Age, Growth, Food, and Yield of the White Sturgeon (*Acipenser transmontanus*) of the Fraser River, British Columbia[1,2]

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ABSTRACT

For white sturgeon taken incidentally in the salmon gillnet fishery in the Fraser River during the summer of 1962, pectoral fin ray sections indicated that over three-quarters were fish aged 9–16 years. Gillnets for salmon apparently select sturgeon over a size range between 30 and 60 inches. Back-calculation of size attained at previous ages indicated that after attaining a length close to 20 inches by age 5, the sturgeon grow about 2 inches per year to about age 25. Limited data from pectoral fin ray sections suggest that age at first spawning is from 11 to 22 years for males, and from 11 to 34 for females. Subsequent spawning is apparently at intervals of 4–9 years. Fraser River sturgeon are more piscivorous than has been recorded for white sturgeon and other sturgeon species elsewhere, about one-half of the stomachs containing fish, especially eulachons. The age distribution in the catch, though biased by selection, was used to estimate rates of natural and fishing mortality. The eumetric fishing curve suggests that present yield could be increased by a greater size at first capture, particularly if the natural mortality rate is as low as 0.05. The history of the sturgeon fishery suggest that sustainable yield could exceed 100,000 lb per year. The commercial landings in recent years average 30,000–40,000 lb. The sport fishery may take an additional 20,000–30,000 lb. Sustained yield in the circumstances of the present fishery could be 80,000 lb per year, about 25% more than the present catch. Some recommendations are made for management, stressing the importance of protection of an annual spawning population of 300–600 females.

INTRODUCTION

The present study attempts primarily to determine age distribution and growth rate in the Fraser River white sturgeon and relates the findings to the historical record of catch. Most of the material was obtained from 250 specimens caught incidentally by salmon fishermen in the lower part of the Fraser River, below Langley, during the period May 1–October 28, 1962. Twenty-two specimens below the legal size of 36 inches were gillnetted at Dewdney Slough, a backwater of the Fraser near Mission City.

METHODS OF AGEING AND BACK-CALCULATION OF GROWTH

Age determinations were made from transverse sections (Fig. 1) of thoroughly dried first pectoral fin rays. The sections were cut using a two-bladed

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saw and were between 0.3 and 0.5 mm thick. These were mounted in glycerine and examined with a binocular microscope. The validity of age determinations by this method is discussed by several authors including Cuerrier (1951), Probst and Cooper (1954), Roussow (1957), and Sunde (MS, 1961).

Sunde (1961) reported the progressive loss of annuli when pectoral fin ray sections are taken at increasing distances from the base. In the present study most sections taken ¼ inch from the base were difficult to read. This area coincides with the notched part of the ray, where the annuli tend to fuse. Sections taken ½ inch from the base were, except in one instance, readable, whereas sections at ¾ inch showed some loss of annuli. Accordingly, sections were taken ½ inch from the base of the fin ray and as close as ¼ inch for fish smaller than 20 inches.

For back-calculation of lengths at previous ages each fin ray section was mounted in glycerine and its image projected, and each annulus was marked at its point of sharp curvature on the ventral radial axis of the arrow-shaped section (Fig. 1). Two series of measurements of each image were taken: (1) the distances along the *curved* line from the centre of the fin ray to the various points of curvature of the annuli; and (2) the distances along the *straight* line from the centre of the fin ray to the point of curvature of the annulus at the periphery (Fig. 1). The relation between each of these fin ray measurements in arbitrary units (x) and fork lengths in inches (y) was apparently linear (Fig. 2 and 3) and the corresponding regression equations were:

$$y = 0.9 + 9.5x \text{ (curved line measurement)}$$

$$y = -3.1 + 10.2x \text{ (straight line measurement).}$$

In each case the correlation coefficient was approximately 0.9 and, there being no basis for choice of the one method, arbitrarily the curved measurement was used in constructing a nomograph for back-calculation. The nomograph procedure assumed that the intercept was constant and the slope variable.

Ages at spawning were assigned on the basis that zones of crowding of annuli reflect the diversion of energy to sex products, the last annulus of a crowded zone corresponding to the age of spawning (Roussow, 1957).

AGE DISTRIBUTION

The sturgeon ranged in age from 7 to 71 years and up to 91 inches in total length. Over three-quarters of the catch were fish from 9 to 16 years of age (Table I) probably reflecting, at least in some measure, a size selection by the limited range of meshes in the salmon gillnets. From February 1 to July 1, all mesh sizes are permitted but after May 1, when the sampling started, 8-inch mesh nylon nets are probably the most common used. During July, August, and early September, large mesh nets are usually replaced with smaller mesh in times of the week when fishing for sockeye salmon is permitted. The range of mesh sizes in common use is thus from 5 to 8 inches. The smaller mesh catches some sturgeon smaller than the legal limit of 36 inches but apparently

