon and steelhead trout were taken from the gatewell bypass trap at Ice Harbor Dam throughout the migration period and were examined for external symptoms of gas bubble disease. One hundred or more fish were captured for study during each sampling.

Adult chinook salmon were examined at Rapid River Hatchery, Riggins, Idaho, for external symptoms of gas bubble disease. The fish were captured in a trap near the hatchery and were examined before they were moved to the holding pond.

During each aircraft flight for data on dissolved nitrogen concentrations, I also searched along the rivers for dead specimens of adult salmon and trout. Numbers of dead fish and location and date of the sightings were recorded and then related to the concentrations of dissolved nitrogen gas near the dead fish.

RESULTS

Dissolved Nitrogen Concentrations

Concentrations of dissolved nitrogen gas (as well as concentrations of dissolved oxygen and related water temperatures) at sampling sites in the Columbia and Snake Rivers are listed in Table 2. Concentrations in the Columbia were lower in 1970 than in the previous years 1968-69 (Beiningen and Ebel, 1971), except during the peak flow period in the first week of June. For example, concentrations between McNary and Bonneville in early May ranged between 100 and 133% of saturation in 1968, 128 and 144% in 1969, and 96 and 107% in 1970. The Snake River, however, had some extremely high concentrations.

The Snake River was supersaturated with dissolved nitrogen (129% below Little Goose Dam) on the first survey, 7 April. During the next 2 months, concentrations between Little Goose and Ice Harbor Dams increased, reaching a high on 3 June of 146% of saturation in the forebay of Lower Monumental Dam. The concentrations remained high in the river until 21 July when marked reduction was noted. This reduction was no doubt caused by the reduced spill at Little Goose Dam—from about 1,981 cubic meter/second (cms) (70,000 cfs) on 7 July to 368 cms (13,000 cfs) on 21 July. On 18 August (the last survey), levels had returned to normal—near 100%. A comparison of average percentage saturation of dissolved nitrogen gas in the forebay of Lower Monumental Dam with mean daily spill at Little Goose Dam (Figure 2) shows a sharp increase in concentration of dissolved nitrogen from 5 May to 19 May at Lower Monumental as spill volume increased at Little Goose.

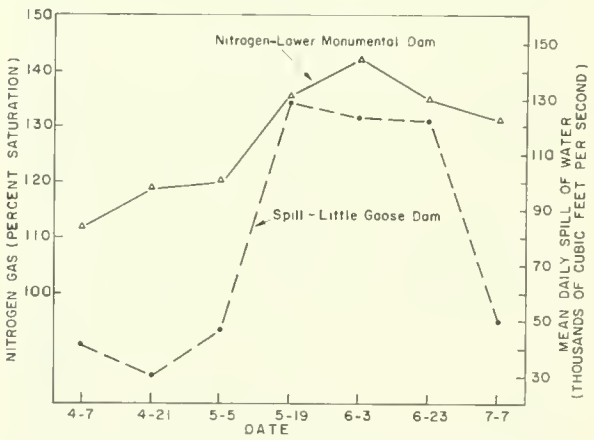

Figure 2.—Average concentration of dissolved nitrogen gas in forebay of Lower Monumental Dam and mean daily spill of water at Little Goose Dam, 7 April to 7 July 1970. (To convert from cubic feet to cubic meters, multiply cubic feet by 0.0283.)

Table 2.—Concentrations of dissolved nitrogen and oxygen gas and related water temperatures in the Columbia and Snake Rivers, 7 April to 18 August 1970.