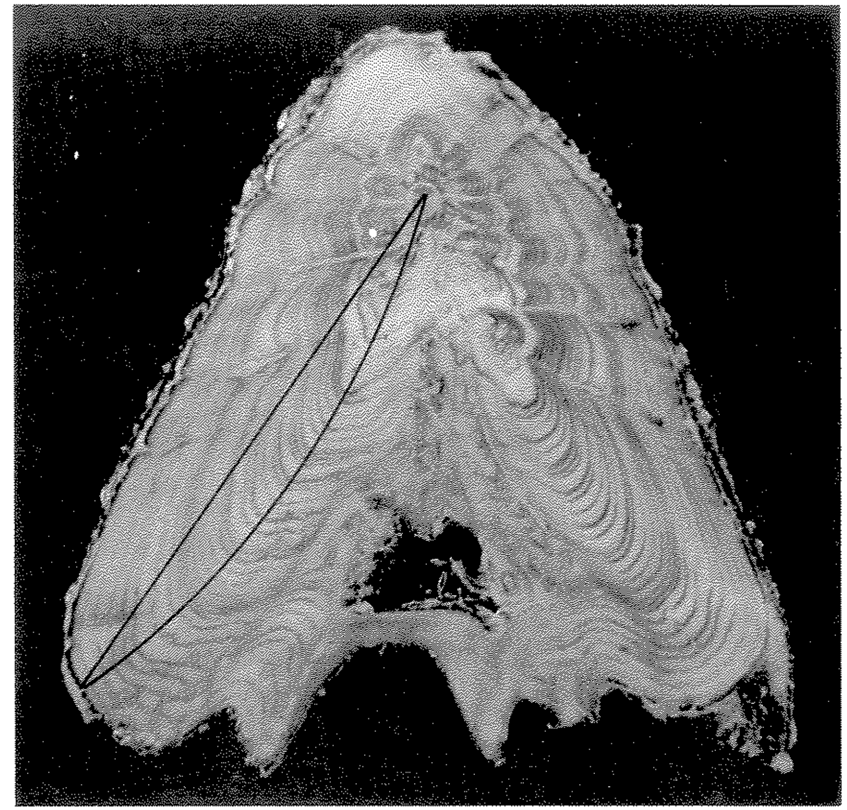

FIG. 1. Cross section of first pectoral fin ray, one-half inch from base, of Fraser River white sturgeon. The superimposed lines from the centre to the periphery are the lines along which radial measurements were made for back-calculations.

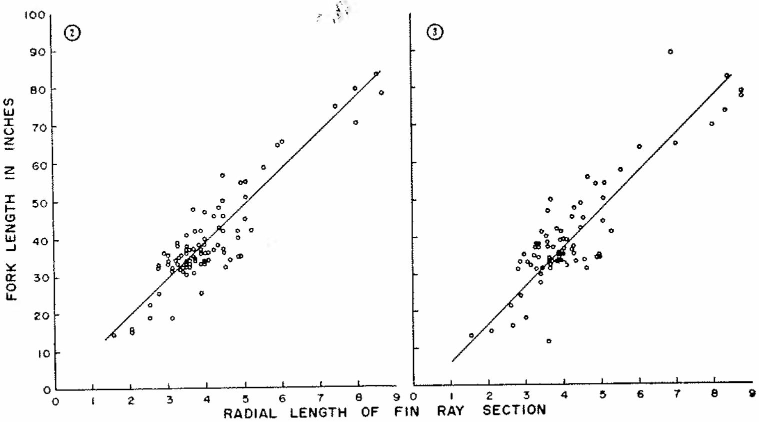

FIG. 2. Fork length in relation to length of the radius of the pectoral fin ray section as measured along a curved line (Fig. 1).

FIG. 3. Fork length in relation to length of the radius of the pectoral fin ray section as measured along a straight line (Fig. 1).

TABLE I. Age and length distribution of white sturgeon caught incidentally in the Fraser River gillnet fishery for salmon in 1962.

Age	No.	Approx length range (*inches*)	Age	No.	Approx length range (*inches*)
7	1	31	19	7	40–55
8	6	29–34	20	4	40–57
9	10	18.5–36	21	0	–
10	20	18–41	22	2 }	
11	31	30–51.5	23	3 }	40–62
12	22	31–48	24	2 }	
13	28	31–43	25	0	
14	14	30.5–51	26–30	1 }	
15	9	33–48.5	31–35	3 }	47–91
16	15	34–50	36–40	2 }	
17	2	32–36	41–50	1 }	
18	4	41–48	> 50	3	79–89

takes fish less than 30 inches only rarely. Large sturgeon may become "rolled" in the gillnets, regardless of the mesh size, but those over 60 inches, if they are available for capture by the salmon fishery, are probably too large for the gear. Hence, the age distribution in the catch is probably not an adequate indicator of age distribution in the population.

This selection may also account for the apparently disproportionate catch of young fish which seem to be relatively large for their age, and of old fish which are relatively small for their age. Thus the largest 10-year-old was larger than the smallest of age 23, and the largest 11-year-old was larger than any other fish under 19 years old in the sample. The upper limit of the effectiveness of the gear is in the range of 50–60 inches.

GROWTH IN LENGTH AND WEIGHT

Growth, as indicated by length at age of capture (Fig. 4), is rapid up to the 10th year, then slows through the 11th–20th years, after which it is again rapid with an apparent decline after about age 35. This apparent pattern is probably related to the selective effect of the gillnet fishery in which the faster-growing younger fish and the slower-growing older fish are over-represented. The period of slower growth in the 10th–20th years is not as apparent in the growth curves based on back-calculated lengths (Fig. 5), the averaging procedure apparently combining the slower-growing older fish and the faster-growing younger fish to suggest a relatively uniform growth rate of about 2 inches a year from age 5 to age 18 for both sexes.

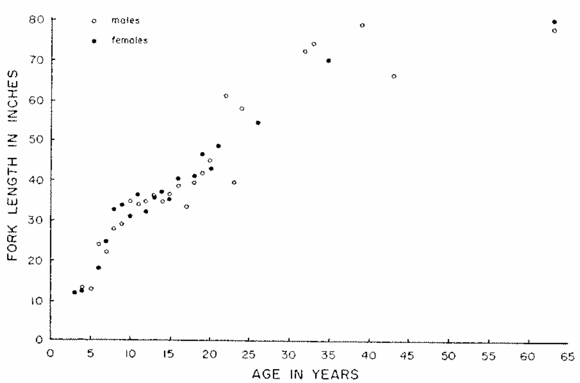

FIG. 4. Mean fork length at capture in relation to age at capture for male and female Fraser River white sturgeon.

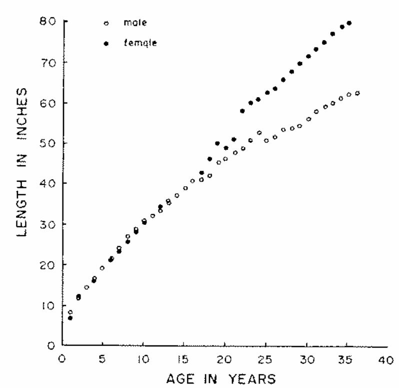

FIG. 5. Mean fork length in relation to age for males up to age 35 and females up to age 36 as indicated by back-calculated lengths.

There is some variability in the size attained at various ages by different year-classes. For example, males and females of the 1949 year-class were larger at all ages after the 5th year than those of the 1950 year-class (Table II). However, there was no suggestion of sequences of good or bad calendar years for growth, nor even the indication that all year-classes grew at comparable rates in the same years. Presumably the differences observed are largely fortuitous.

The relation between round weight in pounds (W) and fork length in inches (L) for all of the sturgeon taken in the Fraser commercial catch, together with small sturgeon taken in Dewdney Slough, is given by:

$$\log_e W = -8.73 + 3.13 \log_e L \text{ (males)}$$
$$\log_e W = -8.79 + 3.15 \log_e L \text{ (females).}$$

TABLE II. Fork lengths (inches) at various ages of male and female sturgeon of the 1949 and 1950 year-classes.

Age (*years*)	Females 1949	Females 1950	Males 1949	Males 1950
1	9	10	7	7
2	11	12	11	11
3	13	15	14	13
4	15	16	19	15
5	19	18	21	19
6	21	20	23	21
7	23	21	25	23
8	25	23	28	24
9	29	27	30	25
10	32	29	31	27
11	33	32	33	30
12	36	35	35	32
13	39	–	39	–

This series of observations (Fig. 6) was made chiefly on immature sturgeon of less than age 20 and the similarity of the length–weight relationships of the sexes may not be characteristic of mature specimens, particularly females. Older mature females develop substantial egg masses which may contribute to greater weight than that for males. For example, one specimen reported by a fisherman was 12 ft long, weighed 825 lb, and contained 200 lb of caviar.

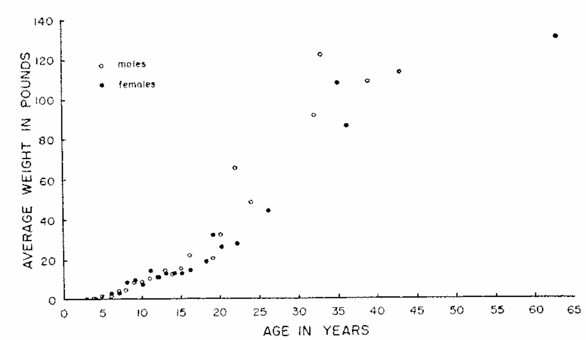

FIG. 6. Mean weight at capture in pounds in relation to age for Fraser River white sturgeon.

AGE AT FIRST SPAWNING AND INTERVALS BETWEEN SPAWNINGS

Sturgeon taken in the commercial catch were routinely examined for spawning condition, mature individuals being distinguishable by the degree of development and differentiation of the gonads. Fifteen of the male specimens were considered as mature, and of these 9, with ages ranging from 11 to 24 years, showed no growth history that suggested a previous spawning. This would suggest that age at first spawning is very variable, perhaps in part related to the variability in growth rate. For the six males with a growth history that suggested previous spawnings, the first spawnings occurred after 3 years of slow growth sometime between age 11 and 22, the second spawnings (5 specimens) at age 16–17, and the third (3 specimens) at age 22–33. The interval between spawning averaged slightly less than 7 years, and ranged from 4 to 11 years.