Date	Station code number	Depth (M)	Temp. °C	Oxygen		Nitrogen	
				Ppm	% Sat.	Ppm	% Sat.
7 April	1	0	8.4	12.0	102.4	18.9	97.9
		10	8.2	11.1	94.2	19.2	99.4
	2	0	8.4	14.9	127.1	24.9	129.4
	3	0	8.6	11.9	102.0	21.2	110.4
		10	8.5	11.7	106.8	21.8	113.5
	4	0	8.6	--	--	--	-- 1/
	5	0	8.6	12.2	105.0	21.0	109.2
		10	8.6	--	--	--	-- 1/
	6	0	8.6	11.9	102.0	21.2	110.2
	7	0	7.2	--	--	--	-- 1/
	8	0	8.0	11.4	96.3	20.6	106.0
		10	7.9	11.1	93.5	20.6	105.7
	9	0	8.0	11.0	92.9	19.2	98.8
		10	7.8	10.8	90.8	19.0	97.3
	10	0	7.9	11.6	98.0	19.9	106.0
	11	0	8.0	11.6	98.0	20.6	106.0
	12	0	8.2	11.7	99.0	19.5	101.0
		10	8.2	11.7	99.3	20.0	103.3
	13	0	8.4	10.9	93.0	19.2	99.6
	14	0	8.2	10.4	87.6	15.8	81.6
		10	8.2	12.0	101.9	19.3	99.8
	15	0	8.3	11.1	94.5	19.8	102.4
	16	0	8.3	11.1	94.5	20.6	106.7
		10	8.2	11.5	97.6	19.5	100.6
	17	0	8.5	11.6	99.1	19.2	99.8
	20	0	8.8	11.3	97.3	19.0	99.3
21 April	1	0	8.1	12.0	101.6	18.7	96.4
		10	8.7	11.4	97.9	19.0	99.2
	2	0	8.9	12.8	110.5	22.1	116.0 2/
	3	0	9.6	14.3	125.7	22.6	120.1
		10	8.6	13.2	112.8	22.7	118.3
	4	0	8.8	15.3	123.2	24.4	127.5
	5	0	10.0	12.8	113.6	22.3	119.5
		10	9.1	13.0	112.6	22.4	118.1
	6	0	9.4	13.2	115.0	22.8	120.5
	7	0	8.0	12.6	106.8	19.6	100.8
	8	0	10.5	13.0	116.7	20.6	111.5
		10	8.8	12.2	105.1	20.0	104.5
	9	0	11.2	13.2	120.5	20.5	107.7
		10	8.9	12.7	109.7	20.6	107.4
	10	0	9.2	12.2	106.2	20.4	107.6
	11	0	9.0	12.2	105.6	20.4	107.1
	12	0	9.2	11.9	103.6	19.4	102.3
		0	8.9	12.1	104.5	20.9	109.6
	13	0	9.0	11.4	98.7	19.0	99.8
	14	0	9.0	11.7	101.3	18.6	97.7
		10	8.8	11.4	98.2	18.6	97.2
	15	0	9.1	11.6	100.7	19.0	100.0
	16	0	9.1	11.6	100.7	18.8	98.9
		10	9.0	10.8	93.5	17.9	94.0
	17	0	9.2	11.4	99.2	19.8	104.3
	20	0	9.6	11.0	96.7	18.2	96.8
	21	0	9.9	11.0	97.3	19.1	99.5
5 May	1	0	12.1	12.5	116.6	18.3	102.2
		10	11.2	11.8	107.8	18.3	100.4
	2	0	10.8	14.2	128.4	24.4	132.8
	3	0	11.4	14.0	128.4	21.7	119.6
		10	10.6	14.1	126.9	22.3	120.6
	4	0	10.7	12.8	115.5	21.2	115.2
	5	0	12.7	13.6	128.7	20.7	116.9
		10	10.8	13.3	120.2	20.7	112.7
	6	0	10.7	12.6	113.7	21.6	117.4
	7	0	11.4	12.6	115.6	19.2	105.8
	8	0	12.0	12.8	119.0	18.2	101.4
		10	11.2	12.6	115.4	19.6	107.5
	9	0	11.7	13.1	121.1	18.6	103.1
		10	10.4	12.6	112.9	19.8	107.0