The 17 mature females in the catch included 11 that had no apparent previous spawning and ranged in age from 11 to 22 years. The age at first spawning for the remaining six specimens ranged from age 26 to 34, with from 6 to 8 years of slow growth involved in the spawning check. Only one specimen clearly suggested a history of repeated spawnings with slow growth periods at ages 25–33, 36–40, and 46–49.

The limited data suggest that the age at first spawning varies considerably, but occurs at an earlier age in males. Additional spawning is also variable, occurring at intervals of 4–9 years, the males exhibiting 2–5 years and the females 3–8 years of slow growth prior to spawning. The observations of Magnin (1966a) suggest that these estimates may be correct for females but misleading for males. Magnin reports that males spawn every 2 years—more frequently than is suggested by the fin ray sections.

Compared with other species of sturgeons, those of the Fraser appear to reach maturity at a relatively advanced age. Roussow (1957) summarizes ages at first spawning reported for six species of sturgeon, all of which are at 14 years or less for males, and generally less than 20 years for females. *Acipenser fulvescens* is reported by Cuerrier (MS, 1949) as first spawning at age 14 for males and 23 for females, and by Magnin (1966b) at age 18–20 for males and 20–23 for females. Pycha (1956) suggests maturity of Columbia River white sturgeon at 11 or 12 years for females, much younger than for the Fraser River population.

FOOD

Stomach contents of fish taken in the period May–October 1962 suggest that sturgeon take a wide range of foods. In May, eulachons (*Thaleichthys pacificus*) were the main food item. Presumably at least some of the eulachons had died after spawning and had been scavenged from the bottom. According to local fishermen, it is common for sturgeon to contain eulachons in the spring months to the extent that the buyers of sturgeon deduct 2 lb from the weight of ungutted fish as a "eulachon allowance."

Fish occurred in 43 of a total of 88 stomachs which contained food. In addition to eulachons, they included, in order of abundance, sculpins (*Cottus* spp.), sticklebacks (*Gasterosteus aculeatus*), lampreys (Petromyzontidae), and, in one stomach, a young sturgeon. Fish were more commonly found in the stomachs of larger sturgeon. Fraser River sturgeon are apparently more piscivorous than has been recorded for *Acipenser* elsewhere (Harkness, 1923; Probst and Cooper, 1954).

Of the invertebrates taken as food, chironomid larvae were the most abundant and were recorded in 31 stomachs from sturgeon of all sizes. Crayfish (*Pacifastacus* sp.), stonefly larvae, and a few Ephemeroptera larvae, mysids, *Daphnia* spp., and freshwater copepods were other items recorded. Many stomachs contained plant material, some of it green and apparently from aquatic plants, but in several instances the plant debris was bark or pieces of wood. It seems likely that the plant material was largely taken incidentally.

MORTALITY RATES AND YIELD

Assuming constant recruitment, the age distribution in the commercial catch, though biased by the selection of the gillnets, may be used to give a first approximation of mortality rates of Fraser River sturgeon. Ignoring the age-groups on the left-hand limb of the catch curve as incompletely recruited, Fig. 7 suggests an instantaneous total mortality rate (F + M) of fish under

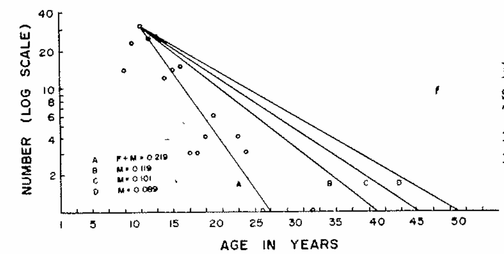

FIG. 7. Catch curve for Fraser River white sturgeon taken in the salmon fishery in 1962. The slope of line A gives the total instantaneous mortality rate; those of lines, B, C, and D, the natural mortalities with life expectancies respectively of 40, 45, and 50 years.

age 25 of 0.219, corresponding to an annual loss of 19.7% percent (line A). As the older age-groups are probably progressively less well represented in the catch because of the selectivity of the gear, this is almost certainly too high as an estimate of total mortality.

Expressing natural mortality in the conventional way as

$$N_{t_2} = N_{t_1}e^{-M(t_2-t_1)}$$

then the survival of one fish at t_2 from a cohort of 31 at age 11 may be associated with various rates of natural mortality. With a reduction of this magnitude by age 40 the natural mortality rate (M) would be 0.119 (line B, Fig. 7); by age 45, M = 0.101 (line C); by age 50, M = 0.089 (line C). Fish of age 50 and over, even though poorly represented in the catch, are nevertheless present, and from what is known of sturgeon, life expectancies of 80 years are not uncommon in virgin stocks. With M = 0.089 the proportion of 11-year-olds surviving to age 80 is only 0.22%. Accordingly, all of these estimates of natural mortality are probably too high. A reduction of a cohort of 31 at age 11 to a single individual at age 80 corresponds to a natural mortality rate of M = 0.05, and the proportion of 11-year-olds surviving to age 80 is 3.2%. For M = 0.05 the implied fishing mortality rate (F) is 0.169 because the total mortality rate (F + M) is 0.219.

All of these estimates are, of course, only very approximate and are biased by the inadequate representation of fish older than age 25 that are largely unavailable to the commercial salmon fishery. Nevertheless, they may be used as a basis for a projection of what yield might be from the *present* type of fishery. To estimate yield per recruitment, Ricker-type yield tables were constructed using instantaneous growth rates at various ages (*g*) based on the back-calculated data of Fig. 5. Fish were assumed to be beyond catchable size after age 35. Table III is an example for M = 0.089, F = .05. The yields

TABLE III. Example of calculation of yield for Fraser River sturgeon in the circumstances of the present fishery. M = 0.089; F = 0.05 from age 10 onward.

Age	Avg L	Avg W	g	g-(F+M)	Wt change factor	Wt of stock	Avg wt of stock	Yield per recruitment of 1000 lb
1	9.0	.154						
2	12.1	.390						
3	14.2	.650						
4	17.0	1.24	.44	+.351	1.420	1000	1210	
5	17.0	1.77	.33	+.241	1.273	1420	1614	
6	21.7	2.46	.31	+.221	1.247	1808	2031	
7	24.1	3.36	.20	+.111	1.117	2254	2386	
8	26.0	4.10	.33	+.241	1.273	2518	2862	
9	28.3	5.70	.24	+.101	1.106	3205	3375	168.75
10	30.6	7.25	.33	+.191	1.210	3545	3918	195.90
11	33.9	10.1	.10	−.039	0.962	4290	4209	210.45
12	35.0	11.1	.17	+.031	1.031	4127	4191	209.55
13	37.0	13.2	.17	+.031	1.031	4255	4321	216.05
14	39.0	15.6	.14	+.001	1.001	4387	4389	219.45
15	40.8	18.0	.16	+.021	1.021	4391	4438	221.90
16	42.9	21.2	.14	+.001	1.001	4484	4486	224.30
17	44.8	24.2	.11	−.029	0.971	4488	4423	221.15
18	46.5	27.1	.10	−.039	0.962	4358	4276	213.80
19	48.0	30.0	.13	−.009	0.991	4193	4174	208.70
20	50.0	43.1	.10	−.039	0.962	4155	4076	203.80
21	51.6	37.8	.10	−.039	0.962	3997	3921	196.05
22	53.2	41.7	.10	−.039	0.962	3845	3772	188.60
23	54.9	46.1	.09	−.049	0.952	3699	3611	180.55
24	54.9	50.4	.09	−.049	0.952	3522	3437	171.85
25	58.2	55.2	.11	−.029	0.971	3352	3304	165.20
26	60.0	61.0	.07	−.069	0.933	3255	3146	157.30
27	61.5	65.4	.08	−.059	0.943	3037	2951	147.55
28	63.0	70.8	.06	−.079	0.924	2864	2755	137.75
29	64.2	75.2	.06	−.079	0.924	2646	2546	127.30
30	65.5	79.9	.06	−.079	0.924	2445	2352	117.60
31	66.7	84.8	.06	−.079	0.924	2259	2174	108.70
32	68.0	90.1	.06	−.079	0.924	2088	2009	100.45
33	69.2	95.1	.05	−.089	0.915	1929	1847	92.35
34	70.6	101.0	.05	−.089	0.915	1765	1690	84.50
35	71.7	106.0	.05	−.089	0.915	1615	1547	77.35
						1478		4566.90

given in Fig. 8 are those corresponding to 1000 lb of recruitment at age 4 with the value of M = 0.089. Over a wide range of fishing mortality rate, increased equilibrium yield would be obtained with a slightly older age of entry than the 5–10 years in the present fishery, but the potential gains are not great. However, if natural mortality rate is lower than 0.089, the potential gain from reduced rates of fishing or older ages of entry is more substantial. For example, with M = 0.05 and age of entry 5 years, the yield at F = 0.07 is about twice as great as that at F = 0.20 (Fig. 9). If natural mortality rates of sturgeon are 0.05 or lower, yield could be considerably enhanced by reducing fishing mortality.

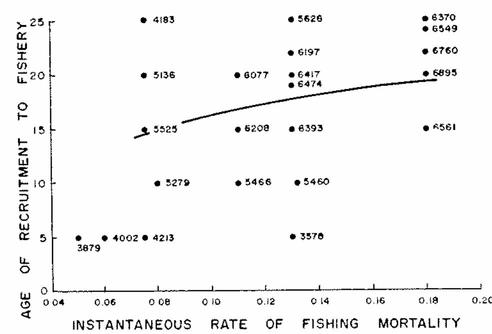

FIG. 8. Yields in pounds per thousand pounds of recruitment of 4-year-old sturgeon (numbers on face of figure) for various ages of recruitment at various instantaneous rates of fishing mortality when natural mortality rate (M) is 0.089. The position of the eumetric fishing curve was approximated by estimating for each rate of fishing, the maximum point on a parabola fitted to values on both sides of the maximum.

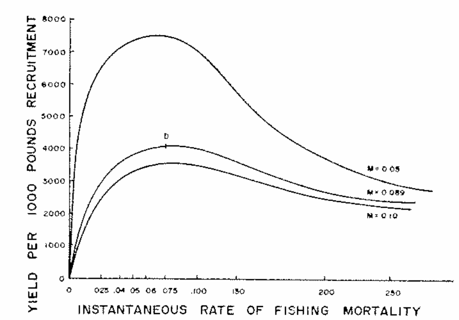

FIG. 9. Yields in pounds per thousand pounds of recruitment at different rates of fishing and three natural mortality rates. Age of entry 5 years. Maximum age of capture 35 years.