	10	0	11.0	12.5	113.6	18.1	99.0
	11	0	11.1	12.6	114.7	19.4	106.2
	12	0	10.2	12.9	114.8	18.5	99.5
		10	9.9	12.8	113.3	18.2	97.3
	13	0	10.2	11.6	103.2	18.4	99.0
	14	0	10.6	11.6	104.4	17.8	96.5
		10	10.6	11.7	105.6	18.6	100.9
	15	0	10.7	11.7	105.6	17.7	96.2
	16	0	10.8	12.1	109.4	18.2	99.1
		10	10.8	12.1	109.4	18.3	99.7
	17	0	11.0	11.6	105.4	18.3	100.0
	20	0	11.5	10.9	100.3	17.9	98.8
	21	0	10.2	11.1	98.7	17.5	94.1
19 May	1	0	14.0	10.6	103.3	18.5	107.1
		10	13.2	10.8	103.3	19.0	108.3
	2	0	13.3	13.4	128.5	23.7	135.3
	3	0	13.0	13.7	130.5	24.0	136.4
		10	12.2	13.5	126.2	23.5	134.0
	4	0	12.2	13.5	126.0	23.8	135.7
	5	0	12.0	13.5	125.6	23.5	131.0
		10	11.7	13.4	123.8	22.9	126.9
	6	0	11.8	13.4	124.2	22.6	125.4
	7	0	12.5	11.3	106.2	18.7	107.2
	8	0	13.7	12.0	116.2	18.8	108.2
		10	13.0	11.8	112.4	19.8	112.5
	9	0	14.0	12.7	123.8	20.3	117.5
		10	12.9	12.8	121.7	21.4	116.7
	10	0	13.1	12.2	116.6	19.6	111.5
	11	0	13.6	13.0	126.0	22.3	126.8
	12	0	13.4	11.3	108.6	18.3	104.7
		10	13.4	11.5	110.6	19.5	111.5
	13 3/	0	13.6	12.0	116.0	20.7	119.0
	15	0	13.1	12.1	115.5	20.9	118.9
	16	0	12.5	11.6	109.2	19.3	110.7
		10	12.6	11.8	111.3	19.6	110.5
	17	0	12.8	13.1	124.2	23.7	134.4
	18	0	12.8	11.7	111.1	20.3	114.7
	19	0	13.0	12.1	114.4	19.7	111.9
	20	0	13.5	11.0	106.0	18.5	106.1
	21	0	13.8	10.7	104.0	18.2	105.0
3 June	1	0	14.0	--	--	--	--
		10	12.5	11.2	105.5	19.8	111.3
	2	0	12.6	14.4	135.8	24.8	139.6
	3	0	14.2	15.1	147.7	25.2	146.4
		10	11.6	15.3	141.0	24.8	137.2
	4	0	12.0	14.4	133.9	24.8	138.2
	5	0	13.6	13.9	134.2	23.2	133.3
		10	12.4	13.0	122.1	22.6	127.0
	6	0	12.6	13.6	128.3	22.9	128.8
	7	0	13.9	12.7	123.5	20.4	117.8
	8	0	15.4	12.8	128.6	19.8	117.5
		10	14.0	12.7	123.8	20.7	119.8
	9	0	14.2	12.3	120.4	20.1	116.8
		10	13.4	12.5	120.2	19.9	113.8
	10	0	13.8	12.4	120.3	20.0	115.3
	11	0	14.5	14.4	141.9	22.7	132.5
	12	0	15.0	12.9	128.6	21.5	126.8
		10	14.0	13.0	126.7	21.9	126.7
	13	0	14.6	14.2	140.3	23.6	138.7
	14	0	14.4	13.6	133.7	23.4	136.4
		10	14.2	13.4	131.1	22.9	133.0
	15	0	14.6	13.0	128.5	21.5	125.8
	16	0	14.6	11.9	117.6	19.9	116.4
		10	14.3	12.7	124.6	21.7	126.2
	17 4/	0	14.4	13.2	129.8	23.1	134.4
		0	14.7	12.2	120.8	21.6	123.1