HISTORY OF THE STURGEON FISHERY

The sturgeon fishery of the Fraser appears to exhibit the properties of fish stocks described by Ricker (1963) which, because of great longevity, may respond to intense initial exploitation with dramatic declines in catches.

Late in the 19th century fisheries for sturgeon were substantial in many parts of the continent, and in British Columbia where almost all of the catch came from the Fraser River, the fishery reached a peak just before the turn of the century (Table IV). Prior to 1880 there was a small subsistence fishery by the native Indians, and Lord (1866) mentioned trade in a crude kind of isinglass (a form of gelatin obtained from the swim bladder lining) between the Indians and the Hudson's Bay Company. This trade ceased by 1886, but with the development of the salmon fisheries, there was a growing incidental catch of sturgeon in salmon nets. The annual reports of the regional fisheries inspector after 1880 contained data and frequently remarks on the sturgeon fishery. Local markets for caviar and sturgeon flesh gradually increased and

TABLE IV. Catch statistics of the sturgeon fishery of the Fraser River from 1880 to 1963. Prior to 1906 catches are for all of British Columbia, but catches in areas other than the Fraser were trivial. (Data for the period prior to 1918 from Annual Reports of the Canada Department of Marine and Fisheries; from 1918 on, from files of the Department of Fisheries of Canada, Pacific Area, Vancouver, B.C.).

Year	Catch in lb	Year	Catch in lb	Year	Catch in lb	Year	Catch in lb
1880	80,000	1901	65,000[a]	1922	32,200	1943	17,600
1881	70,271	1902	33,500	1923	57,400	1944	26,100
1882	79,700	1903	30,000	1924	30,600	1945	31,000
1883	399,393	1904	35,000	1925	27,400	1946	18,200
1884	352,900	1905	20,000	1926	27,500	1947	46,000
1885	354,500[b]	1906	25,000	1927	35,900	1948	25,000
1886	114,900	1907	100,000	1928	27,900	1949	42,100
1887	249,000[c]	1908	180,000	1929	31,400	1950	36,900
1888	215,500	1909	500,000	1930	27,700	1951	25,700
1889	318,600	1910	550,000	1931	25,200	1952	39,200
1890	396,000	1911	516,800	1932	20,200	1952	54,400
1891	324,500	1912	505,100	1933	36,700	1954	27,500
1892	520,500	1913	109,000	1934	21,200	1955	35,600
1893	330,000	1914	114,900	1935	43,600	1956	34,300
1894	592,106[d]	1915	81,100	1936	14,000	1957	30,100
1895	375,000	1916	73,000	1937	8,200	1958	48,800
1896	380,500[e]	1917	44,500	1938	18,700	1959	38,800
1897	1,137,696	1918	10,300	1939	15,600	1960	33,300
1898	750,000[f]	1919	22,200	1940	15,100	1961	35,900
1898	278,650	1920	14,300	1941	22,100	1962	29,100
1900	105,000[g]	1921	19,700	1942	9,800	1963	29,100

[a]"Practically extinct commercially."
[b]Said to be for "home consumption."
[c]Said to be mostly taken in salmon nets.
[d]Increasing demand and expanding market to east.
[e]Reference to substantial "poaching" by local settlers and natives.
[f]Licences 164.
[g]Licenses 23.

by 1888 were the subject of remark in the annual report of the regional fisheries inspector. By 1894 export to eastern markets was underway and by 1896 concern was expressed about "poaching" in lakes and sloughs and the difficulties of protecting a resource of growing importance. The peak catches in 1897 of over a million pounds and in 1898 of three-quarters of a million pounds, were followed by a sharp decline to 65,000 lb in 1901. There was a corresponding reduction in licensed fishermen and a verdict by the fisheries inspector that the sturgeon fishery was "practically extinct commercially."

It was realized that slow growth of sturgeon might be a factor in the rapid decline in catches. In 1907 catches began to increase, reaching one-half a million pounds in each of the 4 years 1909–12. In 1911 regulations allowed only gillnets and drift nets of 12-inch mesh; a closed season was declared from November 15 to March 25. Fishermen were apparently permitted to retain any fish over 8 inches in length or 3 lb in weight (either a misprint or a misunderstanding; Commission of Conservation, Canada, 1911, page 59). In 1915 the size limit became 36 inches. Catches declined despite the regulations and since 1918 commercial catches have ranged from 10,000 to 50,000 lb annually. A diffuse sports fishery, some of the catches of which are included in the commercial landings, might take an additional 20,000 to 30,000 lb annually.

YIELD ESTIMATES

There were thus two distinct periods of harvesting in the sturgeon fishery, the first and largest from 1880 to 1900, the second from 1907 to 1917. Taken together, these two harvests provide an opportunity for estimating the stock size and for testing the validity of the estimate.

It is first necessary to estimate the weight of a stable and unfished stock per 1000 lb of recruitment. This may be done by extending a table such as Table III to age 85 and assuming various growth and mortality rates, and no fishing mortality. It may be supposed that an initial fishery would concentrate on the larger mature fish, say those over age 25, so that recruitment may be expressed per 1000 lb of 25-year-olds. It may be assumed that the natural mortality rate (M) is between 0.089 (probably too high) and 0.05 (which seems reasonable). If it is assumed that growth rate after age 35 is at $g = 0.05$, then a sturgeon weighing roughly 100 lb at age 35 would at age 85 be $100\ e^{.05(50)} = 1220$ lb which is within the recorded weight of sturgeon (Clemens and Wilby, 1961). With this growth rate the increments in weight would exactly balance the losses from natural mortality at a rate of $M = 0.05$, so that the biomass of a cohort of sturgeon would remain constant after age 35! Using the two estimates of natural mortality rate, the weight of a stable and unfished stock of sturgeon per 1000 lb of recruitment of 25-year-olds is estimated as 27,600 ($M = 0.089$) and 65,000 lb ($M = 0.05$).

During the period from 1880 to 1900 removals by the fishery totalled 7,315,000 lb, which may be taken as virtually the whole of the accumulated stock of fish over age 25. During the same period recruitment at age 25 added each year 1000 lb per unit of recruitment. Assuming that these additions were exploited heavily and contributed their full 1000 lb per unit to the catch, and that recruitment was not reduced because of the reduction in stock size, we may set X = the number of units of recruitment per year, and write, for $M = 0.089$, $7{,}315{,}000 = 27{,}600 \times X + 21 \times 1000\ X$. The solution suggests that at a natural mortality rate of 0.089, the virgin stock would be the resultant of a long-term constant recruitment of about 150 units per year, and the virgin stock would be thus 150 (27,600) or 4,140,00 lb of sturgeon aged 25 and over.

For $M = 0.05$, the long-term constant recruitment is estimated as about 85 units per year, each associated with 65,000 lb of stock, or a stock of 5,525,000 lb of sturgeon aged 25 and over.

The period from 1901 to 1906 provided some respite, removals totalling 208,500 lb. With $M = 0.089$, recruitment would have added $6 \times 150 \times 1000$ or 900,000 lb to the stock for a net gain of about 700,000 lb (this calculation also assuming that the reduction in stock did not reduce recruitment). From 1907 to 1917 there was added 11 × 150 × 1000 or 1,650,000 lb which, it may be assumed, was taken immediately upon recruitment. The net gain from 1901 to 1906 and the recruitment additions from 1907 to 1917 suggest an available catch from 1907 to 1917 of 2,300,000 lb, which is in good agreement with the recorded catch of 2,774,400 lb. Alternatively, for $M = 0.05$, recruitment would have added 6 × 85 × 1000 or 510,000 lb for a gain of 300,000 lb from 1901 to 1906, and a further 11 × 85 × 1000 or 935,000 lb from 1907 to 1917, for a total increment of 1,235,000 lb, which is considerably less than the recorded catch of 2,774,400 lb.

The foregoing analysis confirms that the earlier sturgeon fishery exhausted the virgin stock and then after a brief intermission removed a small accumulation. The analysis does not indicate something else that was probably going on, particularly in the period from 1907 to 1917 — the removals of smaller sturgeon under 25 years of age by the salmon fishery which blossomed just before the turn of the century and was highly effective. It is possible that by 1917 there were very few sturgeon over age 15.

Reconsidering now the present situation with an annual input of 85–150 units, each of 1000 lb of 25-year-old recruits, the maximum sustained yield is obviously between 85,000 and 150,000 lb, age 25 corresponding closely to the critical age when gains from growth are the equivalent of losses from natural mortality (Table III). At rates of fishing less than the theoretical maximum, yields are more than two-thirds of the maximum. Figure 8, for example, provides the relation between yield per unit of recruitment and age of entry at various rates of fishing. In the absence of a fishery, each 1000 lb of recruitment at age 4 corresponds to 7500 lb of recruitment at age 25. Thus, 150 units each of 1000 lb of 25-year-old recruits are the equivalent of 20 units of 4-year-old recruits. On this basis, then, it is implied that sustained yield in the present fishery (age of entry 10 years, $F = 0.13$) could be 20 × 5460 or 109,200 lb per year, more than twice the current yield of about 30,000–40,000 lb. A similar calculation assuming $M = 0.05$ suggests a potential yield of 98,000 lb in the circumstances of the present fishery.

If the present rate of fishing is over-estimated, then the potential yield would be scaled downward to perhaps as low as 4000 lb per unit of recruitment, for a total of 80,000 lb per year. Additionally, it is possible that the present catch may be substantially larger than is reported in commercial catch statistics. The sport fishery for sturgeon along the Fraser might take as much as 20,000–30,000 lb per year, bringing the total to 50,000–70,000 lb per year. Making these kinds of adjustments, the analysis of Fig. 8 could be reconciled with the historical catches and would suggest a maximum sustainable yield of perhaps 80,000 lb per year, about 25% more than the possible current combined sport and commercial catch of 60,000 lb.