	20	0	15.2	12.1	121.1	20.6	122.0
	21	0	15.5	11.4	114.9	20.4	121.4
23 June	1	0	17.6	9.6	101.3	17.2	104.5
		10	16.8	10.2	105.7	17.0	103.4
	2	0	16.8	13.2	136.8	22.8	137.0
	3	0	17.3	13.0	136.3	22.0	134.9
		10	16.6	13.0	134.2	22.2	134.5
	4	0	16.8	12.9	133.7	22.0	133.8
	5	0	17.1	13.0	135.7	21.2	129.6
		10	16.3	12.4	127.2	20.8	125.4
	6	0	16.1	12.6	128.7	20.8	125.2
	7	0	17.0	11.4	118.6	17.3	105.5
	8	0	18.0	11.5	122.3	18.3	113.6
		10	16.7	10.9	112.7	16.3	98.9
	9	0	18.0	11.5	122.3	18.0	111.7
		10	16.2	10.9	111.6	17.2	103.5
	10	0	16.2	12.0	122.8	19.6	118.0
	11	0	17.0	12.9	134.2	22.2	135.4
	12	0	17.4	13.6	142.8	20.4	125.3
		10	16.6	13.0	134.2	20.4	123.6
	13	0	16.8	12.4	128.5	21.6	131.4
	14	0	16.4	12.1	124.4	19.6	118.4
		10	16.4	12.6	129.5	20.4	123.0
	15	0	16.4	11.9	122.3	19.2	116.0
	16	0	16.3	11.1	113.8	19.0	114.5
		10	16.4	11.1	114.0	17.9	108.2
	17	0	16.4	12.5	128.5	22.4	135.3
	18	0	16.5	11.9	122.5	21.0	123.9
	19	0	16.4	11.7	120.2	18.1	109.4
	20	0	16.8	11.0	114.0	17.4	105.8
	21	0	16.9	11.0	114.2	18.0	109.7
7 July	1	0	22.4	9.6	111.9	15.5	104.9
		10	19.7	9.3	102.4	15.7	100.1
	2	0	19.6	12.9	136.3	22.5	143.5
	3	0	20.2	12.0	133.6	20.9	134.4
		10	18.0	11.6	123.4	20.5	127.3
	4	0	17.9	12.2	130.6	21.9	135.7
	5	0	19.4	12.0	127.4	21.1	130.7
		10	17.9	12.5	136.9	21.7	137.8
	6	0	17.7	12.3	129.0	21.5	130.4
	7	0	18.6	11.2	120.6	18.3	114.7
	8	0	22.4	11.4	132.6	17.6	116.9
		10	19.4	11.3	123.8	18.4	112.3
	9	0	22.6	11.4	133.2	17.6	117.3
		10	18.7	11.2	120.8	19.3	121.2
	10	0	19.0	10.8	118.3	17.5	110.4
	11	0	19.6	11.8	136.3	19.3	122.9
	12	0	19.8	11.0	121.4	17.9	114.4
		10	18.6	11.0	118.4	18.4	115.4
	13	0	18.8	10.5	113.5	--	--
	14	0	18.6	10.5	113.0	17.9	112.2
		10	18.6	10.7	115.2	17.8	110.2
	15	0	18.8	10.8	108.6	18.8	118.2
	16	0	18.2	10.1	107.9	16.6	103.4
		10	18.2	10.1	107.9	17.2	107.1
	17	0	18.4	11.5	125.8	19.3	126.0
	18	0	18.9	10.3	114.0	16.9	108.2
	19	0	18.9	10.5	112.7	17.7	111.5
	20	0	19.2	9.8	108.0	16.6	105.1
	21	0	19.3	10.4	111.5	17.0	107.7
21 July	1	0	21.1	8.3	94.1	15.4	100.5
		10	21.1	9.5	107.7	17.6	114.7
	2	0	20.9	9.4	106.1	16.7	109.1
	3	0	21.4	9.2	104.9	16.2	104.9
		10	21.4	9.6	109.5	17.0	109.5
	4	0	21.3	8.8	100.1	15.6	100.1

Table 2.—Concentrations of dissolved nitrogen and oxygen gas and related water temperatures in the Columbia and Snake Rivers, 7 April to 18 August 1970.—Continued

Date	Station code number	Depth (M)	Temp. °C	Oxygen Ppm	Oxygen % Sat.	Nitrogen Ppm	Nitrogen % Sat.
	5	0	21.0	8.4	96.8	15.2	96.8
		10	22.0	7.6	87.7	15.3	87.7
	6	0	21.6	9.6	109.8	16.9	109.8
	7	0	19.4	10.6	116.1	15.7	99.7
	8	0	21.0	9.6	108.6	15.6	101.6
		10	20.7	9.8	110.1	16.3	105.6
	9	0	21.4	9.6	109.5	15.6	102.1
		10	21.0	9.6	108.6	15.7	102.2
	10	0	20.8	9.8	110.4	15.7	102.4
	11	0	20.8	9.8	110.4	15.0	97.3
	13	0	20.2	8.9	99.1	15.4	99.0
	15	0	19.9	9.2	101.8	15.7	100.5
	16	0	19.7	8.8	97.0	15.1	96.3
		10	19.7	10.0	110.1	15.3	97.6
	17	0	19.8	10.9	120.3	16.8	107.3
	18	0	19.7	9.6	105.7	16.1	102.8
	19	0	20.0	9.2	102.0	15.8	101.3
	20	0	20.4	9.2	102.8	15.6	100.6
	21	0	20.3	8.5	94.8	15.7	101.1
6 August	1	0	23.1	8.7	102.9	14.7	99.0
		10	21.9	8.0	92.2	15.3	100.9
	2	0	21.9	10.2	117.3	18.1	119.3
	3	0	23.1	9.2	108.5	16.3	109.4
		10	22.0	9.3	107.3	16.5	109.0
	4	0	22.1	8.4	97.6	16.2	107.2
	5	0	23.3	9.3	110.1	15.6	105.1
		10	22.2	8.4	97.3	15.7	104.0
	6	0	22.2	7.9	91.5	14.6	96.8
	7	0	19.8	10.3	113.6	16.3	104.2
	8	0	21.6	10.6	121.3	15.9	104.4
		10	20.5	9.9	110.9	17.1	110.4
	9	0	21.9	10.9	125.6	16.5	108.8
		10	20.3	9.5	105.9	16.5	106.2
	10	0	20.6	9.7	108.4	16.9	109.3
	11	0	21.0	10.0	112.9	15.7	102.2
	12	0	20.6	8.7	97.6	16.1	104.1
		10	20.4	8.5	95.0	16.1	103.8
	13	0	20.6	8.2	92.5	16.3	105.4
	14	0	20.3	8.7	97.0	15.6	100.5
		10	20.3	8.8	98.1	16.2	104.3
	15	0	20.4	8.6	96.5	17.0	109.6
	16	0	20.3	9.0	100.3	15.9	102.4
		10	20.3	9.0	100.3	16.1	103.7
	17	0	20.4	10.9	121.8	18.7	120.3
	20	0	20.5	8.4	94.2	16.3	105.0
	21	0	19.9	8.2	90.3	16.4	104.9
18 August	1	0	22.6	7.7	90.0	14.4	95.7
		10	22.3	6.8	79.0	13.9	92.2
	2	0	22.5	8.5	99.1	15.5	103.1
	3	0	22.4	7.7	91.3	14.8	99.7
		10	22.1	7.5	86.7	15.6	102.9
	4	0	22.2	6.9	80.2	13.7	90.8
	5	0	23.4	8.7	103.2	14.7	99.1
		10	22.3	8.6	99.8	16.3	108.1
	6	0	22.3	8.0	92.9	14.7	97.5
	7	0	20.1	9.9	110.3	16.8	107.8
	8	0	22.3	9.8	113.7	15.2	100.5
		10	20.9	10.1	114.0	16.7	108.2
	9	0	22.0	9.2	106.1	14.4	95.1
	10	0	20.8	9.3	104.2	16.5	107.1
	11	0	21.0	9.4	106.3	15.4	100.3
	12	0	21.3	8.3	94.4	15.8	103.3
		10	20.8	8.1	91.2	15.5	100.6
	13	0	20.9	8.0	90.3	16.0	103.6
	14	0	20.2	8.6	95.8	16.0	102.9
		10	20.2	8.7	96.9	16.5	106.1
	15	0	20.1	8.4	92.9	15.2	97.8
	16	0	19.2	9.2	100.3	16.8	106.3
		10	19.5	8.4	92.1	14.3	90.9
	17	0	19.6	9.1	100.0	15.9	101.0
	18	0	19.5	9.1	99.8	15.4	97.9
	19	0	18.8	9.1	100.4	15.3	97.8
	20	0	20.2	8.7	96.9	15.4	96.5
	21	0	20.0	8.3	92.0	14.9	95.2