In the foregoing analysis the assumption that recruitment is independent of stock size may be a dubious assumption considering the very small numbers of fish involved. For example, if the stock comprises the resultant of 20 units

(20,000 lb) of recruitment of 4-year-olds, there are about 16,100 4-year-olds (which weigh about 1.24 lb each). With a natural mortality rate of 0.089 and a total mortality rate $(F+M)$ of 0.219 after age 11, the number of fish of age 25 is only 502. Assuming no fishery on fish over age 25, the total stock of fish age 25 and over is only 5900. Assuming $M = 0.05$ throughout, there are 85 units of 25-year-old recruits, and their equivalent is 4050 4-year-olds; and with the fishery after age 11, there are 165 fish of age 25 and a total stock over 25 of 3400. If females spawn only every 5 years and the sex ratio is one to one, then the average spawning population comprises about 300–600 females. Plainly, with even a modest fishery on the old large females, it might be expected that recruitment would be affected.

The foregoing estimates are highly speculative but contain an interesting corollary. As the fishery in the past 40 years has been mostly incidental and older fish are therefore largely unexploited, it seems likely that there is a small accumulation of older fish that might temporarily augment a modest fishery. In the circumstances, a trial fishery for 2 or 3 years, specifically for sturgeon over 48 inches long and taking 100,000 lb per year in waters of the Fraser River downstream from Hope, would seem to be warranted and could provide information on which to base a further stock assessment.

OTHER MANAGEMENT CONSIDERATIONS

Little is known of the life history of the Fraser River white sturgeon. Periodically, large specimens are reported along the length of the river downstream from the vicinity of the lower end of the Fraser canyon, and in the large sloughs and tributary lakes of the river below Hope. The fishery should be prosecuted throughout the area because it seems possible that the larger and older fish may in part be found away from the main stem of the river. It is possible that spawning is concentrated in the lower part of the Fraser canyon as it is likely that sturgeon spawn in relatively fast water. If a fishery should indicate that the spawning sturgeon would be too vulnerable to capture in such circumstances, appropriate closures could be instituted. It is indicated in some preliminary studies by Bajkov (1951) on Columbia River white sturgeon that there are seasonal migrations (upstream 100 miles in the fall, downstream to the mouth in the spring). If there are similar migrations on the Fraser, there could be management implications and a tagging study would be a useful adjunct to an experimental fishery.

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REFERENCES

BAJKOV, A. D. 1951. Migration of the white sturgeon (*Acipenser transmontanus*) in the Columbia River. Oregon Fish. Comm. Res. Briefs, **3**(2): 8–21.

CANADA DEPARTMENT OF MARINE AND FISHERIES. Annual reports 1880 to 1919.

CLEMENS, W. A., AND G. V. WILBY. 1961. Fishes of the Pacific Coast of Canada. Bull. Fish. Res. Bd. Canada, No. 168. 443 p.

COMMISSION OF CONSERVATION, CANADA. 1911. Lands, fisheries and game, and minerals. 519 p.

CUERRIER, J. P. MS, 1949. Observations sur l'esturgeon de lac (*Acipenser fulvescens* Raf.) dans la région du lac Saint-Pierre au cours de la période du frai. These. Université de Montréal, Montréal, Qué.

1951. The use of pectoral fin rays for determining age of sturgeon and other species of fish. Canadian Fish-Culturist, No. 11. p. 10–18.

HARKNESS, W. J. K. 1923. The rate of growth and food of the lake sturgeon (*Acipenser rubicundus* Le Sueur). Univ. Toronto Studies, Biol. Ser., Publ. Ont. Fish. Res. Lab., No. 18. p. 15–42.

LORD, J. K. 1866. The naturalist in Vancouver Island and British Columbia. Richard Bentley, London 1. 368 p.

MAGNIN, ETIENNE. 1966a. Recherches sur les cycles de reproduction des esturgeons *Acipenser fulvescens* Raf. de la rivière Nottaway tributaire de la baie James. Canadian J. Zool., **44**(2): 257–263.

1966b. Quelques données biologiques sur la reproduction des esturgeons *Acipenser fulvescens* Raf. de la rivière Nottaway, tributaire de la baie James. Ibid., **44**(2): 257–263.

PROBST, R. T., AND E. L. COOPER. 1954. Age, growth and production of the lake sturgeon (*Acipenser fulvescens*) in the lake Winnebago region, Wisconsin. Trans. Am. Fish. Soc., **84**: 207–227.

PYCHA, R. L. 1956. Progress report on white sturgeon studies. Calif. Fish Game, **42**(1): 23–35.

RICKER, W. E. 1963. Big effects from small causes: two examples from fish population dynamics. J. Fish. Res. Bd. Canada, **20**(2): 257–264.

ROUSSOW, GEORGE. 1957. Some considerations concerning sturgeon spawning periodicity. Ibid., **14**(4): 553–572.

SUNDE, L. A. MS, 1961. Growth and reproduction of the lake sturgeon (*Acipenser fulvescens* Rafinesque) of the Nelson River in Manitoba. M.Sc., Thesis. Dept. Zool., University of British Columbia, Vancouver, B.C.