1/ Sample bottles were broken before data were obtained.
2/ Combination spillway and fishway water.
3/ Sampled in shallow water near shore due to high winds.
4/ Sampled near Corbett, Oreg., about 203 km from Columbia River mouth.

Effect of Dissolved Nitrogen on Fish

Various populations of juvenile and adult salmon and trout were examined in 1970 for mortality and symptoms of gas bubble disease that resulted—directly or indirectly—from supersaturation of dissolved nitrogen in the Snake and Columbia Rivers.

There were substantial mortalities due to supersaturation of nitrogen among stocks of juvenile chinook salmon held in cages at various depths near Ice Harbor Dam (Tables 3 through 6). I believe that data from the 0-4.5 m cage are probably most representative of what may have happened to migrating juvenile fish because the caged fish could sound at their volition to 4.5 m. Mortalities in the 0-4.5 m cage ranged between 45 and 68% from late May to early July.

Examination of juvenile migrants taken in gatewells at Ice Harbor indicated that 25 to 45% of the chinook salmon and 30 to 58% of the steelhead trout had symptoms of gas bubble

Table 3.—Mortality of juvenile spring chinook salmon of wild (native) origin held in cages at various depths in the forebay of Ice Harbor Dam, 21-28 May 1970.[1]

Holding time	Cage depth (m) and mortality (%)				
	Surface	.75-1.0 m	1.5-2.0 m	3.0-4.0 m (control)	0-4.5 m
24 hours	60	No test	No test	--	--
48 hours	92	" "	" "	--	--
7 days	100	" "	" "	[2]6	[3]45

[1] Water temperature was 11.9° C and dissolved nitrogen concentration was 127% of saturation at start of test; water temperature was 12.4° C and dissolved nitrogen concentration was 127% of saturation at end of test.
[2] 17% of survivors had symptoms of gas bubble disease.
[3] 94% of survivors had symptoms of gas bubble disease.

Table 4.—Mortality of juvenile fall chinook salmon of hatchery (Wahkeena Pond) origin held in cages at various depths in the forebay of Ice Harbor Dam, 4-11 June 1970.[1]

Holding time	Cage depth (m) and mortality (%)				
	Surface	.75-1.0 m	1.5-2.0 m	3.0-4.0 m (control)	0-4.5 m
24 hours	98	64	--	--	--
48 hours	98	98	--	--	--
7 days	100	100	[2]40	[3]2	[4]68

[1] Water temperature was 12.4° C and dissolved nitrogen concentration was 127% of saturation at start of test; water temperature was 13.8° C and dissolved nitrogen concentration was 132% of saturation at end of test.
[2] 97% of survivors had symptoms of gas bubble disease.
[3] 92% of survivors had symptoms of gas bubble disease.
[4] 100% of survivors had symptoms of gas bubble disease.

Table 5.—Mortality of juvenile fall chinook salmon of wild (native) origin held in cages at various depths in the forebay of Ice Harbor Dam, 15-22 June 1970.[1]

Holding time	Cage depth (m) and mortality (%)				
	Surface	.75-1.0 m	1.5-2.0 m	3.0-4.0 m (control)	0-4.5 m
24 hours	58	74	--	--	--
48 hours	82	86	--	--	--
7 days	100	100	[2]86	[3]2	[4]50

[1] Water temperature was 13.8° C and dissolved nitrogen concentration was 132% of saturation at start of test; water temperature was 15.8° C and dissolved nitrogen concentration was 127% of saturation at end of test.
[2] 69% of survivors had symptoms of gas bubble disease.
[3] 25% of survivors had symptoms of gas bubble disease.
[4] 88% of survivors had symptoms of gas bubble disease.

Table 6.—Mortality of juvenile fall chinook salmon of wild (native) origin held in cages at various depths in the forebay of Ice Harbor Dam, 24 June-2 July 1970.[1]

Holding time	Cage depth (m) and mortality (%)				
	Surface	.75-1.0 m	1.5-2.0 m	3.0-4.0 m (control)	0-4.5 m
24 hours	100	100	--	--	--
48 hours	--	--	--	--	--
7 days	--	--	34	[2]38	[3]56

[1] Water temperature was 17.1° C and dissolved nitrogen concentration was 127% of saturation at start of test; water temperature was 19.4° C and dissolved nitrogen concentration was 134% of saturation at end of test.
[2] Survivors had no symptoms of gas bubble disease.
[3] 12% of survivors had symptoms of gas bubble disease.

disease. Population estimates made by Raymond (1971)[1] of juvenile chinook in the Salmon River at Whitebird, Idaho, and those arriving at Ice Harbor Dam indicated that about 70% of the migrating chinook were lost between these points. A similar estimate for steelhead from Dworshak Hatchery indicated a 15% loss to Ice Harbor Dam and about a 90% loss to McNary Dam. These independent observations of the effect of supersaturation of nitrogen gas on juvenile migrant chinook and steelhead and the estimate of losses recorded by Raymond clearly indicated that substantial losses of juvenile steelhead and chinook migrants resulted from supersaturation of dissolved nitrogen in the Snake River.

Less data are available to determine the effect of dissolved nitrogen on adult fish than are available for juvenile fish. Examination of adult chinook at Rapid River Hatchery showed that after 6 July about 30% of the arriving fish had symptoms of gas bubble disease. Searches along the Columbia and Snake Rivers for dead salmon and steelhead during each sampling survey indicated no significant mortality until 7 July. On that date, 27 dead adult chinook were counted between Little Goose and Lower Monumental Dams on the Snake River. Although most of the fish were too decomposed to observe symptoms, symptoms of gas bubble disease on three of the fish and high nitrogen concentrations in the river led me to believe gas bubble disease was the primary cause of the mortality. Apparently there was considerable delay between the time these fish were subjected to high levels of nitrogen gas and the time that the mortalities were found. Concentrations of nitrogen gas were high in the Snake River in early April but did not become high in the Columbia until early June. The appearance of mortalities in early July was probably caused by the additional exposure of the later migrating fish to high concentrations in both the Snake and Columbia Rivers. These limited observations cannot measure the extent of the losses to adult migrants. However, a more comprehensive study (Mallet et al., 1971) indicated that 45% of the adult spring chinook in the Snake River were lost before they spawned and that the loss was caused by the delayed effects from exposure to supersaturation of nitrogen gas.

[1] Raymond, H. L. 1971. Survival and timing of the 1970 and 1971 migration of juvenile chinook salmon and steelhead trout from the Snake River. Natl. Mar. Fish. Serv., Biol. Lab., Seattle, Wash. (Unpublished manuscript.)

LITERATURE CITED

BEININGEN, K. T., and W. J. EBEL.
1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Trans. Am. Fish. Soc. 99: 664-671.
1971. Supersaturation of dissolved nitrogen in the Columbia and lower Snake Rivers, 1965-69. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish.

Serv., Data Rep. 56, 60 p. on 2 microfiche.

EBEL, W. J.

1969. Supersaturation of nitrogen in the Columbia River and its effect on salmon and steelhead trout. U.S. Fish Wildl. Serv., Fish. Bull. 68: 1-11.

MALLET, J., T. HOLUBETZ, and D. CORLEY.

1971. Idaho salmon and steelhead status report for 1970. State of Idaho Fish and Game Dep., Boise, Idaho, 13 p. [Processed.]

GPO 999-493

salmon (models I and II), by Daniel W. Bates and John G. Vanderwalker, pp. 1-5, 6 figs., 1 table; 2d paper, Design and operation of a cantilevered traveling fish screen (model V), by Daniel W. Bates, Ernest W. Murphey, and Earl F. Prentice, 10 figs., 1 table.

609. Annotated bibliography of zooplankton sampling devices. By Jack W. Jossi. July 1970, iii + 90 pp.

610. Limnological study of lower Columbia River, 1967-68. By Shirley M. Clark and George R. Snyder. July 1970, iii + 14 pp., 15 figs., 11 tables.

611. Laboratory tests of an electrical barrier for controlling predation by northern squawfish. By Galen H. Maxfield, Robert H. Lander, and Charles D. Volz. July 1970, iii + 8 pp., 4 figs., 5 tables.

612. The Trade Wind Zone Oceanography Pilot Study. Part VIII: Sea-level meteorological properties and heat exchange processes, July 1963 to June 1965. By Gunter R. Seckel. June 1970, iv + 129 pp., 6 figs., 8 tables.

613. Sea-bottom photographs and macrobenthos collections from the Continental Shelf off Massachusetts. By Roland L. Wigley and Roger B. Theroux. August 1970, iii + 12 pp., 8 figs., 2 tables.

614. A sled-mounted suction sampler for benthic organisms. By Donald M. Allen and J. Harold Hudson. August 1970, iii + 5 pp., 5 figs., 1 table.

615. Distribution of fishing effort and catches of skipjack tuna, *Katsuwonus pelamis*, in Hawaiian waters, by quarters of the year, 1948-65. By Richard N. Uchida. June 1970, iv + 37 pp., 6 figs., 22 tables.

616. Effect of quality of the spawning bed on growth and development of pink salmon embryos and alevins. By Ralph A. Wells and William J. McNeil. August 1970, iii + 6 pp., 4 tables.

617. Fur seal investigations, 1968. By NMFS, Marine Mammal Biological Laboratory. December 1970, iii + 69 pp., 68 tables.

618. Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River Basin - past and present. By Leonard A. Fulton. December 1970, iii + 37 pp., 6 figs., 11 maps, 9 tables.

619. Macrozooplankton and small nekton in the coastal waters off Vancouver Island (Canada) and Washington, spring and fall of 1963. By Donald S. Day, January 1971, iii + 94 pp., 19 figs., 13 tables.

620. The Trade Wind Zone Oceanography Pilot Study. Part IX: The sea-level wind field and wind stress values, July 1963 to June 1965. By Gunter R. Seckel. June 1970, iii + 66 pp., 5 figs.

621. Predation by sculpins on fall chinook salmon, *Oncorhynchus tshawytscha*, fry of hatchery origin. By Benjamin G. Patten. February 1971, iii + 14 pp., 6 figs., 9 tables.

622. Number and lengths, by season, of fishes caught with an otter trawl near Woods Hole, Massachusetts, September 1961 to December 1962. By F. E. Lux and F. E. Nichy. February 1971, iii + 15 pp., 3 figs., 19 tables.

623. Apparent abundance, distribution, and migrations of albacore, *Thunnus alalunga*, on the North Pacific longline grounds. By Brian J. Rothschild and Marian Y. Y. Yong. September 1970, v + 37 pp., 19 figs., 5 tables.

624. Influence of mechanical processing on the quality and yield of bay scallop meats. By N. B. Webb and F. B. Thomas. April 1971, iii + 11 pp., 9 figs., 3 tables.

625. Distribution of salmon and related oceanographic features in the North Pacific Ocean, spring 1968. By Robert R. French, Richard G. Bakkala, Masanao Osako, and Jun Ito. March 1971, iii + 22 pp., 19 figs., 3 tables.

626. Commercial fishery and biology of the freshwater shrimp, *Macrobrachium*, in the Lower St. Paul River, Liberia, 1952-53. By George C. Miller. February 1971, iii + 13 pp., 8 figs., 7 tables.

629. Analysis of the operations of seven Hawaiian skipjack tuna fishing vessels, June-August 1967. By Richard N. Uchida and Ray F. Sumida. March 1971, v + 25 pp., 14 figs., 21 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - 35 cents.

633. Blueing of processed crab meat. II. Identification of some factors involved in the blue discoloration of canned crab meat (*Callinectes sapidus*). By Melvin E. Waters. May 1971, iii + 7 pp., 1 fig., 3 tables.

636. Oil pollution on Wake Island from the tanker *R. C. Stoner*. By Reginald M. Gooding. May 1971, iii + 12 pp., 8 figs., 2 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 25 cents.

UNITED STATES
DEPARTMENT OF COMMERCE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE
SCIENTIFIC PUBLICATIONS STAFF
BLDG. 67, NAVAL SUPPORT ACTIVITY
SEATTLE, WASHINGTON 98115

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE