RLO-2237-T12-47

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

RLO--2227-T12-47

DE92 000516

Radioactive Zinc (^{65}Zn), Zinc, Cadmium, and Mercury in the Pacific Hake, *Merluccius productus* (Ayres), off the West Coast of the United States

by

Janakiram Ramaswamy Naidu

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1974

AN ABSTRACT OF THE THESIS OF

Janakiram R. Naidu for the Doctor of Philosophy
(Name) (Degree)

in Oceanography presented on May 6, 1974
(Major) (Date)

Title: RADIOACTIVE ZINC (^{65}ZN), ZINC, CADMIUM, AND MERCURY IN THE PACIFIC HAKE, *MERLUCCIUS PRODUCTUS* (AYRES), OFF THE WEST COAST OF THE UNITED STATES

Abstract approved: _____
Norman H. Cutshall

The Pacific Hake, *Merluccius productus* (Ayres) was used to monitor the coastal waters off the West Coast of the United States, and Puget Sound for zinc (Zn), radioactive zinc (^{65}Zn), cadmium (Cd) and mercury (Hg).

This study has revealed that the Columbia River is not the source for zinc, cadmium and mercury but was the main source for zinc-65 as of January 29, 1971. Since then with the phasing out of all the plutonium production reactors at Hanford, the zinc-65 activity in the river water, and therefore in sea water off the West Coast of the United States, has approached minimum detection levels.

The zinc-65 concentration in the hake reflect the position of the Columbia River water plume. With the decrease in sea water

concentrations of zinc-65 as mentioned above, the activity of zinc-65 in the Pacific Hake has decayed to levels below the limits of detection. Specific activity of zinc-65 also follows a similar pattern and had declined with time (1969-1972).

The data on zinc and cadmium concentrations in the hake were fitted mathematically to the exponential equation: $Y = B_1 + B_2 e^{B_3 X}$; where Y is the concentration of the element, X is the length or weight of the fish, and B_1, B_2 and B_3 are parameters. Attempts were made to give these parameters biological meanings. In relating the data (zinc and cadmium concentrations) to the age of the fish (based on Bureau of Commercial Fisheries data, which relates age to length or weight of the fish), the following biological attributes could be assigned to the parameters:

B_1: asymptotic value for zinc or cadmium or concentration at chemical maturity, that is, when the length or weight of the fish approaches a steady state;

B_2: location of the curve with reference to the weight or length of the fish. This is not a biological but a chemical interpretation of the growth process;

B_3: constant pertaining to the rate of change in the concentration of zinc or cadmium.

Although zinc, cadmium and mercury all belong to group IIB of the periodic table, correlation between zinc and mercury concentrations

or between cadmium and mercury concentrations were present, but the degree of correlation was a function of location, whereas the correlation between zinc and cadmium concentrations were highly correlated for all locations.

Zinc and cadmium concentrations increase with fish size approaching an asymptotic value at maturity. Mercury concentrations were linear with age and the slope was a function of sampling location. The concentration factors follow the pattern: mercury > zinc $\cong$ cadmium. Regulation is seen for zinc and cadmium but in the case of mercury there is evidence that it is cumulative with age.

It may be significant that the age distribution of fish caught commercially coincides with the maximum concentration of zinc and cadmium. In the case of mercury the accumulation is linear and continues to accumulate with age. In terms of environmental pollution hazards, this may have important consequences based on public consumption of such fish.

APPROVED:

Research Associate in Oceanography
in charge of major

Dean of School of Oceanography

Dean of Graduate School

Date thesis is presented May 6, 1974

Typed by Cherly E. Curb for Janakiram Ramaswamy Naidu

ACKNOWLEDGEMENTS

It is not often that one gets an opportunity to express in writing one's profound debt to his teachers and colleagues for making one's study a success. Therefore, it is with great pride that I write this acknowledgement, though very inadequate, to my teachers, colleagues, and friends.

To Dr. Charles L. Osterberg, I express my deepest gratitude for giving me this unique opportunity. He initiated me into the program and since then I have been continually blessed with his kindness, understanding and encouragment, which has been my inspiration and guide towards the completion of my education.

To my major professor, Dr. Norman H. Cutshall, I extend my sincerest thanks. His keen interest in my program and his continual guidance in all stages of my study, course work and thesis writing alike, has been chiefly instrumental in accomplishing this work and with great pride I acknowledge my debt.

Dr. William O. Forster and Dr. William C. Renfro deserve mention for guiding me through the earlier part of my program.

Dr. William G. Pearcy deserves special thanks for initiating me into the problem of marine pollution and providing the samples of Pacific Hake used in this study. His critical appreciation of my thesis in its earlier stages helped immensely to give it the present form.

To my esteemed colleagues I respectfully extend my appreciation and thanks. Mr. Ingvar L. Larsen helped in the radioactive analysis of the samples and the statistical analysis of my data, especially the part concerning the predictive equation. Mr. Jerome Wagner for the elemental analysis of the samples. Mr. Vernon Johnson and Mr. Norman Farrow collected the river water samples.

I sincerely appreciate the guidance and facilities provided by Dr. Roman C. Schmitt, Mr. Thurman C. Cooper and Dr. J. C. Laul in the activation analysis of the samples and biological standards. These analyses strengthened the accuracy of the sample analysis.

To Dr. Robert Holton, Dr. James E. McCauley and Dr. Harry Goheen, my thanks for their guidance at the various stages of the thesis writing.

To Dr. John V. Byrne, Dean, the Staff and the students of the School of Oceanography, a special thanks for making my stay here a very pleasant one with happy memories.

Finally, the patience and encouragement of my wife, Veena, must also be acknowledged, for which I am truly grateful.

The study was accomplished through the United States Atomic Energy Commission Contract No. AT(45-1)-2227, Task Agreement 12. The continual support provided has made this study a rewarding experience. My thanks would seem inadequate in comparison to the aid offered. This thesis bears the Document No. RLO-2227-T12-47.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Zinc	3
Radioactive Zinc (^{65}Zn)	10
Cadmium	12
Mercury	25
INDICATOR ORGANISMS	36
Biology of the Pacific Hake, *Merluccius productus* (Ayres)	38
PURPOSE OF STUDY	47
MATERIALS AND METHODS	49
RESULTS AND DISCUSSIONS	60
SUMMARY AND CONCLUSIONS	111
FUTURE PLANS	115
BIBLIOGRAPHY	117
APPENDIX	135

LIST OF FIGURES

Figure		Page
1	Photograph of the Pacific Hake, *Merluccius productus*, Ayres, showing the change in body form with age.	39
2	Zoogeographic distribution of the Pacific Hake, showing the area of commercial concentrations (Alverson and Larkins, 1969).	41
3	Seasonal migrations and distribution of the Pacific Hake (Alverson and Larkins, 1969).	44
4	Seasonal depth distribution of the Pacific Hake related to geographic area (Alverson and Larkins, 1969).	46
5	Location of sampling stations for the Pacific Hake.	50
6	Location of sampling stations for water samples (fresh and sea water).	51
7	Plot of the number of fishes as a function of length classes indicating a bias in the sampling of the Pacific Hake.	61
8	Plot of log. weight as a function of log. length for the Pacific Hake.	64
9	Plot of weight of the Pacific Hake as a function of its length, the data being fitted to the allometric equation: $Y = B_1 X^{B_2}$.	65
10	Plot of weight or length of the Pacific Hake as a function of its (Nelson and Larkins, 1970).	67
11	Plot of zinc concentration (μg Zn/g. ash) in the entire fish and in the flesh of the Pacific Hake as a function of its length.	69

LIST OF FIGURES (Cont.)

Figure		Page
12	Plot of total zinc concentration (μgZn/entire fish) in the Pacific Hake as a function of its weight.	72
13	Plot of residuals (zinc data fitted to the allometric, growth and exponential equations), these are identified as:	74
	A: allometric : $Y = B_1 X^{B_2}$	
	B: growth : $Y = B_1(1 - e^{B_2 X})$	
	C: exponential: $Y = B_1 + B_2 e^{B_3 X}$	
14	Computer fit relating zinc concentration (μgZn/g. ash for entire fish) in the Pacific Hake and its weight, in terms of the exponential equation:	76
	$Y = B_1 + B_2 e^{B_3 X}$	
15	Plot of zinc concentration (μgZn/g. ash) in the Pacific Hake as a function of its length, showing the change in slope between the juvenile and adult fishes.	80
16	Plot of radioactive zinc concentration (pCi^{65}Zn/g. ash) in the Pacific Hake from different locations (Lat. 32°N to Lat. 48°N, and Puget Sound) as a function of its length. Numbers 2-27 represent locations in Figure 5.	81
17	Plot of specific activity (μCi^{65}Zn/μg Zn) in the Pacific Hake as a function of its length.	85
18	Plot of cadmium concentration (μgCd/g. ash) in the Pacific Hake as a function of its length.	88
19	Plot of cadmium concentration (μgCd/entire fish) in the Pacific Hake as a function of its weight.	89

LIST OF FIGURES (Cont.)

Figure		Page
20	Plot of residuals (cadmium data fitted to the allometric, growth and exponential equations), these are identified as:	90
	A: allometric : $Y = B_1 X^{B_2}$	
	B: growth : $Y = B_1(1 - e^{B_2 X})$	
	C: exponential: $Y = B_1 + B_2 e^{B_3 X}$	
21	Computer fit relating cadmium concentration (μgCd/g. ash for entire fish) in the Pacific Hake and its weight, in terms of the exponential equation: $Y = B_1 + B_2 e^{B_3 X}$	92
22	Plot of cadmium concentrations (μgCd/g. ash) in the Pacific Hake as a function of its weight, showing the change in slope between the juvenile and adult fishes.	94
23	Plot demonstrating the linear relationship between zinc concentration (μgZn/g. ash) and cadmium concentration (μgCd/g. ash) in the Pacific Hake.	96
24	Mercury concentration (μgHg/g. wet) in the Pacific Hake from different locations (Lat. °N).	98
25	Mercury concentration (μgHg/g. wet) in the Pacific Hake as a function of its length.	99
26	Mercury concentration (μgHg/g. wet) in the Pacific Hake as a function of its length, and also showing the regression lines drawn through the data points for specific locations (Lat. °N).	100
27	Mercury concentration (μgHg/g. wet) in the Pacific Hake plotted in relation to its zinc concentration (μgZn/g. ash).	101

LIST OF FIGURES (Cont.)

Figure		Page
28	Plot of mercury concentrations (μgHg/liter) in the Columbia River water samples (surface) from different locations along its flow towards the sea, as a function of the date of collection.	104
29	Mercury concentration (μgHg/liter) in water samples collected at Chinook Point, Columbia River, plotted in relation to the date of collection of the sample.	106
30	Mercury concentration (μgHg/liter) in sea water samples collected off the Oregon and Washington coast-line.	107

LIST OF TABLES

Table		Page
1	Estimated atmospheric cadmium concentration to surface ocean water.	20
2	Concentration of cadmium in sea water, n.μg/l. (μg/kg) filtrate (.22 μm Millipore). (After Preston, 1973).	21
3	Cadmium concentration factors in marine material. (After Preston, 1973).	22
4	Cadmium concentration (mg/kg wet weight) in commercial fish. (After Preston, 1973).	23
5	Length, weight and age data of the hake (derived from BCF data, Nelson and Larkins, 1969).	66
6	The ratio: wet weight/ash weight (W/A), and the ratio: dry weight/ash weight (D/A), for entire fish and flesh for hake from different locations (Lat. °N).	68
7	Results of CURVFIT plots relating Zn concentrations (μg/g ash) and weight or length of fish in terms of the allometric, growth and exponential equations.	75
8	Regression data for specific activity (^{65}Zn) vs. length and weight of the fish as a function of location (Lat. °N).	86
9	Results of CURVFIT plots relating Cd concentrations (μg/g ash) and weight or length of fish in terms of the allometric, growth and exponential equations.	91
10	Correlation coefficients (R), correlation coefficients at the 5% level of significance, and slopes for plots of Hg concentration (μg/g wet weight) as a function of Zn concentrations (μg/g ash) for specific locations (Lat. °N).	102

LIST OF APPENDIX TABLES

Table		Page
1	Data on location; date of collection; length; wet, dry and ash weights; concentrations of ^{65}Zn, zinc, cadmium and mercury; and specific activity (^{65}Zn) in the Pacific Hake, *Merluccius productus* (Ayres) off the west coast of U.S.	135
2	Mercury concentration (μg/l.) in waters from different locations: a: fresh water: Columbia River locations b: fresh water: rivers in Oregon c: estuarine: Chinook Point, Columbia River d: sea water	150
3	Summary of data in literature pertaining to zinc, cadmium and mercury.	154

RADIOACTIVE ZINC (^{65}ZN), ZINC, CADMIUM, AND MERCURY IN THE PACIFIC HAKE, MERLUCCIUS PRODUCTUS (AYRES), OFF THE WEST COAST OF THE UNITED STATES

INTRODUCTION

A man who has done much to call attention to the hazards of metallic pollution, Dr. Henry A. Schroeder of the Dartmouth Medical School, has stated:

> Pollution by toxic metals is a much more serious and much more insidious problem than is pollution by organic substances such as pesticides, weed-killers, sulfur dioxide, oxides of nitrogen, carbon-monoxide, and other gross contaminants of air and water. Most organic substances are degradable by natural processes; no metal is degradable.

Goldberg (1965) calculated ratios of the current rates of extraction of elements by man with their natural rates of cycling in order to gain a first approximation to man's capacity to pollute with each element. Rates of extraction give only a measure of potential pollution, and not of actual pollution, since many of the elements are fabricated into solid products which are protected from weathering. Nevertheless, using the ratio: kg/yr mined to kg/yr lost from ocean, the elements can be divided into four classes according to their potential for pollution, as follows:

Very high pollution: (>5)*	Au, Ca, Cd, Cr, Cu, Hg, Pb, Sn, Tl, Zn;

High potential pollution: (1 to 5)*	Ba, Bi, Fe, Mn, Mo, U;
Moderate potential pollution: (0.05 to 0.9)*	Al, Be, Cl, Co, Ge, K, Li, Na, Ni, Ti, W;
Low potential pollution: (<0.05)*	Nb, Si, Sr, Ta, Zr

*Ratio: kg/yr mined / kg/yr lost from ocean.

Pollution potential can also be assessed by considering what would happen if the entire annual production of an element were dissolved and poured down the drain. An order of magnitude calculation can be made using the values of 5.1×10^{17} kg and 1.42×10^{21} kg for the masses of fresh water and sea water, respectively (Goldberg, 1965). Only for a few elements would the mean concentration in fresh water rise noticeably, and the change in concentration in the ocean after mixing would be immeasurably small. On the other hand, actual times for complete mixing are moderately long, on the order of 10^3 years. Furthermore, living cells have the ability to concentrate elements over their environmental levels.

Food-webs, a characteristic of the trophic dynamism of life, can result in multiple step biological magnification of an element. In some situations an element, ordinarily labeled as essential, might be rendered toxic. With this in mind, zinc (Zn), cadmium (Cd) and mercury (Hg) and radioactive zinc (^{65}Zn) were selected as elements of interest in this study.

Zinc, cadmium and mercury belong to the Zn family, Group IIB of the periodic table. Zinc lies above Cd and Hg, and it is worth noting that the lanthanide series intervenes between Cd and Hg in the periodic table and that the electron structures of Zn and Cd differ fundamentally from that of Hg. The latter has an extra 14 electrons in the fourth orbital which may account for its marked covalency and its tendency to form stable mercury-carbon bonds. Cadmium-carbon bonds can be formed but they are extremely unstable compared with mercury-carbon (Sidgwick, 1950). Also, as seen earlier, all three metals are listed among the "very high potential pollution" category.

Zinc

Zinc alloy ornaments 2500 or more years old have been discovered, and the first smelting and extraction of the impure metal was carried out in China and India, thought to be around 1000 A.D. It occurs to the extent of about 120 grams per ton of the earth's crust. Over 4,000,000 short tons of recoverable Zn per year are mined in the world; nearly 600,000 tons of this comes from the United States (U.S.). The U.S. consumption is about 1,500,000 tons. Extraction of Zn from its ores, industrial processes dealing with the primary use of Zn as a galvanizing agent and its secondary uses in alloys and chemicals all result in some release of the element directly to surface waters.

Zinc in Biological Systems

The presence of Zn in living organisms and its role as an essential nutrient for plants and animals has been recognized ever since Raulin showed it to be necessary for the growth of *Asperigillus niger* in 1869 (Vallee, 1962). Its occurrence in biological matter was first described by Lechartier and Bellamy in 1877 (Vallee, 1962). Rice (1963) has presented an excellent review of "Zinc in Ecology" as of 1961.

The isolation and purification by Keilin and Mann (1940) of an enzyme, carbonic anhydrase, containing .33% Zn as part of its molecule, offered the first concrete explanation of a mode of action of this element. Zinc was demonstrated to be essential to the mechanism of this enzyme which catalyzes the dehydration of carbonic acid and participates in the elimination and incorporation of CO_2. Many other Zn-containing metallo-enzymes were subsequently discovered and include pancreatic carboxypeptidase, alkaline phosphatase, tryptophan desmolase and alcohol, malic and glutamic dehydrogenases. In addition, Zn was found to act as a co-factor in a variety of enzyme systems, including arginase, enolase, several peptidases, oxaloacetic decarboxylase and carnosinase (Parisi and Vallee, 1969). Some chemical and physico-chemical relationship of insulin and Zn is suggested by chemical analysis of isolated islet organs of teleost fish

(Weitzel *et al.*, 1953b).

It is apparent that Zn is involved in a wide range of cellular activities and is vitally concerned with the fundamental process of RNA and protein synthesis and metabolism in plants, micro-organisms and all multicellular animals (Parisi and Vallee, 1969). The ubiquitous distribution of Zn had been the teleological basis for expectations of such discoveries.

The tissues of the eye contain large quantities of Zn. The Zn-cysteine complex in the *tapetum lucidum cellulosum* of the eye accounts for the high Zn content. Zinc appears to be a constant constituent of plasma or serum, erythrocytes and leucocytes. Its importance in erythrocytes is related to carbonic anhydrase activity.

Zinc is present in human and other vertebrate organs, in quantities varying from 10 to 200 μg/gm (Vallee and Altschule, 1949). Most organs, including the pancreas, contain between 20 and 30 μg Zn/gm. wet tissue. Liver, voluntary muscle, and bone contain about double this amount. In another study, the total Zn content of adult, fat-free body weighing 70 kg was reported to vary from 1.36 to 2.32 gm (Widdowson *et al.*, 1951). The normal human intake of Zn has been stated to be 10-15 mg/day, most of which is excreted in the stool (McCance and Widdowson, 1942). The amount excreted being a function of intake, and varies from 5.1 to 10.3 mg/day.

Zinc Deficiency

Zinc deficiency leads to alteration of the activity of enzymes. Such deficiency may result from low zinc intake or may be attributable to a high calcium diet, the presence of chelating agents, or the presence of Cd which is known to be antagonistic to Zn. Replacement of Zn by Cd in tissues might be expected from studies which imply a competition between these metals for protein-binding sites. Presumably binding sites of Zn metalloenzymes are included.

Zinc Toxicity

Because it is essential and because organisms concentrate Zn far in excess of their metabolic needs, it might be suspected that toxic levels would be far above the likely physiological consumption of the element. However, experiments conducted indicate that while 2 mg/kg of Zn gluconate is tolerated well by both dog and man, a diet containing 0.5% Zn/day resulted in impaired production of erythrocytes and in retarded growth (Vallee *et al.*, 1949a).

Zinc in the Environment

Difficulties encountered in the analytical determination of Zn at levels existing in plants and animals, and equal difficulties of freeing water and reagents from contamination with Zn, have been

deterrents to Zn research. However, the presence of ^{65}Zn in the environment, as a consequence of nuclear weapon tests and effluents from nuclear operations, provides an environmental tracer capable of being quantified at atom levels. This has helped in determining the routes, rates, and reservoirs of ^{65}Zn, and also of stable Zn (based on the concept that biological systems do not recognize isotopic differences in mass) in the ecosystem.

Terrestrial

Plants apparently vary greatly in their Zn requirements and also in their ability to obtain Zn from a given soil. Direct foliate absorption of Zn seems to be an important pathway and legumes were found to have high Zn concentrations in roots. Some soils naturally contain insufficient total or available Zn to meet the requirements of plant growth. On these soils the use of Zn containing sprays and fertilizers has become standard agricultural practice. Zinc deficiency symptoms in plants have resulted from excessive liming of the soil, and on soils containing a high phosphate content. This treatment also results in non-uniform distribution of Zn throughout the plant.

Fresh Water

The quantity of Zn that occurs in fresh water, apparently varies considerably from one location to another and from time to time.

Kopp and Kroner (1969) in their summary of trace elements in water of the U.S., lists zinc concentrations, from 2-1182 μg/l with a mean of 64 μg/l (the maximum value of 1182 μg/l, was for Lake Erie). "Water Quality Criteria for Public Supplies" sets the limit for drinking water at 5000 μg/l. High Zn concentrations are found in waters of low pH, such as acidic mine discharges. However, in waters of higher pH, Zn concentrations are lower. At very high pH levels, Zn may form anionic radicals, but such conditions are not likely in natural surface waters.

Marine

Reported Zn concentrations in sea water vary widely around 10 μg/l, ranging from 3-25 μg/l (Bertrand, 1938; Morris, 1968). In sea water off the North Eastern Pacific Ocean, Buffo (1967) found an average of 22 μg/l at the surface, 15 μg/l at 10 m, 12 μg/l at 20 m, 10 μg/l at both 50 m and 100 m, 7.7 μg/l at 150 m and 7.1 μg/l at 300 m. The possibility of contamination by sampling apparatus could not be ruled out. In the Atlantic, Fabricand et al. (1962) found 0.6 μg/l, in surface water, and 0.59-0.72 μg/l in unfiltered samples from depths of 500-1600 feet.

The mean value reported by Kopp and Kroner (1969) in Columbia River water is 22 μg/l. Values higher than oceanic values for Zn have been found in bays, possibly as a result of industrial pollution.

It is important to note that Zn is strongly absorbed on silt (McKee and Wolf, 1963).

Morris (1968) concluded that zinc in seawater is predominantly in the divalent "cationic form". $Zinc^{++}$ and $ZnOH^{+}$ were determined as the chief species (Baric and Branica, 1967), while Rona et al. (1962) suggested a fairly strong organic association for the element in sea water. Piro et al. (1973) identified two and sometimes three chemical forms of zinc in coastal seawater. They called these forms "ionic", "particulate" and "chelated".

Organisms concentrate Zn, and it is not uncommon to find Zn concentrations of 150 mg/kg in marine animals (USDI, 1968b). Concentration factors for Zn in shellfish may be as high as 10^5 (Chipman et al., 1958). Rice (1963) has used ^{65}Zn values to indicate concentration factor variations with trophic level, differences in uptake as a function of source, food or water (the former being more effective), and that in acute pollution, the rate of uptake is much faster than the rate of loss.

In spite of its relatively low acute toxicity, Zn is of concern in the study of coastal pollution because sub-lethal effects have been reported (Bougis, 1961). Acute toxicities of Zn to marine organisms are generally around 5-10 mg Zn/l, although some of these were measured over very short time intervals (Wisely and Blick, 1967). Invertebrate larvae seem to be most sensitive of the organisms tested.

Growth of the larvae of Poracentrotus lividus (a sea urchin) was retarded by as little as 30 μg Zn/l (Bougis, 1961). A concentration of 160 μg Zn/l caused abnormalities in sea urchin eggs (McKee and Wolf, 1963). The division rate of the diatom Nitzschia was reduced by exposure to concentrations as low as 250 μg Zn/l (Chipman et al., 1958).

Radioactive Zinc (^{65}Zn)

Radioactive isotopes entering aquatic environments from the operation of nuclear reactors and the dispersal of atomic wastes are of concern because these radionuclides, being similar to their stable counterparts, might pass to man via the food web. Although many of the neutron activation isotopes released in aquatic effluents have relatively short physical half-lives, there are some that are not only long lived but are also isotopes of physiologically essential elements. Zinc-65 (^{65}Zn) is one such isotope. It is produced by the reaction, $^{64}Zn(n,\gamma)^{65}Zn$, and has a half-life of 245 days. Upon entering an aquatic environment, ^{65}Zn may be bound to sediment or metabolized by living organisms (Polikarpov, 1966) becoming available for transportation through, and concentration in, the trophic levels of the food web.

The major source of ^{65}Zn in the Northeast Pacific Ocean was the Columbia River water that was used as coolant water for the

plutonium production reactors at Hanford, Washington. By the time ^{65}Zn from Hanford reached the ocean it was largely associated with sediment particles (Barnes and Gross, 1966). However, concentrations of ^{65}Zn in the Pacific Ocean waters adjacent to Washington, Oregon, vary with season, position of the Columbia River "plume", and operation of the Hanford reactors.

The direction taken by the Columbia River plume is determined by the prevailing winds and currents along the coast. In winter the plume moves northward and onshore, while in summer it travels southward and offshore (Barnes and Gross, 1966; Seymour and Lewis, 1964; Frederick, 1967). This change in direction substantially influences the levels of ^{65}Zn present in marine organisms throughout the year and results in variations in all trophic levels of the food chain (Osterberg et al., 1964; Pearcy and Osterberg, 1967).

Extensive literature exists on ^{65}Zn concentrations in plants and animals off the West Coast of U.S. (Nakatani, 1966; Renfro and Osterberg, 1969; Jenkins, 1969). However, since the shutdown of all the reactors in Hanford (January 29, 1971), there has been a sharp decline in the ^{65}Zn concentrations in intertidal organisms (Larsen et al., 1971) and even more so in the migratory fishes such as hake, tuna, etc. The persistence of ^{65}Zn in tuna has been attributed to global fallout (Folsom et al., 1971; Pearcy and Vanderploeg, 1973).

Early determinations of this radionuclide were concerned primarily with its concentration in a given mass of tissue. The working committee on Oceanography (NRC, 1962) advocated a more satisfactory index of ^{65}Zn levels in organisms, the Specific Activity Concept, which expresses in a ratio the amount of radioactive isotope to the total isotopes of that element. However, with reduction in the values of the numerator of this ratio and the denominator remaining constant, specific activity values also obviously decline.

Zinc-65, along with other radionuclides in the Columbia River, has served as a unique tracer of the movement of the Columbia River water at sea (Osterberg et al., 1964). Zinc-65 has also contributed towards identifying and tracing trophic levels in the marine environment (Osterberg et al., 1964).

Cadmium

Cadmium (Cd) was discovered by F. Stromeyer, a metallurgist, in 1817, as a result of the study of some impurities found in zinc carbonate. The sulfide was noted to be a particularly beautiful yellow pigment and this remained the principle use of Cd until recent times (Schroeder, 1965).

Cadmium is a relatively rare element, averaging one-half gram per ton of the earth's crust. World production of Cd has steadily risen since 1910, and in 1968 amounted to 31 million

lbs/year (USDI, 1968a). The U.S. produces about 40% of the world output. The relatively low melting point and high volatility of Cd, properties sometimes exploited for extraction of the metal from its ore, also may increase its potential hazard. An estimated 4.6 million lbs. of Cd in various compounds are emitted into the atmosphere each year from a wide variety of Cd processing and manufacturing activities, and from the use and disposal of many commercial Cd-containing products ranging from rubber tires to colored plastic bottles (McCaull, 1971). Its occurrence as a contaminant in superphosphate fertilizers in very small quantities ($\sim$9 mg/kg) is offset by the large usage of such fertilizers resulting in potential exposures from this source.

Cadmium in Biological Systems

With the use of sensitive analytical methods such as atomic absorption, Cd can be found in relatively small amounts (0.03 to 0.9 mg/kg) in nearly all foodstuffs and beverages used by man (Schroeder *et al.*, 1967). Oysters and canned anchovies gave values of 3-5 mg/kg (wet weight). The mean Cd intake was 0.02 mg/day, with a range of 0.032 to 0.158 mg/day. Most of this amount is excreted, principally in feces, but about 2 μg/day are retained in the body. Two μg/day may not sound like much, but it adds to cumulative tissue deposits (Friberg, 1957). The buildup suggests that the body lacks a

mechanism for keeping intake and output of Cd in balance (Schroeder *et al.*, 1967).

Friberg (1957) has indicated that the liver and kidney are organs with relatively high concentrations of Cd in exposed subjects as compared with normal unexposed subjects to Cd. Variations in concentrations between kidney and liver were found to be a function of the Cd compound taken in (Friberg, 1957). The explanation for retention of Cd in the liver and kidney of many species is undoubtedly related to an unusual protein, metallothionien (Margoshes and Vallee, 1957), which is found in the renal cortex and liver. In humans, metallothionien contains 4.2% Cd and 2.6% Zn. Cadmium is more firmly bound than zinc in the protein and presumably these two elements can compete for binding sites (Pulido *et al.*, 1966).

Cadmium has been studied for its effects on various enzyme systems (Stokinger, 1963; Simon *et al.*, 1947; Jacobs *et al.*, 1956). It appears that Cd is able to inhibit -SH containing enzymes *in vitro* and that it can produce an uncoupling of oxidative phosphorylation in very low concentrations in mitochondria. A suggestion has been made that perhaps Cd does play a physiological role in regulating the biosynthesis of molecular variations of albumin and perhaps other proteins (Anonymous, 1968).

Cadmium Toxicity

Cadmium has been known since 1858 to be toxic. Knowledge of the effects on man comes primarily from many studies that have been made on occupationally exposed people as well as from accidental poisoning by ingestion and by abortive attempts to use it therapeutically.

Although Cd is chemically similar to Hg, its toxicity depends less on its chemical form than does the toxicity of Hg. The physiological effects on both acute and chronic poisoning are presumed to be caused by the divalent ion Cd^{++}. Soluble Cd compounds are presumably more hazardous, since the Cd ions are released in solution.

Acute effects of oral ingestion in man are immediate nausea and vomiting and can occur from as little as 15 mg of total Cd. There has been a considerable number of epidemics of acute nausea following the attempts to use Cd plated articles as food containers (Fairhall, 1957; CSWPC Board, 1957).

Chronic exposure produces a rather characteristic emphysema, which can be extremely disabling and may progress even after exposure has ceased. Other ailments in which Cd is implicated are: hypertension and other cardiovascular disease (Carroll, 1966), effects on the course of pregnancy (termination before full term) and on fertility (sterility) (Parizek et al., 1968; Parizek, 1964), as a

carcinogen (Gunn et al., 1967; Shubik and Hartwell, 1971). Overall, studies to date have been too generalized to prove or disprove that existing levels of Cd pollution is a contributing factor to the above symptoms.

The mechanism of protection by Zn against Cd toxicity have been studied intensively by Gunn et al. (1968), wherein the protective effects of Zn-cysteine and selenium against Cd testicular atrophy were examined. The conclusion was drawn that these protective agents probably act at the vascular levels. Whether induction of metallothionein plays a role in such protection is unknown.

Itai-Itai Disease

Considerable interest has been sparked recently by reports of a syndrome occurring in Japan and attributed by many to environmental pollution (Kobayashi, 1970; Tsuchuga, 1969). Itai-Itai (or "Ouch-Ouch" in English onomatopeia) appears to be an endemic condition, seen particularly in elderly females, characterized by decalcification that leaves the bones viewed by X-ray photographs as transparent soft tissues (Anonymous, 1971). The diagnosis of Cd poisoning is consistent with very high levels of Cd in the victims' bones (11472 mg/kg in ash in the ribs). Cases began to be observed about 1912 in an area potentially contaminated with metals from a lead mine. The number of cases increased about the time that the

mine began to produce Zn and Cd. Over a period of 15 years, which included the war years of 1939 to 1945, some 200 persons living along the banks of the Jintsu River suffered from the syndrome. Half of them died. Women 50 to 60 years of age who had borne many children were especially at risk.

There is considerable disagreement on the etiology. Those who suspect metallic contamination as the cause, contend that the air, soil, run-off water, and rice crops were successively polluted, and produce sampling evidence in support. On the other hand, some of the specific disturbances, and particularly osteomalacia (bone softening) are not seen in other cases of Cd intoxication. Since new cases have not appeared since 1955 it is difficult to correlate Cd intake from foods with the disease although it is probable that the intake was elevated. The affected areas were those from low calcium and vitamin D intake and the presence of other elements, such as lead or fluoride may have been involved (Anonymous, 1971). Lee (1972) noted that increased Cd intake alone did not produce the disease but that other factors, e.g., nutritional, were essential.

Cadmium in the Environment

The factors affecting the cycling of Cd through the environment are not all clear but it appears likely that the natural geochemical processes could be the major factor except for localized instances

(cf: Itai-Itai case). Man-made contributions to the environment are relatively recent and localized; most of the material found in soils, water, and food, away from specially polluted areas, can be regarded as natural or background content.

Sulfides in the soil are generally somewhat unstable materials and can be attacked by microorganisms and made available for uptake by plants. This ability of plants to concentrate Cd and their decomposition and dispersion in the environment may be an important factor. Plant cover can utilize as much as 30 to 70 tons of minerals per km^2 (Lukashev, 1958). In general, biological systems can create local concentrations of elements to as much as 10^5 times over their ambient aquatic environment, and in addition, this same aquatic environment could transport these concentrations to different locations, thereby aiding the spread of the pollutant (if the said element is considered as a pollutant).

Cadmium: Aquatic Environment

Kopp and Kroner (1969) indicated that the Cd content of drinking water supplies was well below the drinking water standard of 0.01 mg/l in over 99.8% of the samples examined. Zinc seemed to exceed its standard more frequently than Cd.

Bowen (1966) reviewed information on the occurrence of Cd in plants and animals. It is clear from his study that Cd content is of a

very low order of magnitude. He also indicates a Cd concentration factor of about 900 for plankton and brown algae and a mean concentration factor of 1620 in the case of 32 fresh water plants. This is considerably lower than the concentration factors for plankton in the case of zinc and also for zinc and mercury in the case of fresh water plants. Nevertheless, it is apparent that considerable concentration of Cd can occur by certain water plants without apparent injury to the plant.

Cadmium: Marine Environment

Following the recent concern about mercury and lead in the environment and particularly their concentration in marine foodstuffs, considerable interest has been turned toward cadmium in a marine context, and Preston *et al.* (1972), Peden *et al.* (1973), and IDOE (1972) have reported Cd concentrations in coastal waters and selected marine biota. The intake of Cd in human diet with special significance of marine foodstuffs (in particular, shellfish) has recently been the subject of a UK Government White Paper (HMSO, 1973).

Oceanic Cd data are listed in Table 3 (Appendix). The residence time in the ocean is estimated at 10^4 years (Goldberg, 1965). The present mining output of Cd is approximately 10^4 tons per year (USDI, 1970). Assuming that this represents the annual loss of Cd to the environment from human activities, and that all in due course

reaches the sea, this loss rate, or input to the sea, would have to be maintained for 10^4 years to alter significantly the ocean Cd concentration (50% increase in 7000 years). Clearly, therefore, we are not concerned with a global ocean Cd pollution problem.

However, it has been suggested that the atmospheric input of Cd may be a significant source of Cd to ocean surface waters, and may change the concentration there. The data in Table 1 (IDOE, 1972) are used in an attempt to examine this situation by an analogy with Pb concentrations in surface ocean water, based on the contention that Pb concentrations in surface waters are ten times more than those in deep waters, due to atmospheric input from man's activities (Chow and Patterson, 1966). Assuming that Cd is transported in the atmosphere in a manner analogous to Pb and then mixed vertically at the same rate, it seems unlikely, from Table 1 (IDOE, 1972), that there is a significant contribution of Cd to open ocean via the atmosphere.

Table 1. Estimated atmospheric cadmium contribution to surface ocean water.

Concn. open ocean, $\mu g/l$	Concn. urban air, $\mu g/m^3$	Ratio air/ocean	% Increase upper 200 m ocean
Pb 10^{-2}	10^3	10^5	1000*
Cd 10^{-2}	10^2	10^3	10

* Based on Chow and Patterson (1966) - Pb concentration in surface seawater = 10 x Pb concentration in deep water.

The major Cd pollution problems in the marine environment therefore lie largely in inshore waters, where primary sources of Cd are river input, pipe-line discharges, sewage sludge dumping and close-in aerial fallout in the vicinity of industrial cities. The filtered sea water concentrations of Cd in UK coastal waters, when compared with those in offshore waters and the open ocean (Table 2), support the view that the contamination lies inshore (Preston, 1973).

Table 2. Concentration of Cd in sea water, n. μg/l (μg/kg) filtrate (.22 μm Millipore) (after Preston, 1973).

Shoreline	Coastal	Shoreline	Coastal
$n - n.10^{1}$	$n.10^{-1} - n$	$n.10^{-2} - n.10^{-1}$	$n.10^{-2}$

(Filtrate as % total Cd = 80; river water Cd concentration = $n.10^{-1} - n$).

Furthermore, surveys of concentration in British Coastal waters based on either water sampling or biological indicator systems indicate that even inshore contamination is localized and related rather obviously to drainage from mineralized catchment areas of industrialized conurbations (Preston et al., 1972). Nevertheless, such areas may exhibit significant concentrations in both water and biological materials.

Topping (IDOE, 1972) has shown that Cd values for zooplankton collected in the Clyde Sea area were higher in winter (1.5-6 μg/g dry wt.) than in summer (0.3-1.2 μg/g dry wt.). Assuming that the

standing stock of zooplankton is much smaller in winter than in summer, this could suggest that the metals associated with the sample area are a reflection of the plankton population levels. His value for fish were below the detectable level for this metal (0.03 mg/kg, wet wt.).

Robertson et al. (1972) reported that cadmium levels in muscle tissues of marine organisms from off the West Coast of U.S. never exceeded 1 mg/kg (dry wt.), although a very high concentration of 38 mg/kg (dry wt.) was found in rat-tail (Macrouridae) kidney tissue. He found Cd levels ranging between 1-5 mg/kg (dry wt.) in several whole organisms, which further indicates that Cd is concentrated in the internal organs of some marine animals. High levels of Cd in the liver of the Adelie penguins (90 mg/kg, dry wt.) are probably due to natural processes, since it is unlikely that the Antarctic environment has been appreciably contaminated by anthropogenic addition of Cd.

Preston (1973) tabulated Cd concentration factors in marine organisms, based on the work of several investigators (Butterworth et al., 1972; Peden et al., 1973) (Table 3).

Table 3. Cd concentration factors in marine material (after Preston, 1973).

Sediment	Plankton	Seaweed	Molluscs	Crustacea	Fish
10^3	10^4	10^2-10^3 (10^4)	(10^3-10^4) (10^5)	10^3	10^2

$$\text{Cd concentration factor} = \frac{(\text{Cd; g. dry wt.})}{(\text{Cd; g. sea water filtrate})}$$

A brief look at concentration in commercial fish and shellfish species appears in Table 4. As already indicated by the concentration factor data, molluscan shellfish exhibit the highest concentration and range from n. 10^{-2} to n. 10^{1} mg/kg wet weight; the lowest values being exhibited by mussels and the highest by periwinkles. Crustacean shellfish are also in the range n. 10^{-2} to n. 10^{1} mg/kg, but high values are all attributable to the brown meat of crabs (hepato-pancreas) from areas of high ambient Cd concentration due to drainage from mineralized catchment areas (HMSO, 1973). Interestingly enough, the data suggest that oysters exhibit their highest Cd concentration in areas where contamination is probably largely attributable to industrial discharge and crabs in these areas have a relatively low Cd concentration. Where crabs are high in Cd, oysters are significantly lower than in areas of industrial pollution. Is this evidence of difference in physico-chemical form or different pathways facilitating uptake by oysters in one case and crabs in the other?

Table 4. Cadmium concentration (mg/kg wet weight) in commercial fish (after Preston, 1973).

Molluscan shellfish	Crustacean shellfish	Demersal fish	Pelagic fish
n. 10^{-2} - n. 10^{1}	n. 10^{-2} - n. 10^{1}	n. 10^{-1}(n)	n. 10^{-2} - 10^{-1}

The values in demersal and pelagic fish are all quite low, n. 10^{-2} - n. 10^{-1} mg/kg, wet weight; and there does not seem to be

any evidence of concentration up the food chain, or of fish in coastal waters or shallow areas being significantly more contaminated than those from distant deep water grounds.

Concern regarding human intake of Cd from consumption of marine foodstuffs thus appears to be restricted to a few "hot spot" areas in coastal waters, and the main vehicle of Cd intake by man in this context are molluscan shellfish and the b 'own meat of crabs. A recent report (HMSO, 1973) concluded that the amount of Cd contributed to the average diet from these sources is negligible.

Preston (1973), however, designated several problems needing further attention:

a: the importance of the chemical state in relation to biological availability and the apparent contrast between the behavior of Cd from natural sources and industrial discharge.

b: impact of Cd on marine organisms, especially when high values for Cd occur in non-commercial species in areas of high Cd contamination. What effect, if any, are these concentrations having?

c: the kinetics of Cd metabolism in marine organisms; the probability is that the biological half-life is long and that the important pathway for entry to the organism is food and not water. However, in reduced Cd regimes, how long will organisms take to cleanse themselves?

d: the concentration factor data presented indicate that the majority of Cd in estuarine situations will be present in sediments, and in spite of the high concentration factors involved, the biological compartment will be small because of the relatively small size of the biomass compared with bed sediments and the water

mass. If we are able to reduce rates of input of Cd, then to what extent and under what conditions will it be released from sediment to sustain contamination levels in other compartments?

Mercury

Mercury was well known to ancient civilizations. It was mined at Almaden, in Spain, for 27 centuries and its toxic properties were known to Hippocrates in 400 B. C. In recent years Hg has become recognized as an environmental problem with many deaths in Japan (Minamata disease), banning of fishing in parts of Sweden, Canada and the United States, and the closing of the game bird season in the prairie provinces of Canada.

The toxicity of mercury and its compounds has produced much interest in the detection and determination of this element. But analysis is only one problem. The sources of environmental mercury, where it goes, what reactions it undergoes, and what are the toxic levels to man and other organisms, are related problems that need to be considered as well.

Mercury in the Environment

Natural Processes. The major natural source of the element is cinnabar (mercuric sulfide), which contains about 86% Hg by weight, and is generally found in mineral veins or fractures near volcanic or

hot spring areas. Weathering and erosion of rocks and soils can introduce Hg into surface and ground waters. Unpolluted surface waters in the U.S. contain less than 0.1 μg/kg. Ground water values range from 0.02 to 0.07 μg/kg, with higher values occurring in regions where underground waters have been in more intimate contact with Hg-rich minerals over a longer period of time. Hot springs and geothermal stream fields have also been associated with high Hg levels (0.5 to 3.0 μg/kg) (U.S. Geological Survey, 1970). Stock and Cucuel (1934) gave a value of 1 μg/kg for the River Rhine, which is higher than values recently determined in Sweden, where Johnels et al. (1967) gave a value of 0.13 μg/kg for an uncontaminated river and 0.25 μg/kg for the Stockholm Archipelago; Aidin''yan (1962, 1963) gives values of 0.4 to 3.0 μg/kg for rivers in European Russia and states that the levels are much higher than those in other European rivers. Wershaw (1970), examining samples from 73 rivers in the U.S., found 34 with less than 0.1 μg/kg, 27 between 0.1 and 1.0 μg/kg and only two over 5 μg/kg.

Mercury has a vapor pressure of 0.001426 mm Hg at 22°C, hence can be found in the air over Hg bearing ores (3 to 9 ng/m^3), in excess of normal atmospheric levels encountered in air over non-mineralized areas (U.S. Geological Survey, 1970). Mercury is scrubbed from the atmosphere by rain and snow, and subsequently becomes associated with the upper layer of the soil. This Hg can be

carried to streams by runoff.

Weathering and erosion processes are estimated to transfer about 4500 metric tons of Hg per year from the continents to the oceans via the rivers (Goldberg, 1970). In the Pacific Ocean, Hosohara (1961) found values of 0.15 to 0.27 μg/g at a depth of 3000 meters.

Man's Activities

The total world production of Hg during the period 1963 to 1969 was eight to nine million kilograms (18 to 20 million pounds) per year. The U.S. usage of Hg during this period has been 2.2 to 2.7 million kilograms (5 to 6 million pounds) per year. As much as one-third of this has been lost into the environment (Hammond, 1971).

Mercury is used industrially in two predominant forms. The first is as metallic Hg and is used mainly in electrical apparatus (13.1 to 19.9%) and in the production of electrolytic chlorine and alkali. In these chlor-alkali plants, the average loss of Hg to the environment was about 225 g of Hg for each ton of chlorine produced. Wallace *et al.* (1971) estimated a release of 1800 kg of Hg into U.S. waters each day (0.66 million kg/yr) from this source. Goldberg (1970) noted that this industry requires about 400 metric tons annually (0.4 million kg/yr). The second major use is as organic Hg compounds. In pulp and paper mills and in agriculture these compounds

have been extensively used as fungicides. The usage of Hg over the period, 1963 to 1969, has varied from 81 to 127 thousand kilograms annually (180, 000 to 280, 000 lbs) which amounts to 2. 9 to 5. 6% of the total usage (USDI, 1969). It was this latter use that led Löfroth (1970) to state, "It was shown beyond any doubt that the use of methyl-mercury in agriculture was responsible for poisoning and drastic decrease of wild bird populations."

Burning of coal is estimated to release on the order of 3000 tons per year of Hg, a quantity comparable to that emitted as waste from all industrial processes (Joensuu, 1971).

Goldberg (1970) concluded that, in addition to the 4500 metric tons of Hg entering the oceans from continental weathering processes each year, about 3850 metric tons (half of the world production of mercury) is annually released to the environment in an uncontrolled way. Most of this eventually reaches the ocean.

Toxicity of Mercurials

The first inkling of a dangerous environmental Hg problem appeared from 1953 to 1960 in Japan when 111 fishermen and their families living along the shores of Minamata Bay developed a mysterious neurological disease and 44 people died. A similar outbreak occurred in Niigata, Japan, in 1964 with 26 cases and five deaths. The afflicted individuals suffered from neurological symptoms and

brain damage and many of the survivors were paralyzed for life. Cause of the disease was eventually determined to be methylmercury that had been discharged into Minamata Bay by an acetaldehyde factory. The methylmercury was concentrated by fish and shellfish which were subsequently eaten by the victims.

In 1965, authorities in Sweden learned of a severe water pollution problem with Hg. Analysis of fish indicated dangerously high concentrations of Hg. It was also noted that the most common form of Hg in the organisms was methylmercury, which also appears to be the most toxic form. Methylmercury is rapidly assimilated, with almost complete absorption from the diet of both animals and man, and slowly excreted with a biological half-life in humans of 70 to 74 days (Aberg et al., 1969). Biological half-lives range from 8 to 1000 days for other species. Methylmercury achieves a much more uniform distribution throughout the body, including the brain, than other forms of Hg and readily passes through the placental barrier. It mainly affects the central nervous system. However, it was not clear why methylmercury was the predominant form found in Swedish fish when the normal discharge effluent contained inorganic forms of Hg. A major research effort was initiated, and the Swedish scientists discovered that microorganisms were capable of transforming inorganic mercury to the much more toxic methylmercury (Jernelov, 1969). Wallace et al. (1971) have detailed the process, whereby

inorganic Hg and some Hg-containing compounds are converted to methylmercury. This latter substance is more water soluble and is readily taken up by smaller organisms. Johnels et al. (1967) found that with each upward step in the food chain, methylmercury became more and more concentrated so that tissues of some carnivorous fish high up in the chain showed a 3000 or more fold concentration compared with the ambient medium.

Other documented toxicological findings include the highly significant decrease in activity of serum alkalinephosphatase in workers exposed to Hg vapor (Nagorzanski, 1968); chromosome breakage in lymphocyte in humans following consumption of fish containing methylmercury (Skerfving et al., 1970).

In the aquatic system, Harriss et al. (1970) have shown that 1 μg/kg mercury of four organic compounds caused 40 to 60% inhibition of photosynthesis in a fresh water phytoplankton. In the case of a marine diatom, the effects were even more marked (10 to 90% inhibition) and an effect could be seen for methylmercury at 0.1 μg/kg. Current oceanic levels are 0.1 μg/kg, which in the form of methylmercury could cause 20% inhibition on the basis of these experiments. In view of the finding that significant inhibition of photosynthesis occurs at current environmental levels, further studies in this field are desirable.

On the basis of toxicological data, the lowest steady intake of methylmercury producing toxic symptoms, or the allowable daily intake (ADI), was set at 0.4 μg/kg of body weight by the Swedish Commission of Evaluating the Toxicity of Mercury in Fish. Using a ten-fold safety factor the Commission arrived at an ADI for methylmercury of 0.03 mg per day, or 0.21 mg per week, for a 70 kg man. This intake is equivalent to eating 60 g of fish containing 0.5 mg/kg each day. The U.S. Food and Drug Administration (FDA) prohibits commercial sale of any fish that exceeds 0.5 mg/kg. Bans on commercial and sport fishing, or warnings against excessive fish or bird consumption, have been issued in more than 20 states in the U.S. because of Hg levels greater than 0.5 mg/kg.

Current Levels in Biological Systems

The most detailed studies have been made in Sweden on fish (Johnels *et al.*, 1967; Westöö, 1967a; Westöö and Nören, 1967a; Westöö and Rydalv, 1969), and seed-eating birds (Tejning, 1967b). Westöö (1967a) has shown that the Hg content of pike (*Esox lucius*) increased with increased body weight. Studying trout of known age, Bache *et al.* (1971) have shown increasing concentration of Hg and also increasing proportion of methylmercury with age. Parallel analysis showed that the methylmercury content of white dorsal muscle does not vary appreciably from different parts of fish

(Westöö and Nören, 1967a). It has been found that practically all the Hg in fish is in the form methylmercury (Westöö and Rydalv, 1969). The data on fish in Sweden are difficult to summarize; the paper by Westöö and Rydalv (1969) alone gives analytical data on over 3000 fish collected from 44 sites. Suffice it to say that the averages ranged from 0.2 to 5 mg/kg, with many values in the range of 0.5 to 1.5 mg/kg. There has been some decrease, although not in all waters, following bans on alkyl Hg as a seed dressing and on the use of some Hg organics as slimicides in paper manufacture. Reductions of 25 to 45% in pike were noted in five waters between 1966 and 1968-1969. Tejning (1967b) concluded that in Sweden, enough alkyl Hg treated seed would be available to pheasants and other seed-eating birds to explain completely the levels of Hg found in these birds and their predators.

In Canada, the use of Hg seed dressing and the use of alkyl Hg derivates as fungicides (Fimreite, 1970a) have resulted in quite high values in the livers of birds, ranging from 0.1 to 0.55 μg/g; and in their predators, ranging from 0.76 to 6.84 μg/g.

Wobeser et al. (1970) examined the concentration of Hg in the muscle of ten species of fish collected from nine sites on the North and South Saskatchewan River in late 1969. For seven sites the average values were in the range 1.0 to 1.8 μg/g; the other two sites averaged 5.0 and 6.7 μg/g. Investigations by Fimreite (1970a)

showed high levels of Hg in fishes from Lake St. Clair, Ontario, in 1969. Subsequently, fishes in the St. Clair River, Detroit River, and some areas of Lake Erie were found to have levels up to 5 μg/g (Turney, 1970) and fishing was restricted in these areas in May 1970. By September 1970, fishing in some waters of 18 states was restricted (Celeste and Shane, 1970), and newspaper reports indicate that this list was increased to 33 by the end of 1970. Reader and Snekvik (1941) give values of 0.04 to 0.16 μg/g for fresh fish muscle from marine fish. Uthe and Bligh (1971) gave values of 0.02 to 0.09 μg/g for herring; 0.02 to 0.23 for cod; 0.33 to 0.87 μg/g for tuna; and 0.82 to 1.00 μg/g for swordfish.

Levels in Food Other than Fish

The levels of Hg in food, with the exception of those in fish, are generally low. Rice in Korea had levels of 0.031 μg/g (Kim *et al.*, 1969) and in England the maximum in rice was only 0.015 μg/g (Smart and Hill, 1968). Reigo (1970) gives the range of values of Hg in milk in Sweden as 0.003 to 0.022 μg/g. Eggs in Sweden averaged 0.021 μg/g (Underdal, 1968). Levels in meat in Denmark and Sweden were in the range 0.003 to 0.060 μg/g (Westöö, 1969a). Potatoes have been dipped in mercurials before storage and this foolish practice gave rise to levels of 0.9 to 2.4 μg/g (Hamilton and Ruthven, 1967). However, potatoes grown from dipped potato seed do not have appreciable residues.

Biological Concentration of Mercury

The work of Stock and Cucuel (1934) clearly shows biological magnification in the aquatic food chain. They found 0.03 μg/kg in sea water, 30 to 37 μg/kg in algae, and 105 to 110 μg/kg in fish. Johnels *et al.* (1967) found levels of 0.13 μg/kg in a stream in Central Sweden whereas the level in a one-kilo pike was 300 μg/kg; they found an even greater concentration in the Stockholm Archipelago where the values were, respectively, 0.25 and 2300 μg/kg. Hannerz (1968) examined the biological concentration of Hg experimentally in a pond situation. His results indicate that the concentration factors for inorganic Hg and alkoxyalkyl Hg compound are similar and show the lowest amount of concentration, whereas the highest values are for the alkyl Hg compound. These findings parallel the toxicological findings, and the comparisons of alkyl Hg with alkoxyalkyl Hg also parallels the findings of Westöö (1969a) on the incorporation of these compounds into eggs. Hannerz (1968) also determined the concentration factors for cod (two day exposure to Hg in water or food), the values for methyoxyethyl mercuric hydroxide were 388 and 118, respectively, whereas for methylmercuryc hydroxide the values were 606 and 1107.

Great blue heron (*Ardea herodias*) with carcass levels of 21.2 to 23.0 μg/g Hg had fishes in their stomach containing 1.8 to 3.6 μg/g. The levels in the liver were 137 to 175 μg/g. A common tern

(*Sterna hirundo*) had a carcass level of 7.5 μg/g and its stomach contained a fish with 3.8 μg/g. In this case the liver level was 39.0 μg/g (Dustman *et al.*, 1971).

The concentration via the aquatic food chain is much more marked than that for terrestrial systems. Hanko *et al.* (1970) noted that the percentage of birds with high Hg levels in livers were significantly higher for predatory birds than for seed eaters, and Fimreite *et al.* (1971) came to the same conclusion.

In view of the documented and suspected input of Hg to the environment many have called for strict bans to be placed on Hg. Two problems preclude strict bans from being effective. First, many industries are extremely dependent on Hg (USDI, 1970), and would collapse without it, though no doubt substitutes could be found in many instances. Second, strict bans even if feasible, would eliminate only about 50% of the input. Normal geological loss from rocks, fossil fuels, etc., contributes the other 50% of total input, over which we have no control (Goldberg, 1970). In conclusion, it is heartening to note that, as Goldberg (1970) points out, that man's direct use of Hg is unlikely to affect the concentration in the oceans since the amount in the oceans is four orders of magnitude greater than man's annual usage.

INDICATOR ORGANISMS

The practical use of biological indicators to monitor environmental quality has a long history dating back to the miner's canary; to the recognition about 100 years ago of the effect of sulfur dioxide on the vegetation surrounding smelters; and the observation, around the turn of the centu. y, of the effect of pollutants on the population of flora and fauna living in natural waters. Since that time, our knowledge of the biological effects of environmental pollutants has increased enormously, and monitoring schemes employing biological indicator organisms have been proposed and are in fact in daily use. There are intrinsic advantages in biological indicators as compared to chemical analysis for individual compounds. Forchhammer observed the utility of this fact as early as 1865, when he stated:

> the analysis of seaweeds and animals living in the sea offers us precious means of determining those elements which occur in so small a quantity in sea water that hitherto it has been impossible to ascertain their presence in water by chemical means (Riley, 1965).

Also, biological indicators are screening agents in that they respond to many different compounds, and they are integrating devices in that they show the cumulative effects over a period of time or over some spatial area; but their primary advantage is that the bio-indicators directly measures the property that we are really interested in, is there something in the air or water that is harmful to life?

Ideally, an "indicator organism" should possess the following attributes (modified after Schelske, 1966):

a: be of commercial value, or at least be easily obtainable and also be an organism of direct value to man (as food);

b: be widely distributed, so that comparisons between areas can be made;

c: be available in large numbers during all seasons;

d: be capable of rapid accumulation and high concentrations of several toxicants, so fewer organisms are needed to determine environmental burdens;

e: be sessile or semi-sessile in nature, thus acting as integrators of the pollutant in time;

f: be extensively studied, so as to have a well documented life history, feeding habits, etc., so as to better evaluate the observations made.

However, in real life, it is practical to look for an organism that can satisfy most of the above characteristics.

The Pacific Hake, Merluccius productus (Ayres), is one of the most abundant species of fishes in the northeastern Pacific Ocean. It undertakes a north-south migration along the coast. Its importance in world fishery is increasing. Alverson (1968) has made a preliminary estimate that the sustainable yield may be as great as 540 million pounds. As a latent protein source, it is receiving serious attention from the food industry. Finally, as detailed below, it is being extensively studied, and its life history, feeding and reproductive habits, etc., are well documented (USDI, 1970). The above

characteristics permit one to consider the Pacific Hake as a likely candidate capable of qualifying as an "indicator organism".

Biology of the Pacific Hake, *Merluccius productus* (Ayres)

Hakes of the genus *Merluccius* are represented in all coastal areas throughout the Atlantic and Pacific Oceans, except the Northwest Pacific. A review of the pertinent literature indicates that the genus has rapidly become important in world fish catches. Marshall (1966) provided the most recent interpretation for the systematic position of merlucciid fishes, distinguishing family Merluccidae from other groups of anacanthine fishes: *Melanomus*, Muraenolepidae, Bregmacerotidae, Gadidae, Moridae, and Macrouridae. Norman (1937) recognized seven species of worldwide hakes based on their characteristic location. *M. productus* (Ayres) from the Northeastern Pacific, was chosen for this study (Figure 1).

The Pacific Hake ranges from the Gulf of Alaska to the Gulf of California and occurs from shallow shelf waters to depths of 490 fathoms (DeWitt, 1952; Clemens and Wilby, 1961; Nelson, 1967). According to Alverson *et al.* (1964), major concentrations appear to be associated with the California Current and California Undercurrent Systems, which lie between Lat. 23° and Lat. 48°N, of the Pacific coast of North America (Sverdrup *et al.*, 1942). In the northerly part of its range the Pacific Hake seldom is taken and throughout much of

Figure 1. Photograph of the Pacific Hake, Merluccius productus (Ayres), showing the change in body form with age.

the Gulf of Alaska it is apparently replaced by Pacific cod and walleye pollock (Alverson et al., 1964)(Figure 2).

Genetic studies suggest that a single population inhabits the oceanic region between British Columbia and Mexico (Nelson and Larkins, 1970). Among hake collected throughout this region, gene frequencies reflected by each of the two enzyme systems show insignificant intersample variation. Enzyme system analysis indicates, however, that the Puget Sound hake population, which has a much slower growth rate than ocean fish, form a genetically distinct group.

Pacific Hake have been taken in bottom or mid-water trawls in waters from near the surface to at least 800 meters deep (Clemens and Wilby, 1961), but are occasionally taken at depths exceeding 600 meters. Commercial concentrations of Pacific Hake have been found at depths between 50 and 500 meters. The mature or adult population is normally confined to waters overlying the continental slope and shelf except during the spawning season when hake may be found several hundred kilometers seaward in the southern part of the range.

Investigations by the U.S. Bureau of Commercial Fisheries (now, National Marine Fisheries Service) and Soviet scientists indicate that the adult population of the coastal stock occupies the northern portion of the range (Northern California, Oregon, Washington and British Columbia) during the spring, summer and fall and the southern portion (Southern California and Baja California) during the winter

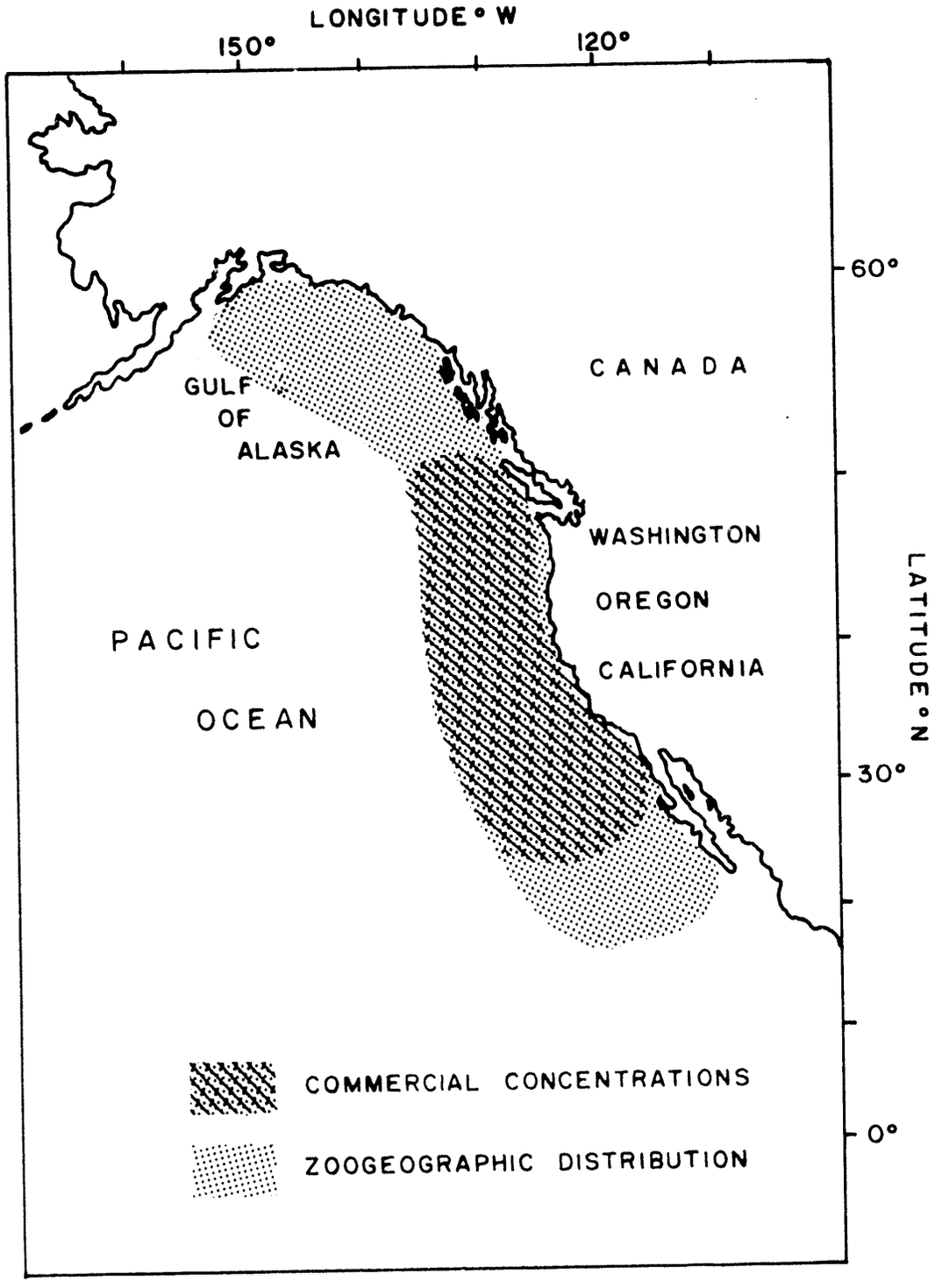

Fig. 2. Zoogeographic distribution of the Pacific Hake, showing the area of commercial concentrations (Alverson and Larkins, 1969).

(Nelson and Larkins, 1970). The availability of Pacific Hake to bottom and midwater trawls off Oregon, Washington and Vancouver Island drops sharply in November and is practically nil in the winter. During late April and May, hake again become available in the northern part of the range, and abundance increases sharply during the early spring. The adult stock remains in the northern areas until late fall.

In the winters adjacent to Southern California and Baja California large quantities of spawning hake have been taken offshore during the winter. The mature stock is concentrated during spawning in the deeper portion of its bathymetric range (200 to 500 meters), for the remainder of the year (May through September), it is concentrated in the waters overlying the continental shelf at depths less than 200 meters.

The work of Ahlstrom and Counts (1955) provides the best usable data on the general bathymetric distribution of hake eggs and larvae, and hence the distribution of spawning adult stocks. Eggs and larvae of the Pacific Hake are abundant off the coast of Southern California during the late winter and spring (February through April). Concentrations are greatest between Santa Barbara, California and Central Baja California but annual variations in distribution are substantial. Eggs and larvae have been encountered in relatively large numbers several hundred kilometers seaward, but concentrations are generally highest within 320 kilometers of the coast. Large scale

sampling of plankton by the BCF in April 1967 revealed no hake eggs or larvae between northern Vancouver Island and the California-Oregon border, offshore to 480 kilometers. Except for local, resident stocks in Puget Sound and perhaps other inshore areas, the entire coastal hake population apparently spawns off Southern California and Baja California.

Catches of Pacific Hake during exploratory fishing surveys between Vancouver Island, British Columbia, and Baja California have suggested that during the summer the average length (and presumably age) of the hake decreases from north to south (Alverson and Larkins, 1969). This size gradient, however, is often non-existent or even reversed within smaller areas (Alverson and Larkins, 1969). This difference in average length appears to be associated with increased availability of juveniles in the southern portion of the range and an almost complete absence of juveniles off Washington and British Columbia.

Investigation of the seasonal and annual distribution and abundance of Pacific Hake allows one to propose the following hypotheses concerning hake migrations (Alverson and Larkins, 1969).

a: Within the geographic range occupied by Pacific Hake, the adult segment of the population exhibits a large-scale north-south movement;

b: The movement is to the north during the spring and summer and to the south during the late fall and winter (Figure 3);

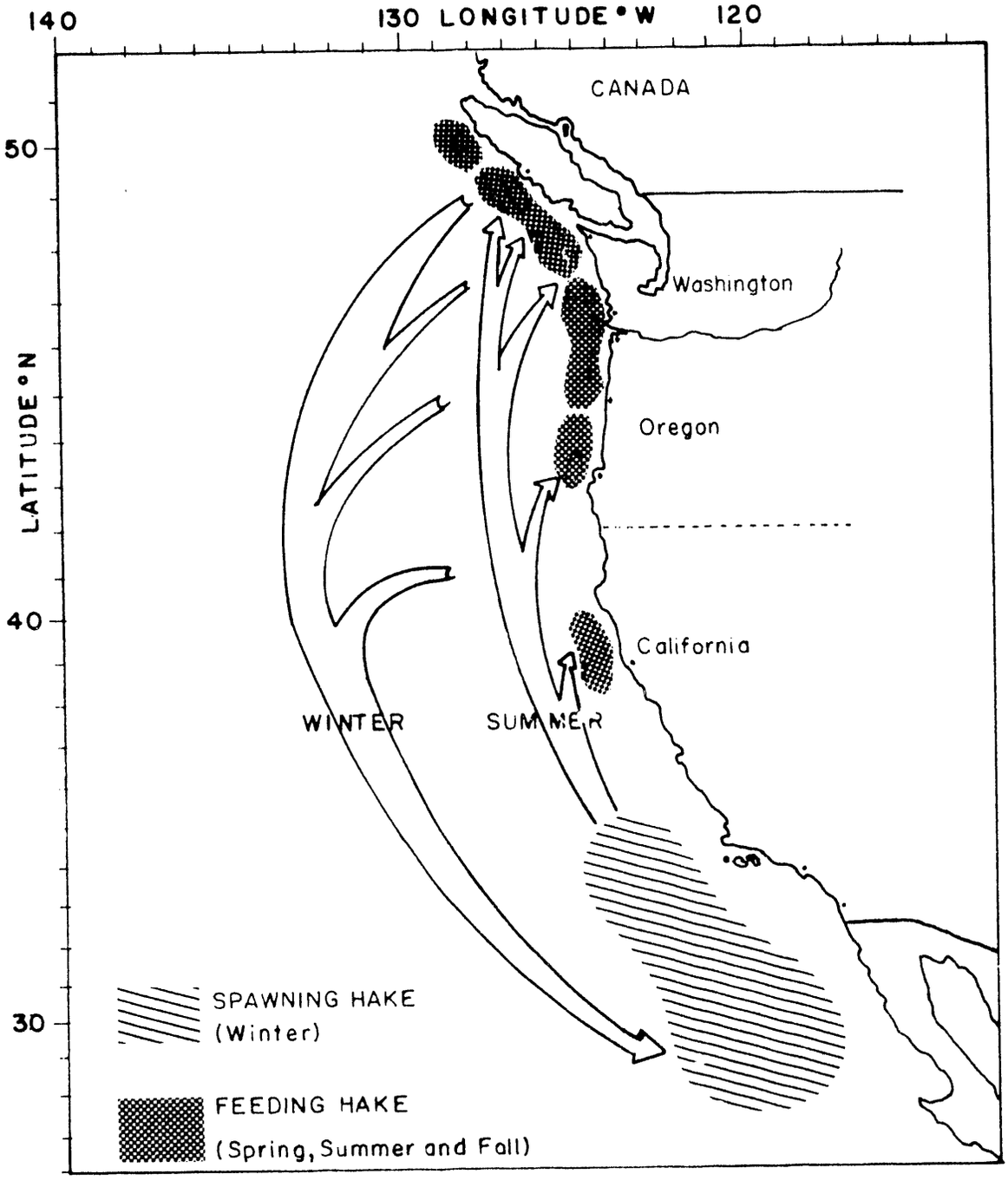

Fig. 3. Seasonal migrations and distribution of the Pacific Hake (Alverson and Larkins, 1969).

c: The northward migration of the adults is accompanied by movement towards the shore and into shallower waters (Figure 4);

d: The southward migration is accompanied by movement into deeper water and seaward (Figure 4);

e: Spawning occurs during the winter when the species occupies the southern portion of its geographic range;

f: The young live in the waters over the continental shelf but apparently do not make the large-scale migrations demonstrated for the adult portion of the stock, although one and two year olds have been collected as far north as the mid-Oregon coastline.

The diel vertical movements of Pacific Hake and the timing of such migrations suggest that they are correlated with the distribution and abundance of food. Hake schools rise and disperse in the water column during the evening. During darkness, hake are scattered throughout the water column and midwater trawls catch only small numbers of fish. By dawn, schools have regrouped near the sea bed but not necessarily near the areas from which they had dispersed.

Best (1963) and Gotshall (1969) noted that stomachs of adult hake contained a wide variety of organisms, including flounder, small hake, anchovies, clams, squids and euphausiids, and juvenile hake feed on euphausiids, red crabs, and small squid.

Pacific Hake live up to at least 13 years, and the maximum total length recorded was 80 cm (Best, 1963). Generally, fish four years old and older (mean length about 45 cm) are mature. Best (1963) found that in samples from California, all hake over 40 cm were

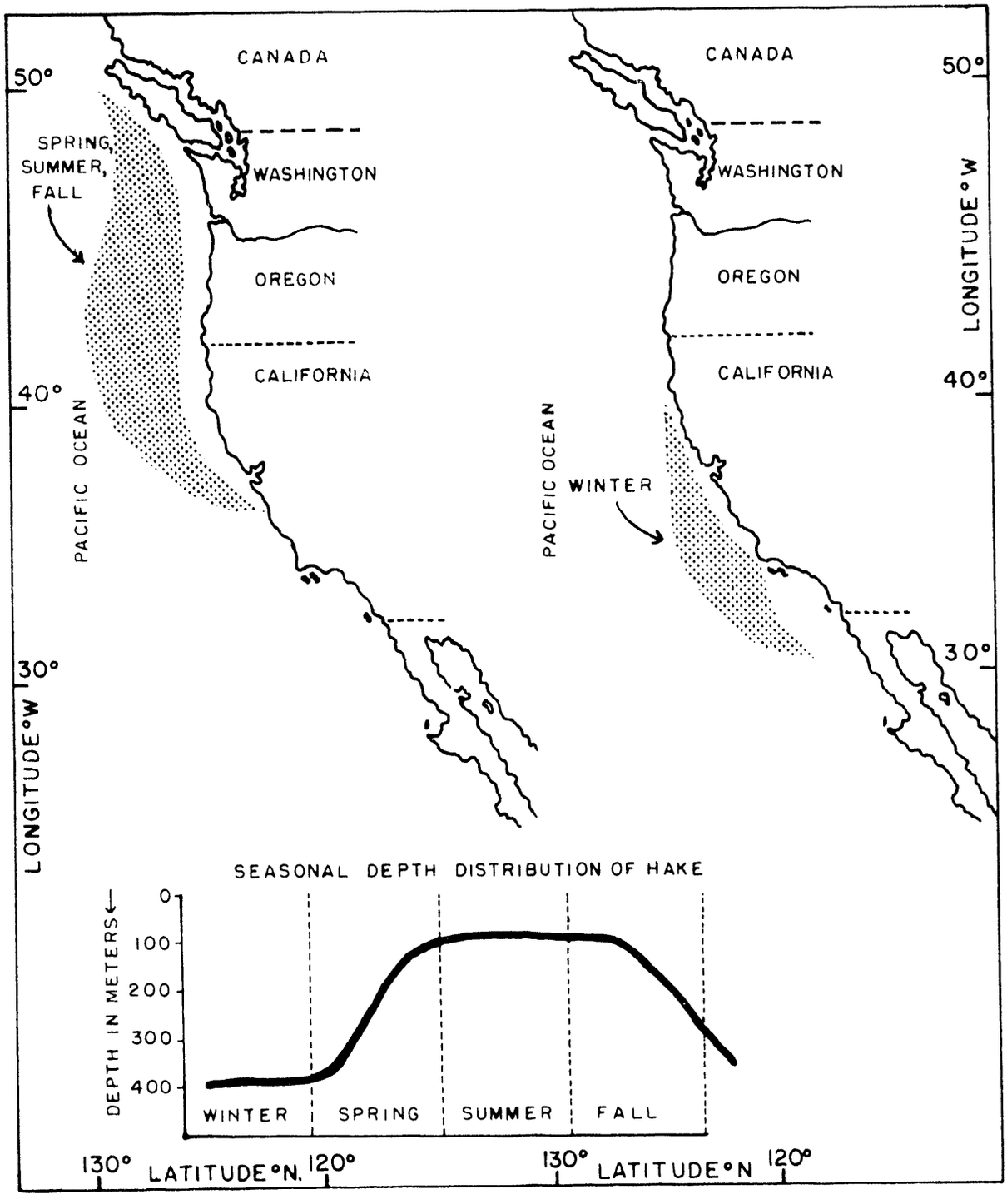

Fig. 4. Seasonal depth distribution of the Pacific Hake related to geographic area (Alverson and Larkins, 1969).

mature and concluded that most four year old fish and the larger three year old fish would spawn. All fish sampled from the Washington-Oregon fishery have been mature (either they had spawned or would spawn the following season). Three year old fish made up less than 0.5% of samples from the fishery. Four year old fish as small as 36 cm have occasionally been caught by research vessels in the area of the fishery.

Purpose of Study

Pollutant concentrations in fish tissues are crucial indicators of environmental quality. Fishes, like other organisms, integrate environmental exposures from multiple routes, thus providing an excellent sensory system for many environmental trace elements. Pollutant concentrations are important knowledge for the setting and appraisal of environmental standards. This study uses the Pacific Hake, *Merluccius productus*, to sense the trace elements, Zn, Cd, Hg, and ^{65}Zn and also examines the hypothesis that the Columbia River is a major source of Zn, Cd, Hg, and ^{65}Zn to the hake.

Specific activity, defined as the ratio of the quantity of a given radioisotope to the total element in a sample, is utilized to interpret the results found. The National Research Council (NRC, 1962) discussed specific activity:

> If the specific activities of the elements of the sea in the region of growth, development and habitation of marine food organisms can be maintained below the allowable specific activities of these elements in man and his sea food, the allowable radiation for any individual cannot be exceeded as a result of the consumption of marine products.

Renfro (in his lectures on Radioecology, 1970) cites the advantages in using the specific activity concept in determining the radioactive safety of food products:

a: specific activities of species having widely differing elemental compositions can be readily compared;

b: specific activities of individuals of the same species can be directly compared although their elemental compositions vary with season, age, size, and sex. Such comparisons afford useful data regarding relative rates of turnover;

c: specific activities of all components of the ecosystems (i.e., sediments, water, plants, animals) can be directly compared. Furthermore, organisms from environments having different stable element concentrations can be contrasted;

d: specific activities may provide insight into the vertical rate of radioactive transport, since radioactive decay causes the ratio to change with time;

e: specific activity measurements may be the most meaningful indicators of the degree of radioactive pollution hazard.

MATERIAL AND METHODS

Sample Collection and Processing

Collection of Samples of the Pacific Hake, *Merluccius Productus*

Specimens of the Pacific hake were harvested by Russian scientists on board "PROFESSOR DERYUGIN", in collaboration with the U.S. Bureau of Commercial Fisheries (BCF). These samples were collected during late July and early August, 1969. In addition, samples collected from the "JOHN N. COBB", M. V. "BARON", and the M. V. "COMMANDO" Cruises were also used in this study. Collection data, location of stations and number of specimens analyzed are given in Table 1 (Appendix). Figure 5 gives the sampling areas.

Standard procedures in preserving the fishes were followed in all the cruises. This consisted of packaging the fishes in plastic bags, labeling them and immediately freezing them in the ship's freezer ($\sim -10^{o}C$). In the laboratory the fishes were stored frozen ($\sim -25^{o}C$) until ready for analysis.

Collection of Water Samples

Collection data for water samples (fresh and sea water) are given in Table 2 (Appendix). Figure 6 shows the location of the

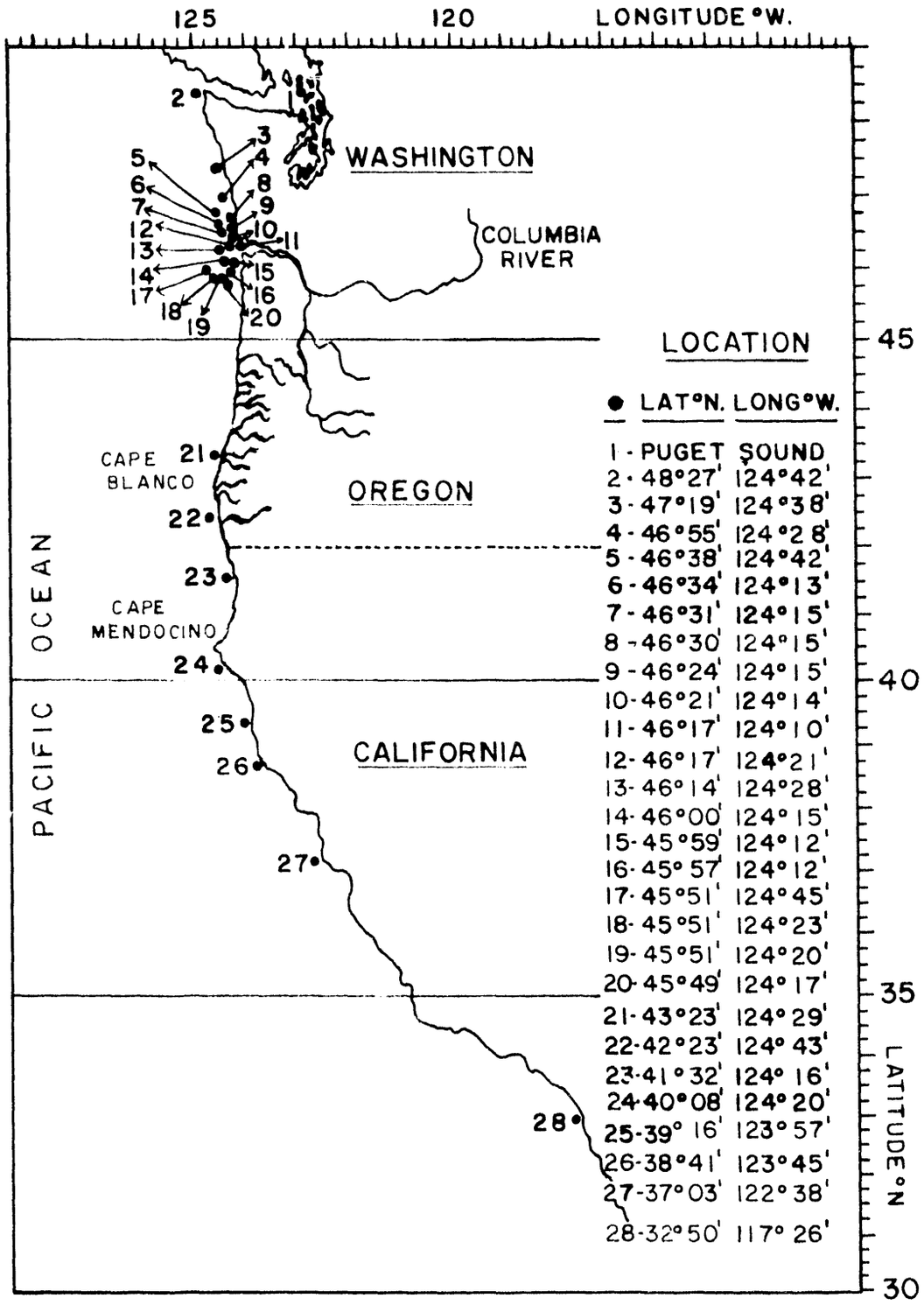

Fig. 5. Location of the sampling stations for the Pacific Hake.

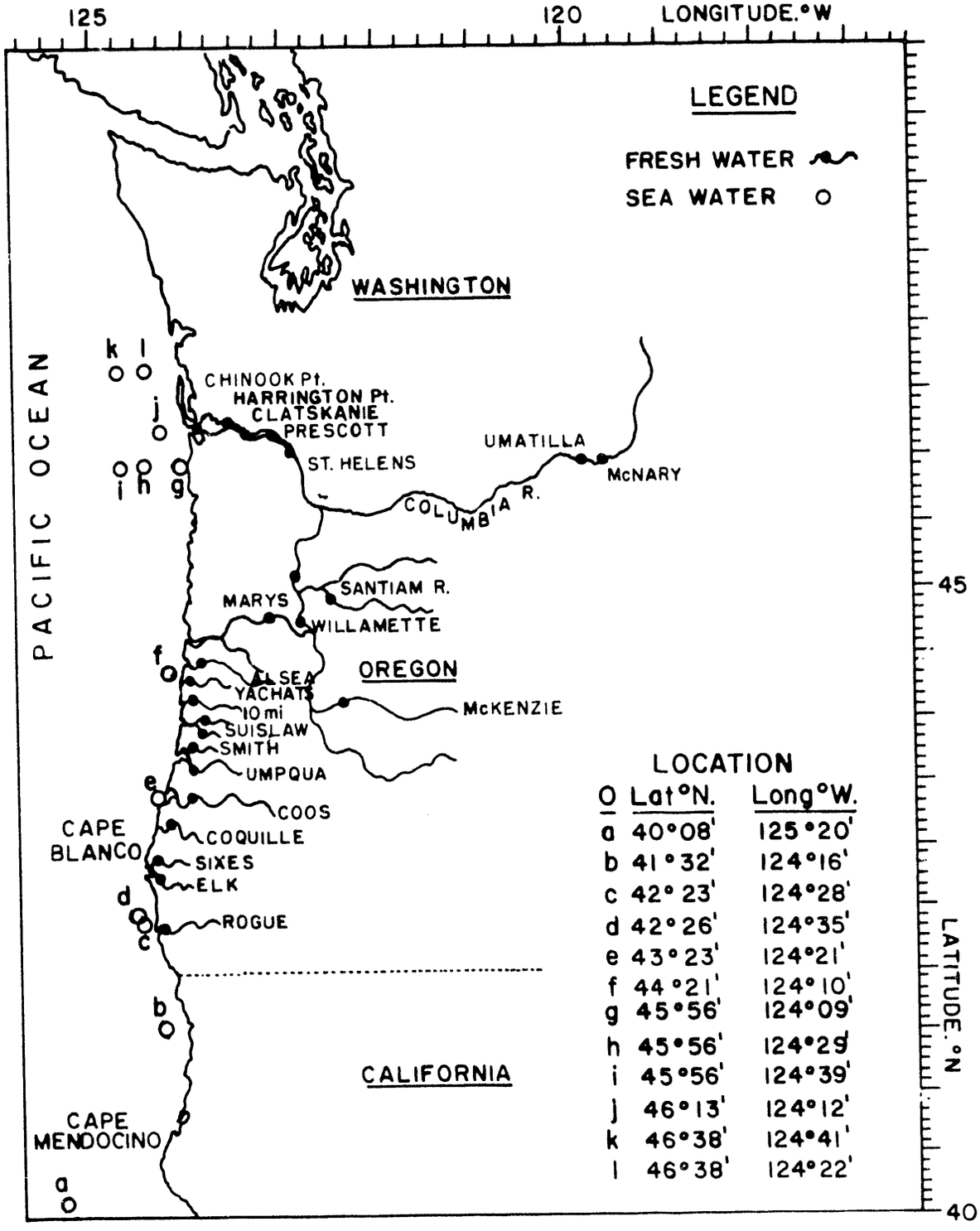

Fig. 6. Location of sampling stations for water samples (fresh and sea water).

sampling stations. The surface water samples were collected in a cleaned plastic bucket, and samples at depth were collected using a Van Dorn water sampler. The samples were immediately transferred into a well cleaned two-liter polyethylene bottle, acidified with 15 ml concentrated (70%) nitric acid and immediately frozen. The samples were kept frozen till ready for analysis. The samples were not filtered.

Preparation of the Pacific Hake for Analysis

The samples were prepared for elemental (Zn, Cd, and Hg) and radioactivity analyses (^{65}Zn) in the following manner. Since total Hg was also to be determined, and that only in flesh, the samples were prepared in two ways:

1. Entire fish: After standard length measurements were taken, the entire fish was cleaned of its stomach contents and then cut up into small pieces so as to fit into previously cleaned and tared Pyrex beakers;
2. Flesh: The fish was skinned while still in the frozen condition. The muscle portion (flesh) from both sides were taken out, and then cut into pieces so as to fit into previously cleaned and tared Pyrex beakers. Approximately 30g of the flesh was kept aside in cold storage ($\sim$-25°C), for Hg analysis.

The above two samples were dried in an oven at 90 $\pm$ 5°C for approximately three days. When ready, the beakers were taken out of the oven and immediately sealed with Saran Wrap (TM) to form an air tight seal, as seen by the depression in the center of the seal as the beaker seals. Such a procedure prevented any increase in sample weight due to absorption of moisture, etc. The dry weights were corrected for the weight of the Saran Wrap (TM).

The samples were then ashed in a muffle furnace at 400°C. Temperature was monitored with a separate thermometer and generally ranged within $\pm$ 20°C of the set temperature. Samples were kept in the oven for 48 hours, by which time a grey-white ash was obtained. Air was constantly circulated through the muffle furnace to accelerate the ashing process, especially since the temperature was set at 400 $\pm$ 20°C. After ashing, the samples were taken out of the furnace and sealed, as in the drying stage, with Saran Wrap$^{(TM)}$. Ash weights were corrected for the weight of the Saran Wrap$^{(TM)}$.

A Mettler balance, readable to $\pm$ 0.1 milligrams, was used in each of the four weighings.

The ashing in this study was done at 400 $\pm$ 20°C, well below the 600°C maximum temperature recommended by Gorsuch (1959), to prevent loss of Zn and Cd.

The ash obtained from the samples was first ground to a fine powder using a cleaned mortar and pestle, and then packed into 12 ml

polyethylene vial for counting. Usually there was sufficient ash to fill the vial to the 12 ml mark. In the event this was not possible, the height of the sample in the vial was measured, and geometry correction was made. A portion of the same ash was used for determination of the stable elements, Zn and Cd.

Methods of Analysis

Radioactive Zinc (^{65}Zn)

The ashed samples were analyzed for radioactivity by gamma-ray spectrometry, the principles of which have been described by Bowen and Gibbons (1963) and also by Seigbahn (1966). The vials containing the ashed samples were counted in a 5" x 5" NaI (TI) well-type detector coupled to a 512-multichannel analyzer. Counting times ranged from 100 to 800 minutes depending on the level of radioactiv ty in the sample. After counting, the corresponding background count was subtracted and the data compared to that of standards of known radioactivity. Data were reduced by a spectrum stripping computer program similar to that utilized by Osterberg (1963). Counting errors were computed by the method used by Osterberg (1963) and represent the error at the 95% confidence level with background subtraction and Compton correction for ^{40}K taken into consideration. Calibration standards for ^{65}Zn are certified by the

supplier to within ± 2%.

Stable Element Analysis by Atomic Absorption Spectrophotometry

The principles and applications of atomic absorption spectrophotometry (AAS) have been described by Slavin (1966, 1968), Crow *et al.* (1967), Kahn (1968), and Ramirez-Muñoz (1968). In this analysis, one metal has little or no effect on the measurement of another (Platte and Marcy, 1965; Robinson, 1966), and compared to other spectral methods, it is relatively free from interferences.

In preparing the ash for atomic absorption analysis, weighed portions of the ash were placed in 25 ml volumetric flasks together with 5 ml of 70% nitric acid. The flasks were heated on a hot plate. Digestion was further aided by dropwise addition of 5 ml of hydrogen peroxide (30%). The resulting solution was usually colorless. The solution was then taken down to dryness, and 0.36 N hydrochloric acid was added dropwise, to drive off the nitrous fumes, and then once again the mixture was evaporated to dryness, removed from the hot plate, allowed to cool and then dissolved in 5 ml 0.36 N HCl, and finally, made up to volume with 0.36 N HCl. Since a large number of samples were analyzed, one out of every five was done in duplicate. A blank solution containing only the reagents used was also prepared in a similar manner. Standard Zn solutions (0.25 to 6.00 μg/g) were made from Fisher AAS Certified Standards.

A calibration line was established from the standards prior to analyzing the unknown samples. An automatic direct concentration readout device coupled to the atomic absorption instrument gave readings directly in terms of the concentration (μg/g) of standards. The concentration of Zn originally present in the sample was then calculated.

Details pertaining to the calibration line, absolute sensitivity, detection limit, precision and accuracy for Zn determination, have been described by Larsen (1972) and therefore will not be repeated here.

Cadmium

In the preliminary analysis of the fish ash for Cd, it was recognized that the traditional flame technique was not sensitive enough for estimation of Cd at the levels occurring in the hake. The Delves sampling cup technique (Delves, 1970; Clark *et al.*, 1972) was also tried but results indicate coefficients of variation in the range of 20 to 30%. Carbon cup atomization offers increased sensitivity (Matousek and Stevens, 1971) and was found to yield coefficients of variation of 2-3%. A Varian Techtron™ Model 63 carbon cup atomizer coupled to a Model AA-5 spectrophotometer was therefore used for Cd analysis.

Ash in amounts ranging from 0.2 to 0.4 g was weighed out and transferred to 50 ml volumetric flasks. Dissolution of the ash was carried out in a manner similar to that for Zn determinations. Volume (50 ml) was made up with acidified distilled deionized water (ddw). Blanks were also prepared in a similar manner (without the analyte). Due to the large number of samples, one out of every five was done in duplicate. Standards were prepared by using Fisher AAS Certified Standards.

The time/temperature parameters for drying, ashing and atomizing stages were optimized for Cd (Matousek and Stevens, 1971). A 5 λ Eppendorf micropipette was used to transfer the sample solution into the atomizer. Such a dispenser gives freedom from both contamination by dispenser corrosion and cross-contamination from consecutive samples (5 λ capacity dispenser had a precision of ± 3%). After introduction of the sample into the cup, the drying, ashing and atomizing stages were initiated and the peak height recorded on a strip chart recorder. Appropriate standards and blanks were analyzed in a similar manner. Interferences due to the matrix were identified and measured by the use of a hydrogen continuum lamp operated at identical instrument settings for Cd. It was necessary to decontaminate the atomizer by increasing its temperature to ca. 3000°C after every sample to facilitate reproducibility.

The difference between the peak heights of the sample and blank were used in the calculations. Correction for non-atomic absorbance was not necessary in the case of the standards and blanks, but in the case of samples, corrections were necessary. Since these values were in percent absorption, they were first converted to absorbance. A least squares line was fitted to the calibration points. From this line, the values for the samples were estimated.

Total Mercury

Until recently, comparatively little effort had been expended in developing useful methods for determining Hg in most environmental samples. The difficulties of Hg analyses are formidable because of the range of samples (air, blood, hair, rocks, soil, sediment, fresh and sea water, fish, and urine), because of the sensitivity required (less than 1 μg/kg), and because of the need to detect total Hg, as well as amounts of different species of Hg. Finally, in most instances, a further demand was imposed, convenience for routine use. The method of choice in this study was determination by flameless atomic absorption spectrometry (FAA). FAA takes advantage of the facts that elemental Hg is volatile and that various Hg compounds can be converted into elemental Hg. The vapor is swept into a tube, ground-state atoms absorb light from a hollow cathode lamp, and the decrease in intensity is related to concentration. The drawback of

FAA is that it does not allow determination of separate chemical forms.

Several procedures are available for analysis of Hg by FAA spectrophotometry, including those described by Hatch and Ott (1968), the Dow Co. (1970) and Braman (1971). Apparatus for the first two is commercially available; the apparatus for the last is easily fabricated.

Essentially, the procedure consists of three steps: digestion, volatilization and detection. Solid substances (sludge, tissue) must be digested and mercury must be converted to a form that is easily reduced. Samples must also be free from organic contaminations that absorb at 2537 Å, and digestion is necessary to remove organics. Insoluble Hg compounds are solubilized with oxidizing agents (nitric and sulfuric acids, potassium permanganate). The digested sample is reduced typically with stannous chloride or sulfate, or hydrazine (though Braman (1971) used sodium borohydride) and the elemental Hg thus formed is volatilized into a 20 cm analysis cell. The sample absorption is determined by comparison at 2537 Å and the concentration is determined by comparison with appropriate standards. A more complete description of the procedure is given in Buhler _et al._ (1973).

RESULTS AND DISCUSSION

Collection of the Pacific Hake

Most of the fishing vessels involved in the hake fishery for this study used the Bureau of Commercial Fisheries (BCF) Universal Trawl specifically designed for catching hake (Johnson and High, 1970). The hake so caught were relatively free from damage, and this could be attributed to the fact that the 2.5 inch mesh eliminated gilling the hake. However, this large mesh imposed a lower size limit on the hake available for this study. Figure 7, a plot of number of fish as a function of length classes, indicates that 62% of the fish were in the range 400 to 500 mm, 23% below 400 mm and 15% above 500 mm. Based on age, weight and length relationships (Nelson and Larkins, 1970), the majority of fishes were adults three to four years of age and above. Such a biased catch is not without effects on data derived from such a population.

Length, Weight and Age Relationships

As mentioned earlier, since one sampling method was used, the catch does not represent all the ages, the fishing technique being more efficient for fish of the intermediate size, has shown tendencies to select more of the larger members of the younger age groups and more of the smaller members of the older age groups. Hence,

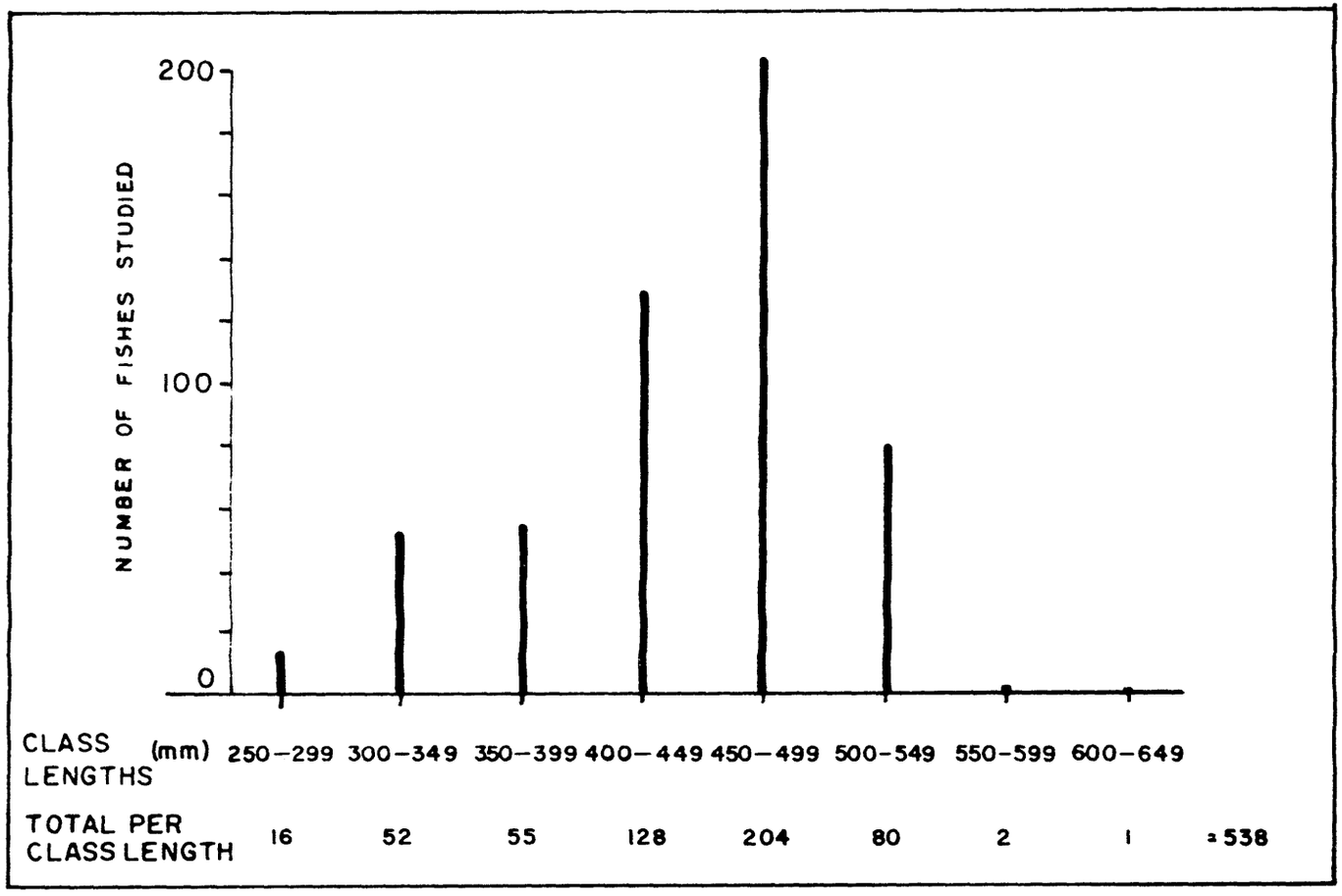

Fig. 7. Plot of the number of fishes as a function of length classes indicating a bias in the sampling of the Pacific Hake.

estimations of the growth rates must take this factor into account. Ideally, several different methods of sampling, i.e., different kinds of sampling apparatus, might have been used. Not having several sampling methods, the data on length and weight obtained in this study must be treated with caution.

Nelson and Larkins (1970) indicate that few fish younger than three to four years or older than ten years have been taken in the commercial fishery, and that ages through seven have dominated catches. Pacific Hake apparently grow rapidly during their first six or seven years. Thereafter, growth in length and weight becomes slower and may cease in old age. Females tend to grow faster than males and at any age after three to four years are slightly longer and heavier; however, the differences were negligible (Nelson and Larkins, 1970). As a consequence, sex differentiation was not taken into consideration in this study.

The allometric relationship, $W = A L^b$ (Ricker, 1958), was intended to describe growth of an <u>individual</u> fish. However, such data are rarely available. In this equation, W and L represent the weight and length of the fish, respectively. The value of "b" is usually determined by plotting the logarithm of weight against the logarithm of length for a large number of fish of various sizes, the slope of the line being an estimate of "b", and "a" is the y-intercept.

Ricker (1958) notes that the value of b = 3, describes "isometric" growth, such as would characterize a fish having an unchanging body form and unchanging specific gravity. Figure 8 shows a plot of log. weight as a function of log. length for the hake in this study. We get:

$R^2 = 0.83$ (R = Correlation coefficient)

$b = 3.43 \pm 0.044$

Though these values are derived only from the intermediate length-range of the fish, they do reflect the marked differences in body form over the range in question (Figure 1). This could account for the value of b = 3.43, as opposed to the "ideal" value of b = 3.00 (Ricker, 1958). Larger fish appear to add weight more by increase in girth than by increase in length.

Figure 9 is a plot of weight of the fish as a function of length as fitted by the CURVFIT* program of the allometric equation.

$Y = B_1 X^{B_2}$, where

B_1 = Y-intercept = $3.3 \times 10^{-6} \pm 1.0 \times 10^{-7}$

B_2 = slope = 3.41 ± 0.049

The estimate of Y is plotted on the figure and the line drawn through them. The values of "b" by either method are very similar (3.43 and 3.41).

---

*CURVFIT is a non-linear least squares fitting program on file at the O.S.U. Computer Center.

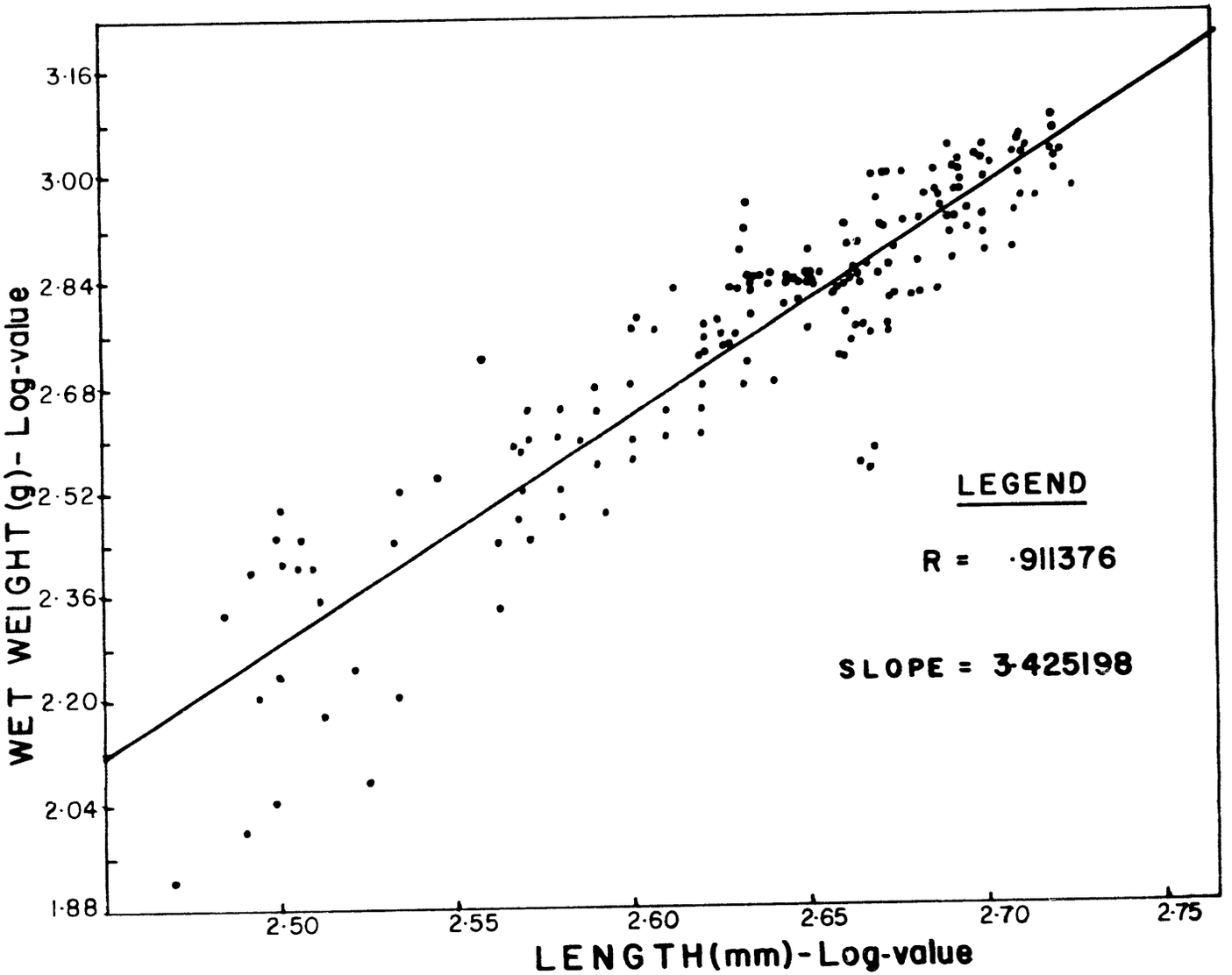

Fig. 6. Plot of log. weight as a function of log. length for the Pacific Hake.

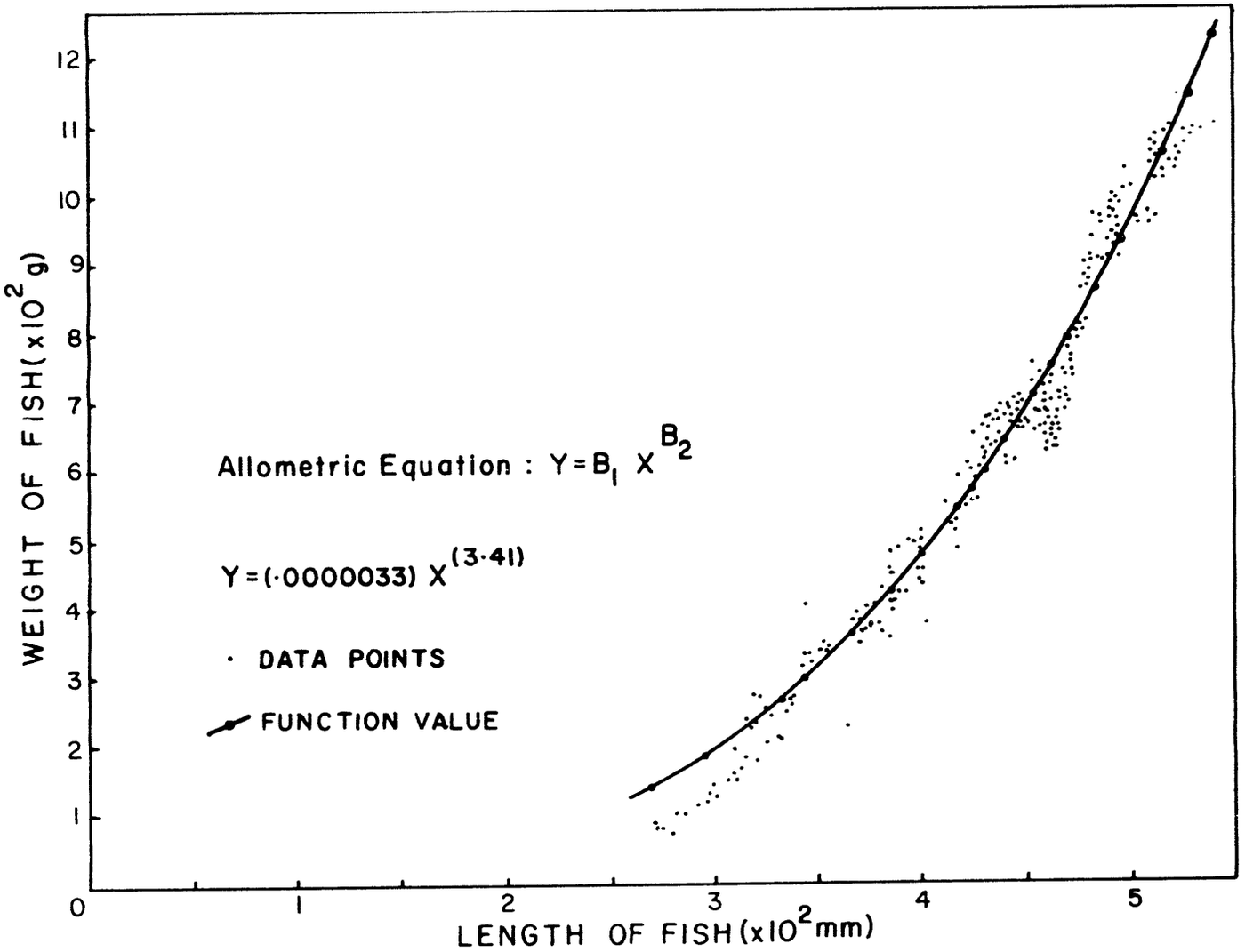

Fig. 9. Plot of weight of the Pacific Hake as a function of its length, the data being fitted to the allometric equation: $Y = B_1 X^{B2}$

The data plot, log weight as a function of log length, was needed in order to compare with similar plots of BCF data (Nelson and Larkins, 1970). The latter indicates the relationship between length, weight and age. Since these two sets of data were not greatly different, the hake in this study could be evaluated in terms of age, weight and length. Table 5 gives the length and weight of the fish at different ages, and Figure 10 is a plot of the same.

Table 5. Length, weight and age data of the hake (derived from BCF data, Nelson and Larkins, 1970).

Length (mm)	Weight (g)	Age (years)
197		.5
245	100.13	1
325	398.22	2
395	569.19	3 Juvenile
465	682.59	4 Adult
522	789.26	5
555	878.41	6
581	980.34	7
590	1021.66	8
595	1090.55	9
605	1131.29	10
609	1179.35	11
612	1209.11	12

As will be seen later this relationship was deemed necessary to evaluate the pattern of elemental concentration in terms of juveniles and adults.

Table 6 shows the average wet ratio to ash weight (W/A) and the average dry to ash weight ratio (D/A) for the entire fish and flesh, as a function of location:

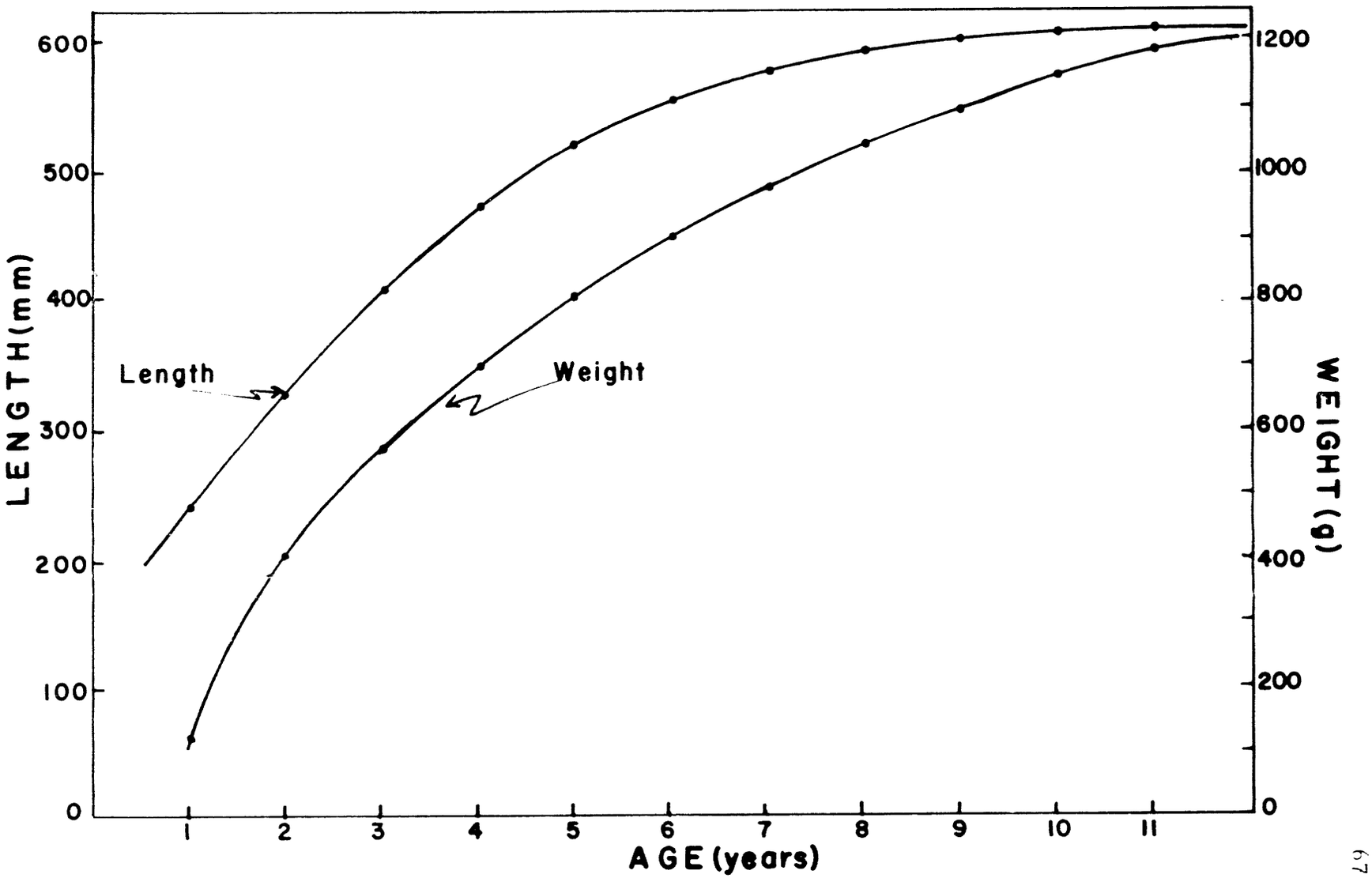

Fig. 10. Plot of weight or length of the Pacific Hake as a function of its age (Nelson and Larkins, 1970).

Table 6. The ratio: wet weight/ash weight (W/A), and the ratio: dry weight/ash weight (D/A), for entire fish and flesh for hake from different locations (Lat. °N).

Location (°N)	Ratio W/A (entire fish)	Ratio D/A (entire fish)	Ratio W/A (flesh)	Ratio D/A (flesh)
32	32.3	7.0	71.7	14.4
37	33.1	7.4	74.7	15.1
38	36.0	7.4	74.2	15.4
39	33.2	7.0	71.3	14.4
40	32.6	6.9	74.5	15.2
41	32.7	7.1	74.8	15.3
42	32.9	6.9	74.9	15.2
43	31.6	6.7	73.2	15.0
46	32.2	6.8	75.0	15.4
Puget Sound	32.3	7.0	73.0	15.1

Zinc

Growth represents a fundamental property of living matter, and through mathematics growth processes can be quantified. Therefore, the search for suitable mathematical formulation of growth is a very important biological problem.

The process of growth may be described mathematically by an exponential equation. The same is the case in other vital processes, as seen in this study, in the relationship between Zn in the hake as a function of length or body weight of the hake. Table 1 (Appendix) gives total Zn as Zn μg/g ash, in the entire fish and in flesh, as a function of length or weight of the fish. Figure 11 shows these relationships. It is obvious from these figures that:

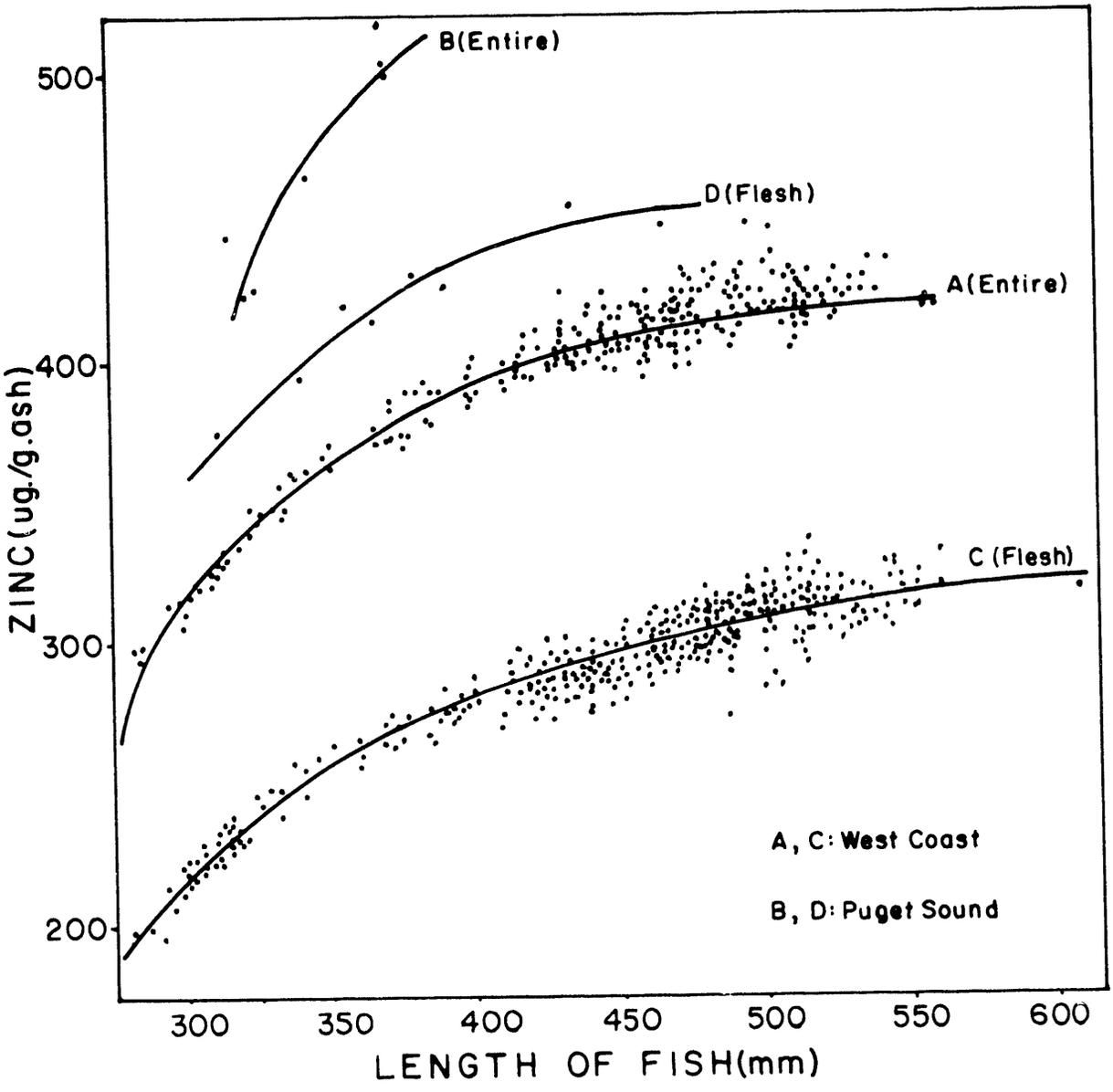

Fig. 11. Plot of zinc concentration (μgZn/g. ash) in the entire fish and in the flesh of the Pacific Hake as a function of its length

1. zinc concentration is a function of length or body weight;
2. the body weight is a good index of Zn concentration;
3. during the juvenile stage, the relationship between Zn and the parameters, length, body weight, or age is recti-linear (where anabolism or building processes predominate) and during the transition to the adult stage and during the adult stage, it is curvi-linear (when anabolism and catabolism processes are in balance);
4. the various processes of growth differ; length is one-dimensional; surface area is two-dimensional; and weight is three-dimensional. The corresponding relative increments will therefore be quite unlike in magnitude, as shown by the fact that length increases nearly three and one-half-fold; surface area, seven-fold; and body weight, 20-fold, between the juvenile and adult stages in man (Medawar, 1944). Because of these widely different rates of growth, the referral of any measurement of chemical composition to the various standards of reference such as length, surface area, body weight, or age, may not yield corresponding trends. This does not mean that the results are inconsistent but rather that their interpretation is dependent on the growth pattern of the standard applied. This was obvious when attempts were made to find a functional relationship between Zn concentration in the hake and the various parameters (length, weight, and age).

The choice of functional relationship is important. From Figure 11, it is obvious that the relationship between Zn concentration and either length or weight of the fish is not linear. Neither are the relationships between logarithms of Zn concentration and length or weight linear. However, a plot of total Zn versus weight of the fish (Figure 12) did give a linear relationship. Such a plot serves to indicate the total Zn in the entire fish and hence would not be useful when related to food standards which are most reasonably expressed as concentrations in edible portions. Figure 11 was therefore considered as a better frame of reference, with respect to the consumption of the fish by man, though it lacks linearity and requires curve fitting. There are two distinct common objectives of curve fitting. The simpler one is to provide a formula usable for interpolating values of the dependent variable. For this use, simplicity of the selected function, especially simplicity of calculation, is the aim and a polynomial is often used. The more complex and more important objective is to approximate the natural relationship, that is, to determine values for theoretical parameters. To do this, the selected function should satisfy several requirements. For example, to be considered for representing elemental concentration during growth to maturity, a function should approach asymptotically an upper value which, for this example, is the concentration of the element at maturity.

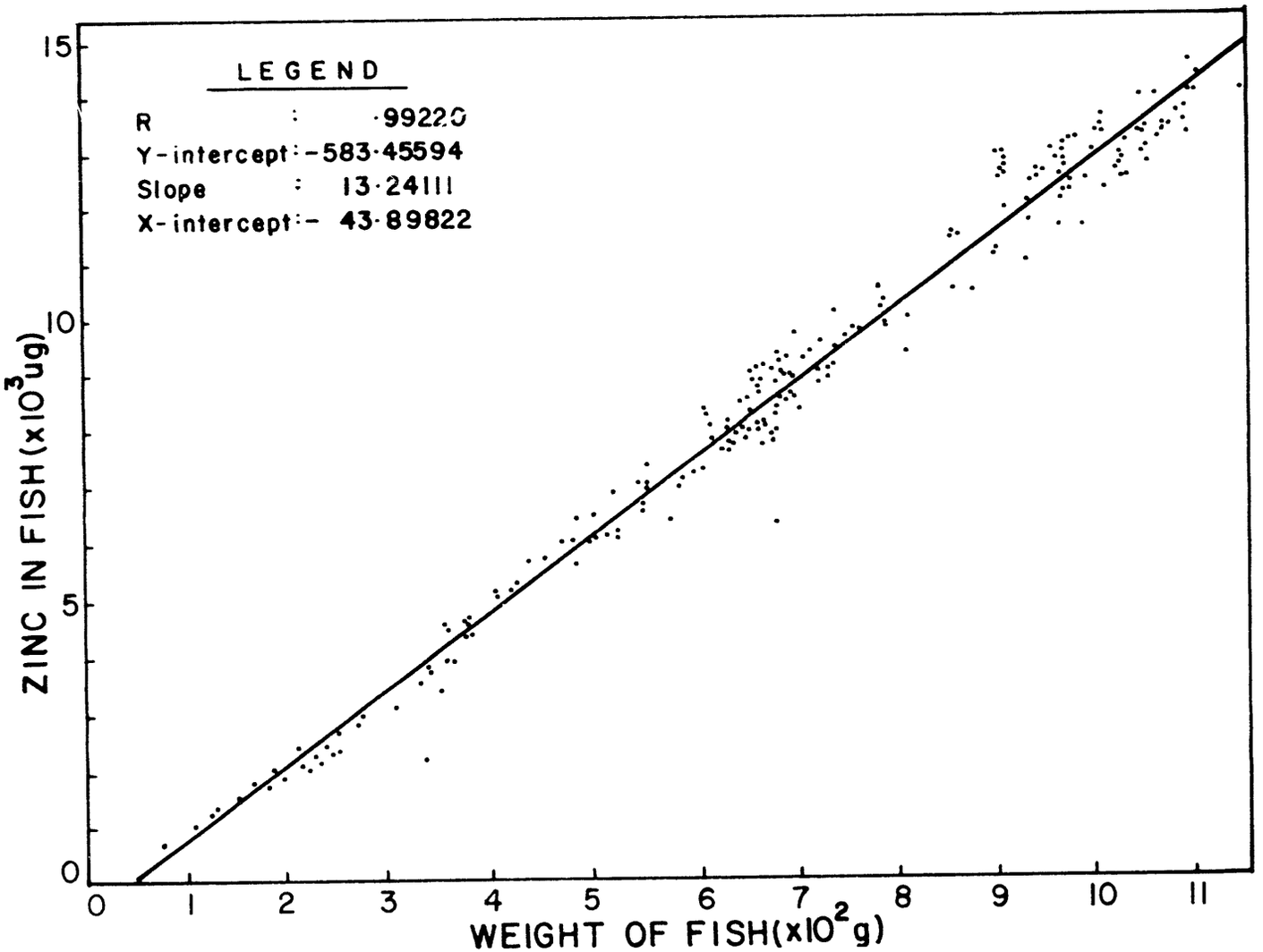

Fig. 12. Plot of total zinc concentration (μgZn/entire fish) in the Pacific Hake as a function of its weight.

Allometric, growth, and the exponential equations were fitted to the Zn data. Table 7 lists the results on the three equations tested. Figure 13 shows residuals after fitting to each of the three equations. Both the allometric and growth equations show a definite pattern indicating lack of conformity between the data points and the fitted equation. The exponential equation, on the other hand, shows not only a random distribution in the plot of the residuals, but also gives the lowest variance. Hence the exponential equation was considered, mathematically, to give the best fit. The equations are also described in terms of the corresponding values for the parameters as determined by the CURVFIT program (Table 7). It may be noted that the exponential model used contains three parameters whereas the other models contain only two. It may be this factor rather than the curve shape itself that yields a better fit to the exponential model.

Figure 14 is the CURVFIT plot relating Zn concentrations, μg/g ash (entire fish) and weight of the fish in terms of the exponential equation:

$$Y = B_1 + B_2 e^{B_3 X}$$

where

$$B_1 = 426.42 \pm 1.44$$

$$B_2 = -192.18 \pm 5.49$$

$$B_3 = -.0037 \pm .00017.$$

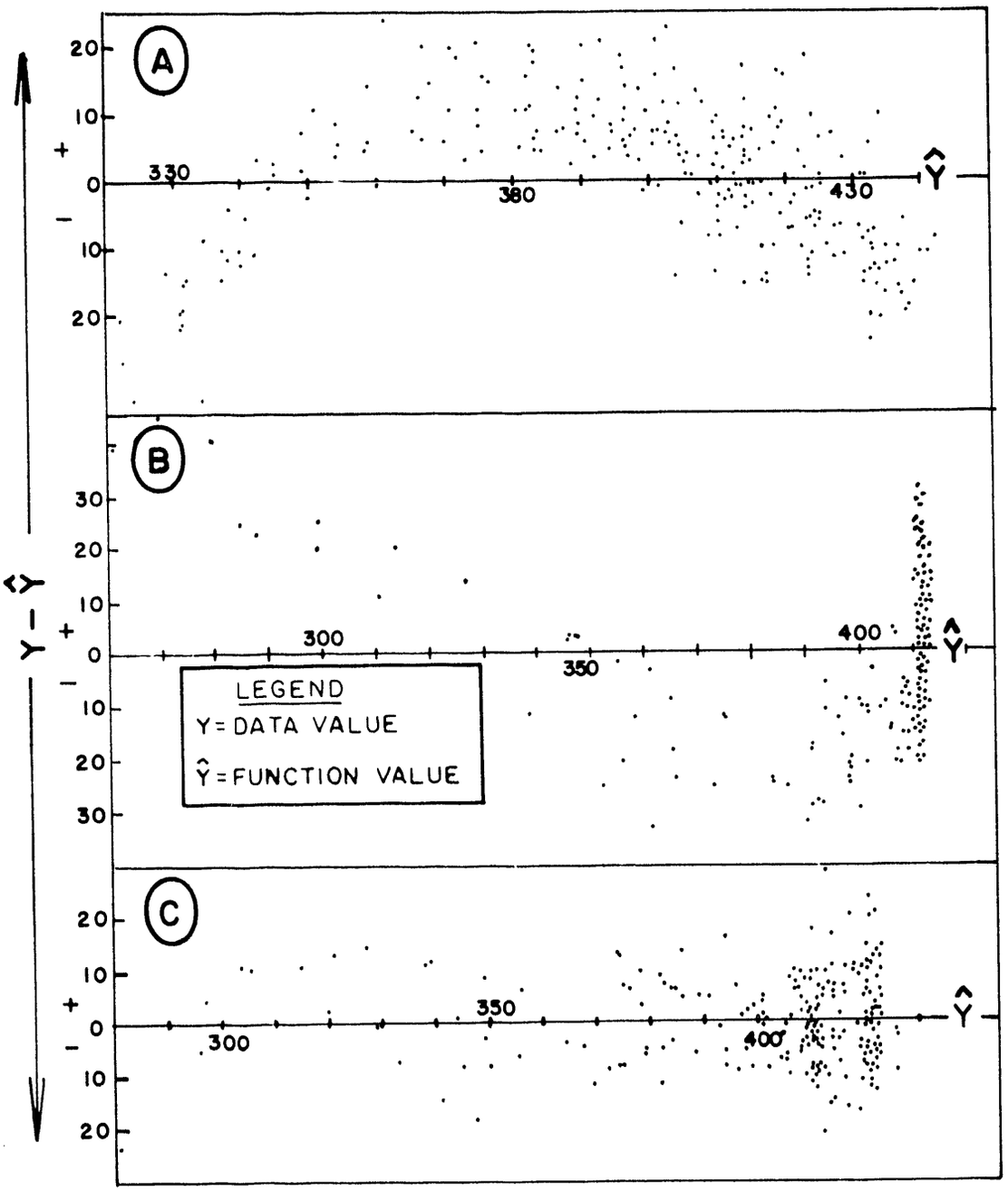

Fig. 13. Plot of residuals (zinc data fitted to the allometric, growth and exponential equations); these equations are:

A: allometric : $Y = B_1 X^{B_2}$

B: growth : $Y = B_1 (1 - e^{B_2 X})$

C: exponential : $Y = B_1 + B_2 e^{B_3 X}$

Table 7. Results of CURVFIT plots relating Zn concentrations ($\mu g/g$ ash) and weight or length of fish in terms of the allometric, growth and experimental equations.

Entire (E) Flesh (F)	Equations and Parameters	Function of: Length (L) Weight (W)	Variance
	Allometric: $Y = B_1 X^{B_2}$		
	B_1 = Y-intercept		
	B_2 = slope		
E	$Y = (197 \pm 1.95) x (.495 \pm .016)$	L	425
F	$Y = (8.36 \pm .61) x (.583 \pm .012)$	L	196
	Growth: $Y = B_1 (1 - e^{B_2 X})$,		
	B_1 = asymptote value		
	B_2 = decay constant		
E	$Y = (535 \pm 9.44)(1 - e)^{-(.0032 \pm .0012)X})$	L	160
F	$Y = (433 \pm 8.05)(1 - e)^{-(.0025 \pm .00009)X})$	L	695
E	$Y = (413 \pm 1.11)(1 - e)^{-(.0088 \pm .0002)X})$	W	215
F	data not directly applicable		
	Exponential: $Y = B_1 + B_2 e^{B_3 X}$,		
	B_1 = asymptote value		
	$B_1 + B_2$ = Y-intercept		
	B_3 = slope		
E	$Y = (429 \pm 1.8) - (6004 \pm 1060) e^{-(.013 \pm .0006)X}$	L	73.5
F	$Y = (341 \pm 3.95) - (920 \pm 98.8) e^{-(.0068 \pm .0045)X}$	L	42.2
E	$Y = (426 \pm 1.44) - (192 \pm 5.49) e^{-(.0037 \pm .00017)X}$	W	71.0
F	data not directly applicable.		

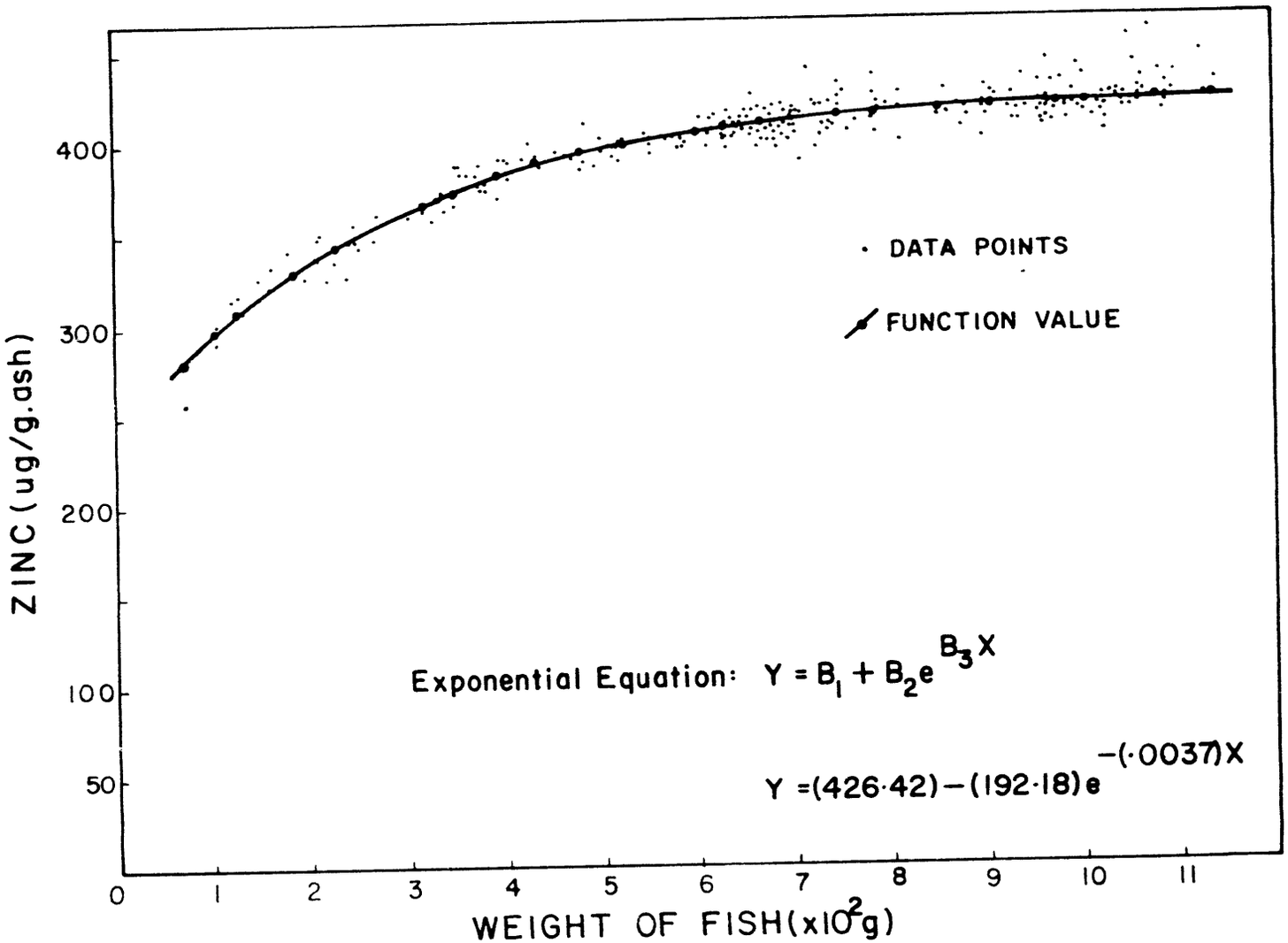

Fig. 14. Computer fit relating zinc concentration (μg Zn/g. ash for entire fish) in the Pacific Hake and its weight, in terms of the exponential equation:

$$Y = B_1 + B_2 e^{B_3 X}$$

Brody (1945) used the equation: $W = W_{max} - be^{-kt}$, to describe growth. He referred to W_{max} and k as genetic constants. This equation is equivalent to the exponential equation used here. Though we have not derived the two equations mathematically, we can speculate that in the exponential equation relating Zn concentration to body weight or length of the fish, the parameters B_1, B_2, and B_3 have descriptive biological values. For example:

B_1 = asymptotic value for Zn, or concentration at chemical maturity, that is, when the length or weight of the fish approaches steady state. This is similar to W_{max} in Brody's (1945) equation.

B_2 = location of the curve with reference to the weight or length of the fish. This is not a biological interpretation, but a chemical interpretation of the growth process. This is similar to b in Brody's (1945) equation.

B_3 = constant pertaining to the rate of change in the concentration of Zn. This is similar to k in Brody's (1945) equation.

The shape of the curve (Figure 14) is analogous to the findings of Payne and Wheeler (1968) where the approach to the asymptotic value is a function of the amount of utilizable protein in the diet.

A biological interpretation of the relationship between Zn concentration and length or weight of the fish might involve the physiological need of Zn by the fish. There is ample evidence, as reported

elsewhere in this thesis that Zn is an essential element and plays an important role in the enzyme system. Cross et al. (1973) have shown that Zn concentration in other species of fish tends to decrease with age, or maintain a constant level throughout its lifetime. In this study, a positive correlation between Zn concentration and length or body weight of the fish was found. That is, Zn concentration apparently increases with age in juveniles and approaches an asymptotic value at maturity.

Pequegnat et al. (1969) have shown that the amount of Zn present in organisms is far above what is estimated stoichiometrically (2.7 μg/g Zn represents the maximal enzymatic requirement for marine organisms). The functional value of this large excess of Zn is not clear. One hypothesis is that this excess may act to minimize uptake of other chemically similar but toxic metals such as cadmium. The Cd^{2+} ion interacts physiologically with Zn to which it is chemically similar (Pulido et al., 1966).

The most plausible source of Zn to hake is through food. Best (1963) has indicated that hake feeds exclusively on euphausiids during its juvenile stage, and shifts on to higher trophic levels (fish, squid, etc.) for feeding as it approaches maturity. Cutshall and Holton (1972) reported Zn values of 86-157 μgZn/g dry weight in euphausiids as compared to small fish, 18-44 μg Zn/g dry weight.

The BCF data (length, weight and age) (Nelson and Larkins, 1970) were used to categorize the hake samples in this study, as juveniles or adults. Using this distinction, plots were made of Zn, μg/g ash, as a function of length or weight of the hake, and regression lines drawn through the data points (Figure 15). It is obvious from these plots that the slopes for the juveniles and adult fishes are distinctly different. The ratio of slopes, Zn (juveniles) to Zn (adults) for Zn as a function of length or weight of the fish, are 3.80 and 6.56, respectively. These plots may explain the change in Zn concentration with length or body weight of the fish, from rectilinear to curvilinear, in terms of the change in food habits of the hake from an almost exclusive euphausiid diet (juveniles) to a mixed diet of pandalid shrimp, anchovies, herring, smelt, etc. (adults).

Zinc-65 (^{65}Zn) and Specific Activity (SA) of ^{65}Zn in the Pacific Hake

Figure 16 is a plot of ^{65}Zn (pCi/g ash) as a function of lengths of fish (mm) for fish from different locations (Lat. 32°N to Lat. 48° N and Puget Sound). From this plot the following observations are clear.

1. Zinc-54 concentration decreases with:
    a. increasing length of fish at each location
    b. later date of collection, i.e., from 1969 through 1972

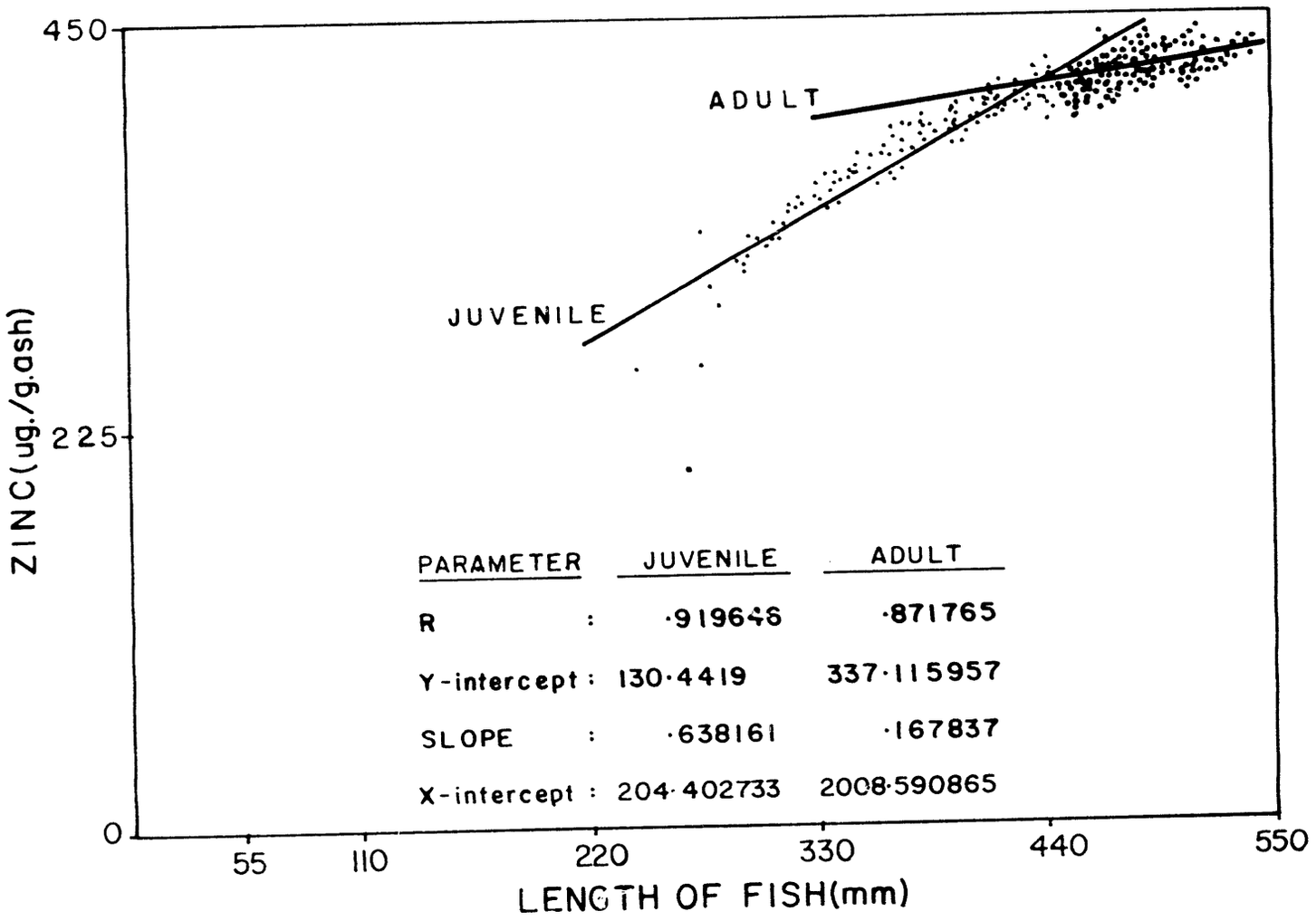

Fig. 15. Plot of zinc concentration (μgZn/g. ash) in the Pacific Hake as a function of its length, showing the change in slope between the juvenile and adult fishes.

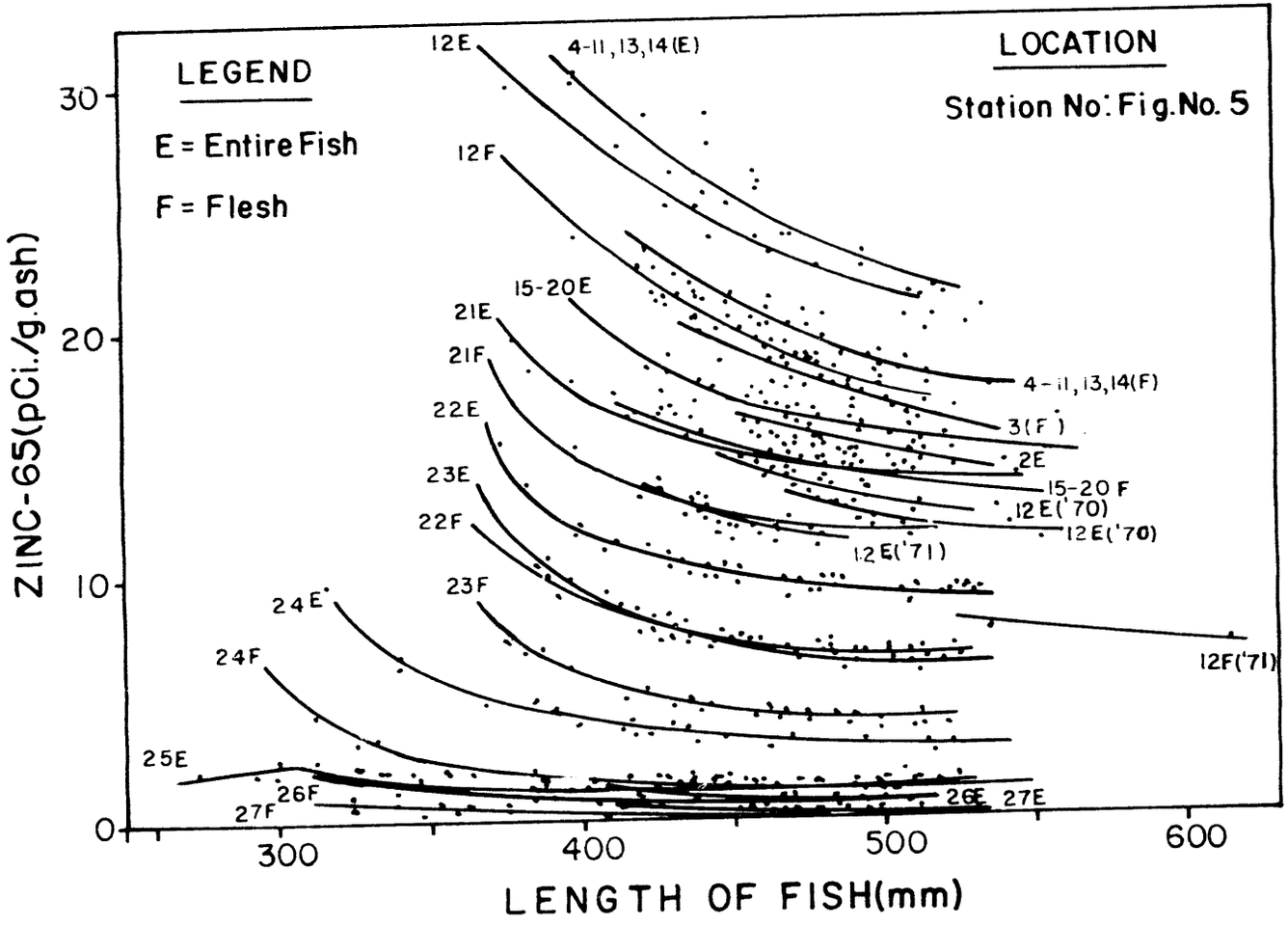

Fig. 16. Plot of radioactive zinc concentration (pCi ^{65}Zn/g. ash) in the Pacific Hake from different locations (Lat. 32°N to Lat. 48°N, and Puget Sound) as a function of its length. Numbers, 2-27, represent locations in Fig. 5.

c. increasing distance away from the Columbia River mouth (Lat. 46°17'N)

2. The highest ^{65}Zn concentration occurred in hake off the Columbia River mouth (Lat. 46°17'N).

3. Hake from Puget Sound and hake caught off California at Lat. 32°N appear to contain for ^{65}Zn from regional deposition of fallout from atmospheric nuclear detonations.

Worldwide fallout and the Columbia River are considered as the two principal routes of entry of ^{65}Zn into the Pacific Ocean. Alexander and Rowland (1966) suggest a zero contribution of ^{65}Zn from the Columbia River at distances greater than 1300 km south of the Columbia River mouth. This is corroborated by the clear association of ^{65}Zn content of marine organisms with the known position of the Columbia River plume (Osterberg et al., 1964). Samples collected near the mouth of the Columbia River have higher ^{65}Zn content than samples more distant. Zinc-65 in plankton have been used as an indicator of the distribution of the Columbia River water (Seymour, 1960).

The euphausiid, Euphausia pacifica, an important forage organism which is eaten by many carnivorous animals, is known to concentrate ^{65}Zn. Zinc-65 in the marine environment is chiefly associated with particulate matter. This, combined with the setal feeding habit of the euphausiids, results in relatively high

concentrations of ^{65}Zn. Osterberg (1963) has shown that the variability of ^{65}Zn in euphausiids from the same location at one time was not large; however, the amount of ^{65}Zn taken up is a function of the length of time spent in the waters containing ^{65}Zn.

The hake, as described elsewhere in this thesis, moves north in summer and south in winter. The Columbia River plume during summer flows southeast and away from the Oregon coast (Barnes et al., 1972). Consequently, as the hake move north approaching the plume, they are exposed to increasing concentrations of ^{65}Zn via the food chain, but beyond the Columbia River mouth, i.e., further north toward Lat. 48°N and beyond, the ^{65}Zn present in the water is much lower. This situation apparently results in the ^{65}Zn activity maximum at 46°N. An interesting feature is that the ^{65}Zn activity in hake at Lat. 40°08'N is higher than at Lat. 39°16'N, while stations south of Lat. 39°16'N are not lower. It appears that Lat. 40°08'N is the southernmost latitude where elevation of ^{65}Zn levels by the Columbia River is noticeable. The contour of the coastline, as seen in Figure 5, also changes abruptly at this latitude. Perhaps there is some physical control of water containing ^{65}Zn by the coastline. Also the Columbia River plume gradually moves away from the coastline as it flows southward. These factors could reduce the exposure of the hake to ^{65}Zn from the Columbia River. However, Folsom et al. (1971) based on observations of ^{65}Zn activity in tuna, conjecture

that the ^{65}Zn from the Columbia River can be detected in fish caught some 1500 miles (south) from the river mouth.

Zinc-65 could be detected in hake from Lat. 32°N and Lat. 37°N, though the counting errors were high (~30%). The values were distinctly higher than that of the Puget Sound hake. The samples from the California region, therefore, may have accumulated ^{65}Zn from the Columbia River as proposed by Folsom et al. (1971) or, more likely, the hake had accumulated ^{65}Zn from exposure to Columbia River water off Oregon during a previous annual migration to the north. The unfortunate lack of juveniles in the samples prevents testing the latter hypothesis here. The Puget Sound population apparently does not migrate out of the Sound.

Specific activity is considered to be more indicative of the history of the animals' environment than as an indicator of their immediate environment. It is also less variable than either ^{65}Zn or total Zn. If the amount of stable Zn is uniform, then any decrease in the SA would result primarily from a decrease in the ^{65}Zn activity. Forster (1972) reported that the surface to 10 m depth value for stable Zn for locations between Lat. 37°N to Lat. 45°N is relatively constant (~19 μg/kg); however, the decrease in ^{65}Zn activity from the mouth to the southern end of the "plume" (indicated by a salinity of 32 °/oo) is 100-fold. Figure 17, which represents the plot of SA (^{65}Zn), in flesh as a function of length; in the entire fish as a function

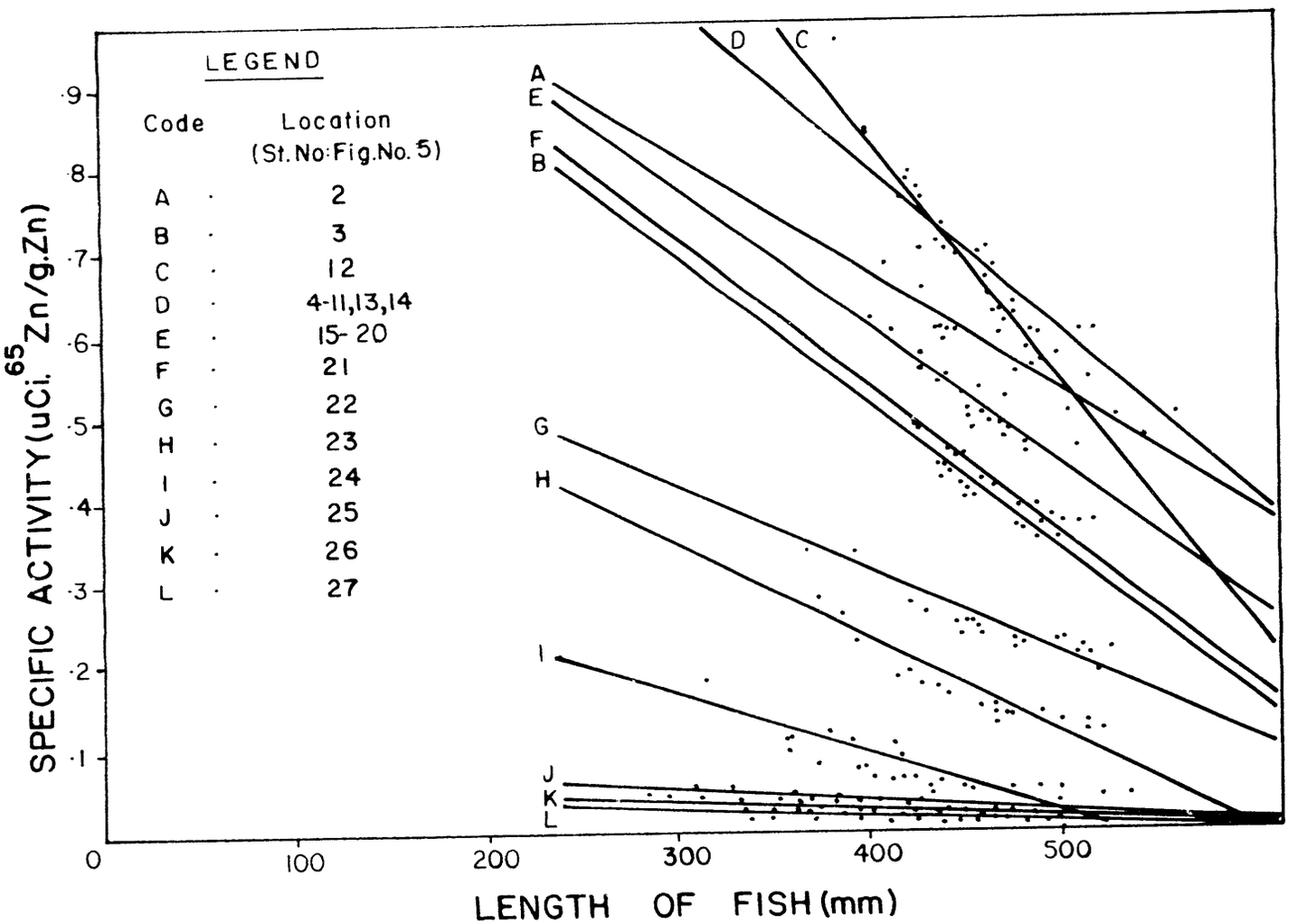

Fig. 17. Plot of specific activity ($\mu Ci^{65}Zn/g.$ Zn) in the Pacific Hake as a function of its length.

of length; and in the entire fish as a function of weight, respectively. These plots were made for each location, and regression lines were fitted (Figure 17). An analysis of co-variance indicates that the slope at any particular location increase significantly with increasing latitude, and decrease slightly north of Lat. 46°N.

Table 8. Regression data for specific activity (^{65}Zn) vs. length and weight of the fish as a function of location (Lat. °N).

Function	Lat. °N	R^2	Slope (X 10^{-5})
SA (^{65}Zn) in entire fish as a function of weight of fish	48	.94	-1.5
	46	.79	-4.7
	45	.49	-1.7
	43	.64	-2.2
	42	.64	-2.5
	41	.67	-2.0
	40	.53	-1.8
	39	.86	-0.6
	38	.68	-0.5
	37	.73	-0.4
SA (^{65}Zn) in entire fish as a function of length of fish	48	.83	-8.1
	46	.94	-23.6
	45	.56	-13.5
	43	.83	-13.6
	42	.74	-13.2
	41	.70	-9.9
	40	.66	-8.3
	39	.91	-2.4
	38	.79	-2.2
	37	.79	-2.5
SA (^{65}Zn) in flesh as a function of length of fish	48	.72	-17.9
	47	.91	-14.3
	46	.96	-10.3
	46(NR)	.69	-19.8
	45	.78	-16.9
	43	.83	-18.1
	42	.75	-10.1
	41	.81	-11.4
	40	.64	-7.2
	39	.92	-1.2
	38	.82	-1.1
	37	.82	-1.1

Cadmium

Table 1 (Appendix) gives total Cd (μg/g ash) in the entire fish and in flesh, as well as length and weight of the fish. Figure 18 shows that Cd concentration is non-linear with either length or weight of the fish. However, a plot of total Cd (μg in entire fish), when plotted as a function of the weight of the fish, gave a positive correlation (Figure 19). Conclusions drawn from these plots and from curve fitting are identical to those for Zn and will not be repeated here. The allometric, the growth and the exponential equations were all tried on the data and based on the residuals (Figure 20) and the variances, the exponential equation was again found to give the best fit. The values of the parameters, and the form of the equation when plotted are outlined in Table 9 and Figure 21, respectively.

Data on Cd physiology are scanty, and attempts to give a biological meaning to the parameters would be difficult, hence the relationship expressed by the exponential equation was deemed empirical. However, the plot of Cd concentration as a function of length or body weight, which exhibits a shape very similar to that of Zn (Figure 11) could be explained in the following manner:

1. Soluble Cd concentrations for open oceanic waters fall within 0.01 and 0.05 μg/l, being very similar to Hg concentrations (IDOE, 1972). Inshore levels may be a factor of 10 higher.

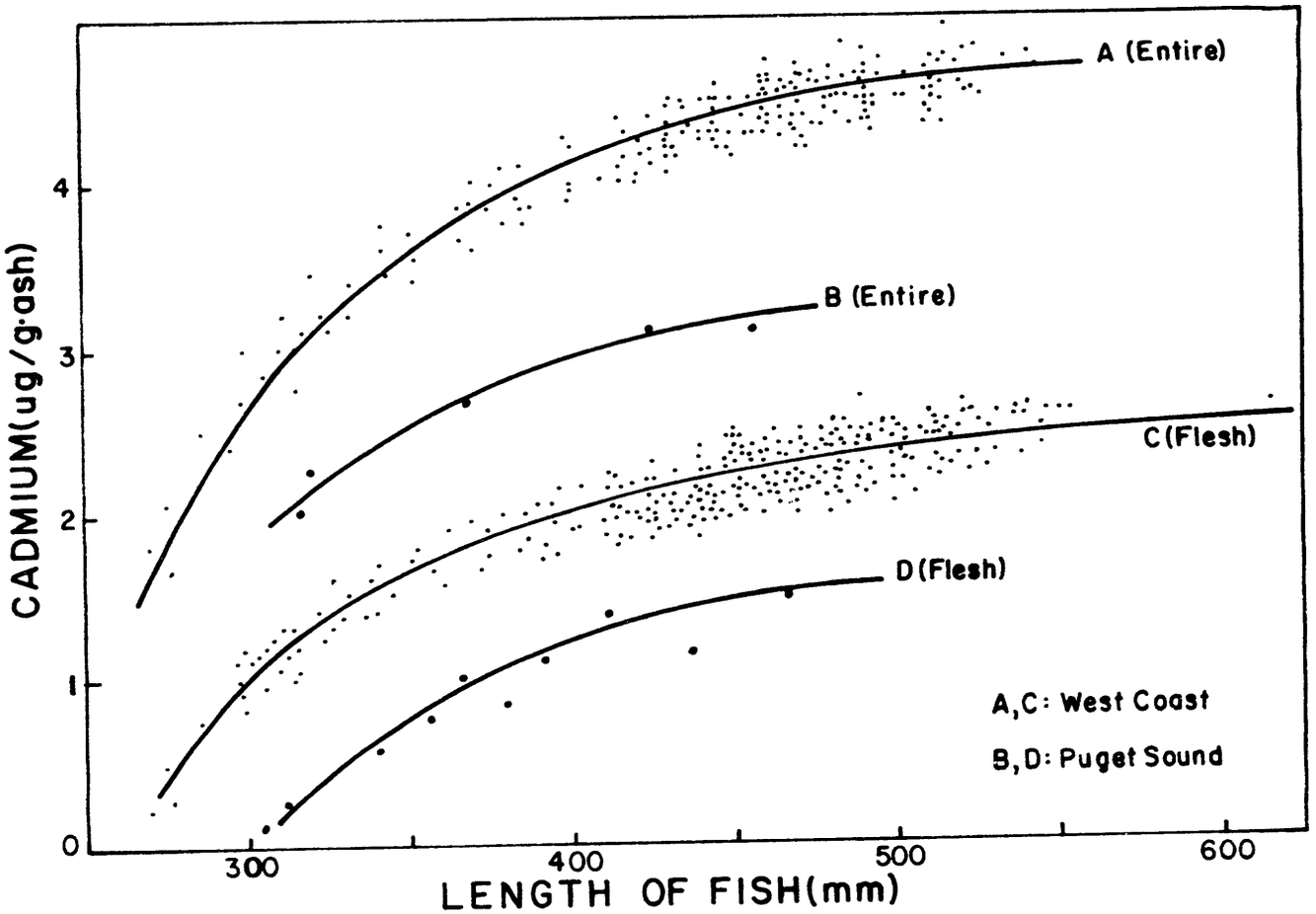

Fig. 18. Plot of cadmium concentration (μgCd/g. ash) in the Pacific Hake as a function of its length.

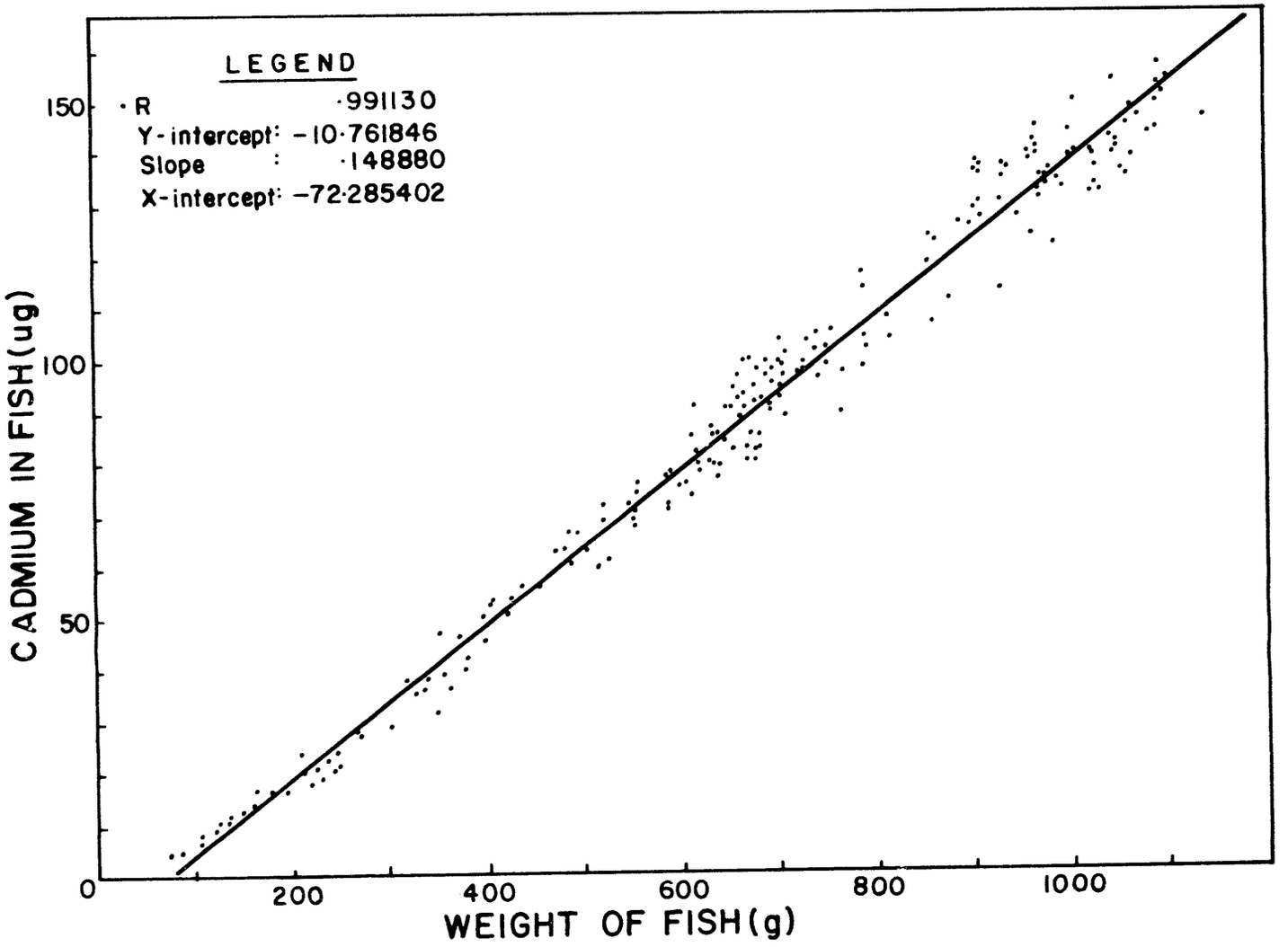

Fig. 19. Plot of cadmium concentration (μgCd/entire fish) in the Pacific Hake as a function of its weight.

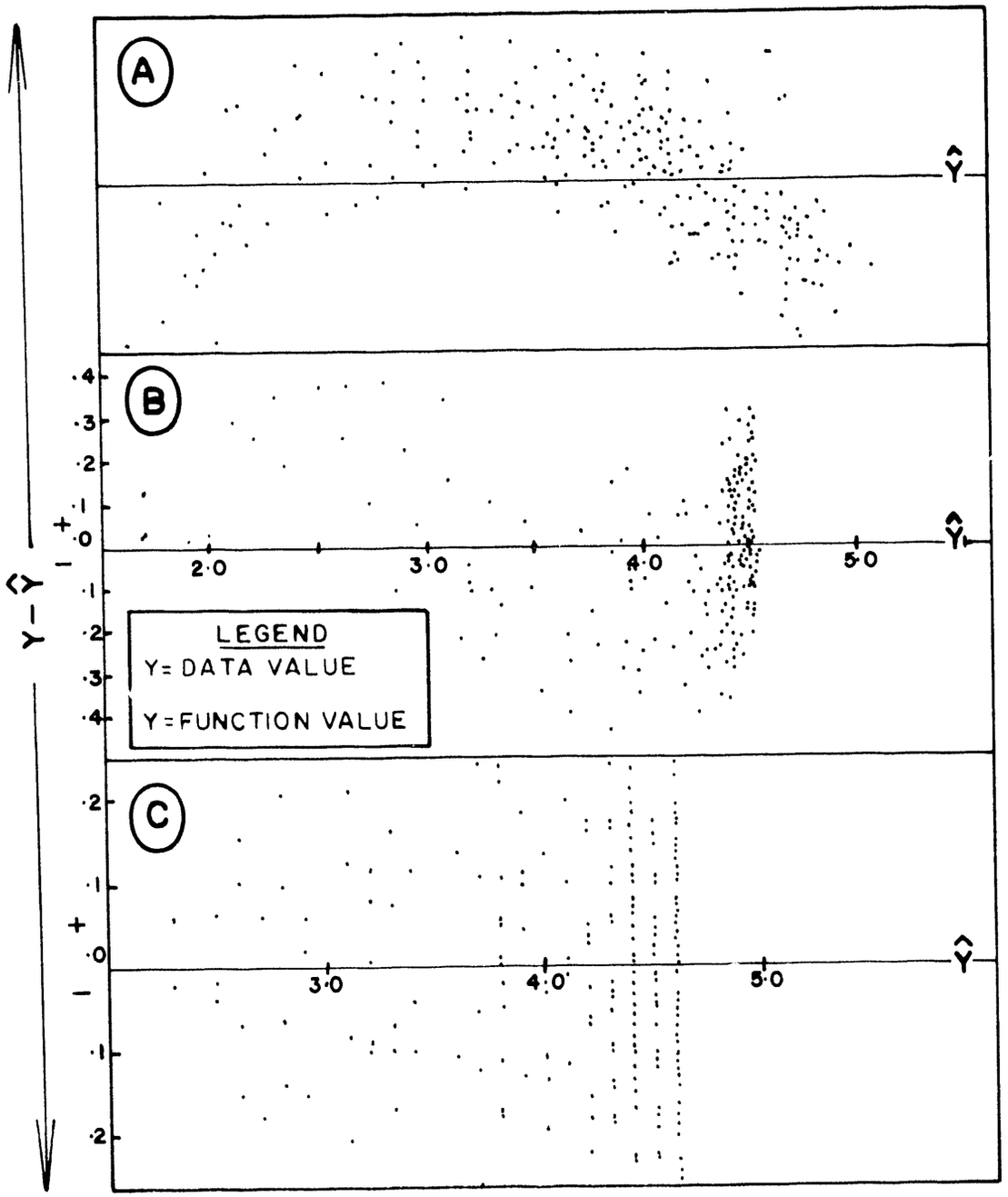

Fig. 20. Plot of residuals (cadmium data fitted to the allometric, growth and exponential equations); these equations are:

A: allometric : $Y = B_1 X^{B2}$

B: growth : $Y = B_1 (1 - e^{B_2 X})$

C: exponential : $Y = B_1 + B_2 e^{B_3 X}$

Table 9. Results of CURVFIT plots relating Cd concentrations (μg/g ash) and weight or length of fish in terms of the allometric, growth and exponential equations.

Entire (E) Flesh (F)	Equation and Parameters	Function of: Length (L) Weight (W)	Variance
	Allometric: $Y = B_1X^{B_2}$		
	B_1 = Y-intercept		
	B_2 = slope		
E	$Y = (0.29 \pm .0047)X(.82 \pm .023)$	L	.052
	$Y = (.00125 \pm .00031)X(1.22 \pm .04)$	L	.033
	Growth: $Y = B_1(1 - e^{B_2X})$		
	B_1 = asymptote value		
	B_2 = decay constant		
E	$Y = (4.54 \pm .0175)(1 - e^{-(.0054 \pm .00012)X})$	W	.033
F	Data not directly applicable	W	---
	Exponential: $Y = B_1 + B_2e^{B_3X}$		
	B_1 = asymptote value		
	$B_1 + B_2$ = Y-intercept (X=0)		
	B_3 = slope		
E	$Y = (4.80 \pm .039)-(58.5 \pm 9.3)e^{-(.011 \pm .0006)X}$	L	.02
E	$Y = (4.66 \pm .027)-(3.47 \pm .099)e^{-(.00376 \pm .00018)X}$	W	.025
F	Data not directly applicable		

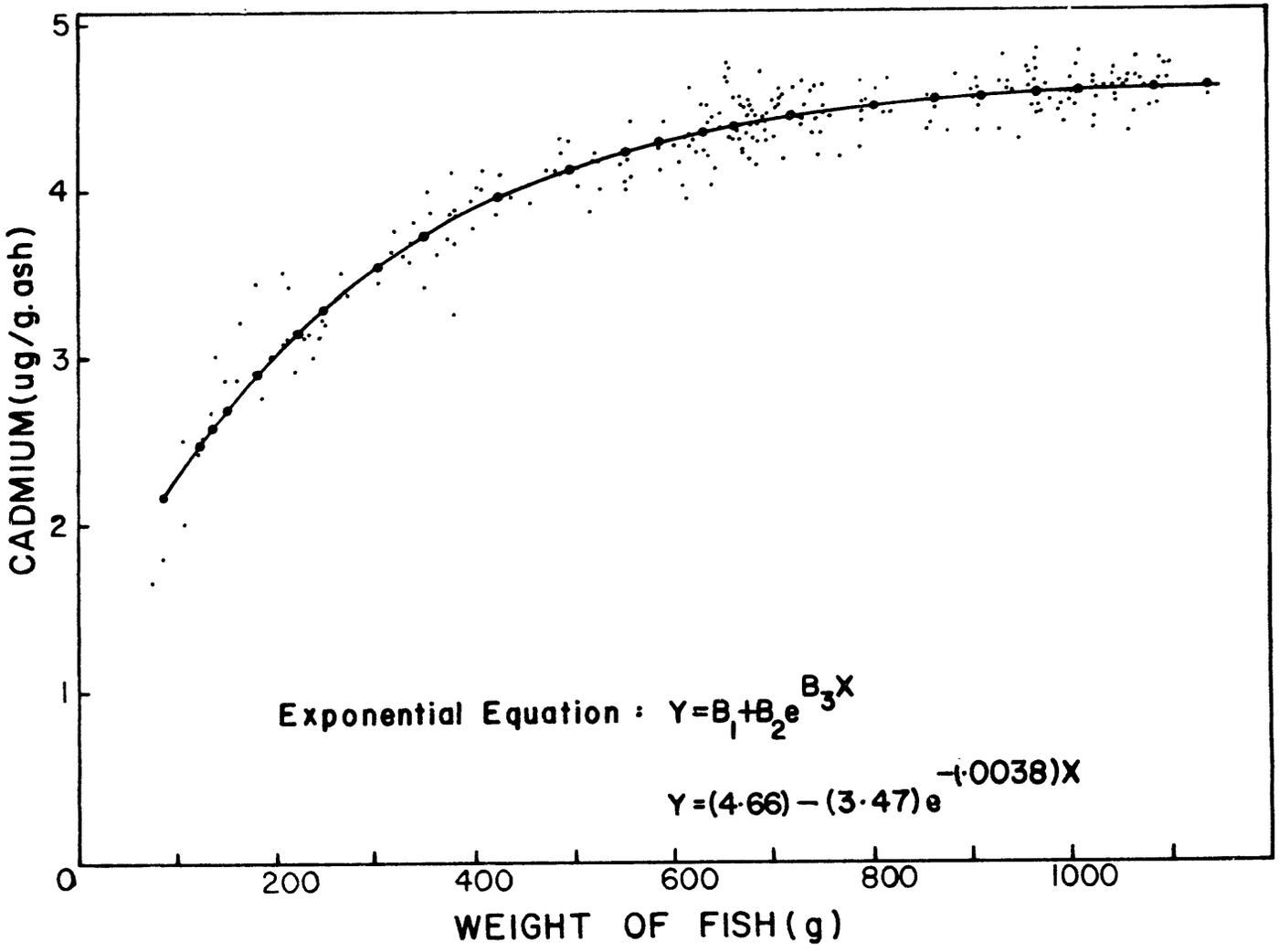

Fig. 21. Computer fit relating cadmium concentration (μgCd/g. ash for entire fish) in the Pacific Hake and its weight, in terms of the exponential equation:

$$Y = B_1 + B_2 e^{B_3 X}$$

Total Cd concentrations range from 0.08 to 0.18 μg/l (IDOE, 1972);

2. In general, the occurrence of Cd in the organisms is of a low order of magnitude. Preston et al. (1972) and Windom (1972) report concentration factors in the range 10^2 to 10^3 for most organisms, with large concentrations being found in the internal organs of fishes. Cadmium appears to be highly concentrated in phyto- and zooplankton in nearshore areas. The concentration factor for Cd (9400) is greater than that of Zn (1800) in zooplankton. This high concentration could result from the same principle as in Zn, adsorption. Krauskopf (1956) has shown that dead plankton can take up by surface adsorption a high percent of Zn (50%) and Hg (98%). This could be equally true for Cd, too. Concentration of Cd in the tissues may affect rates of uptake or accumulation.

Using the BCF data (Nelson and Larkins, 1970), linear regression plots of Cd, μg/g ash, as a function of length and weight of the fish in relation to the maturity of the fish were made, as was done in the case of Zn. Figure 22 shows significant differences in slopes of juveniles in relation to adults. The ratio of slopes, Cd (juveniles) to Cd (adults) when related to weight and length of the fish, comes out to be 7.17 and 3.65, respectively. Incidentally, this was also noted to be the case in Zn data. Once again, as in the case of Zn, the change in the type of organisms it feeds on as it grows from juvenile stage to

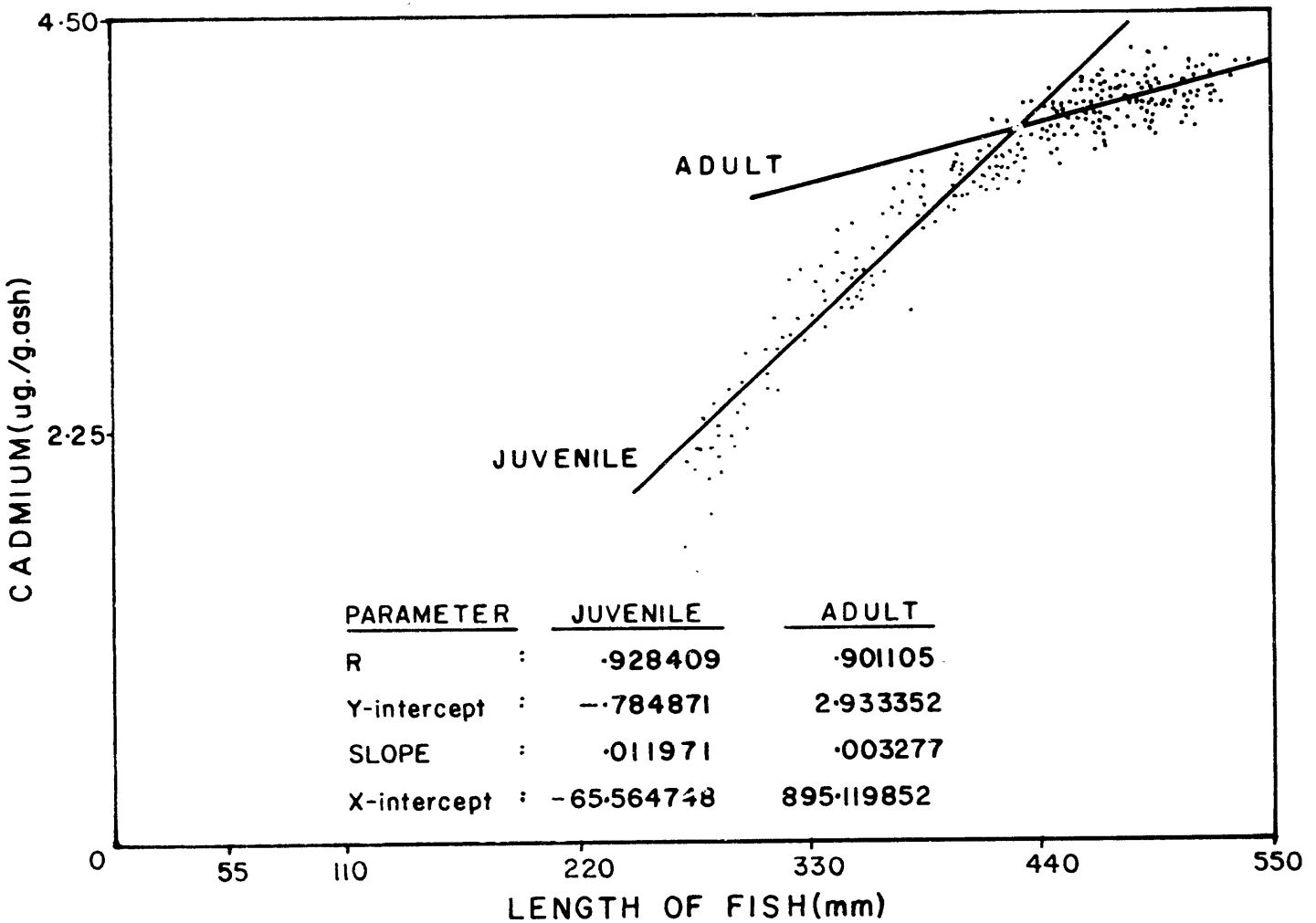

Fig. 22. Plot of cadmium concentration (μgCd/g. ash) in the Pacific Hake as a function of its weight, showing the change in slope between the juvenile and adult fishes.

adult stages, could as well be the causative factor for the shape of the resulting curve of the above data.

Underwood (1971) reported that Cd uptake in rats was enhanced by small concentrations of Zn, but uptake was depressed at high concentrations. Competition between the two metallic ions for the same binding sites is a function of the ratio of Cd/Zn. Therefore, it appears that the level of Zn in an organism is a controlling factor in the assimilation of Cd. However, in this study, it is not possible to conclusively say that the Zn level in the hake has inhibited the uptake of Cd. The ratio of Zn/Cd in the hake from off the coast is lower ($\sim$85) than in the hake from Puget Sound ($\sim$150). Whether this difference is a function of the inhibitory effect of Zn on Cd uptake, or a function of the concentration of the elements in the food of the hake, or a manifestation of the genetic differences of the two populations, is not possible to say with the evidence on hand.

Zinc and Cadmium

Figure 23 shows an excellent positive linear relationship between the concentration of Zn (μg/g ash) and the concentration of Cd (μg/g ash) in the hake. Furthermore, the curves for Zn and Cd, as a function of either length or body weight, are similar (Figures 11 and 18).

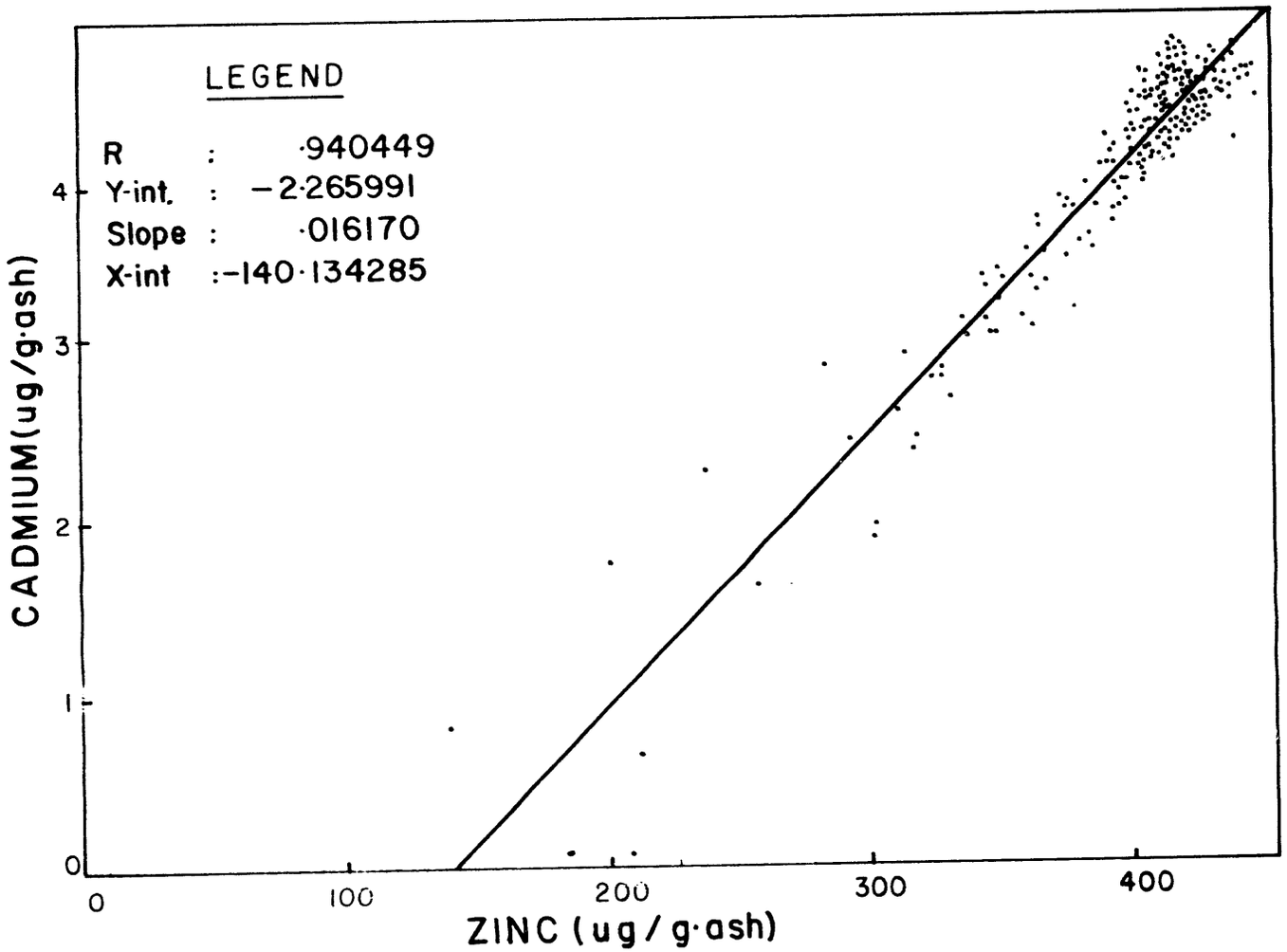

Fig. 23. Plot demonstrating the linear relationship between zinc concentration (μgZn/g. ash) and cadmium concentration (μgCd/g. ash) in the Pacific Hake.

The slope of the regression line of cadmium concentration on zinc concentration is 0.01217 (Figure 23), so that the Zn is approximately 80 times the concentration of Cd in the fish. Wagner (personal communication) has indicated that a number of marine organisms exhibit similar values for the ratio, Zn to Cd, i.e., two orders of magnitude ($\sim$100).

Mercury Concentration in the Hake

Table 1 (Appendix) lists the Hg concentrations in the hake from the different locations. Figure 24 is a plot of the same data. The mean, standard deviation, and range of Hg concentrations for each location are also indicated on this plot. A line has also been drawn connecting the individual means. Mercury concentration data are plotted as a function of length in Figure 25. The same data with the regression lines drawn for specific locations are shown in Figure 26. Mercury concentrations are plotted against zinc concentrations in Figure 27. Regression analysis was done on the same data for specific locations. Table 10 summarizes the results in terms of correlation coefficients (R), correlation coefficients required for significance at the 5% level, and slopes.

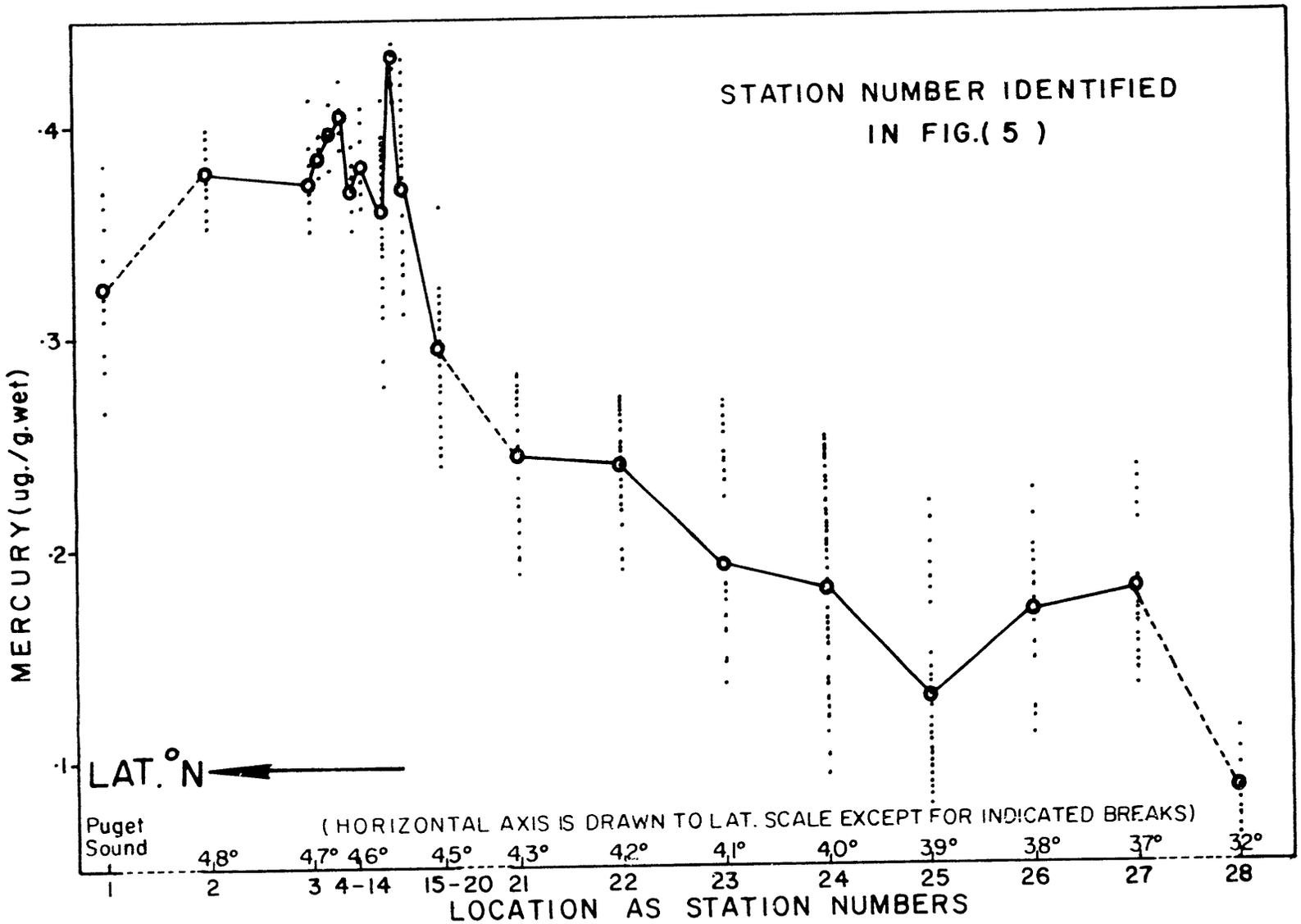

Fig. 24. Mercury concentration (μgHg/g. wet) in the Pacific Hake from different locations (Lat. °N).

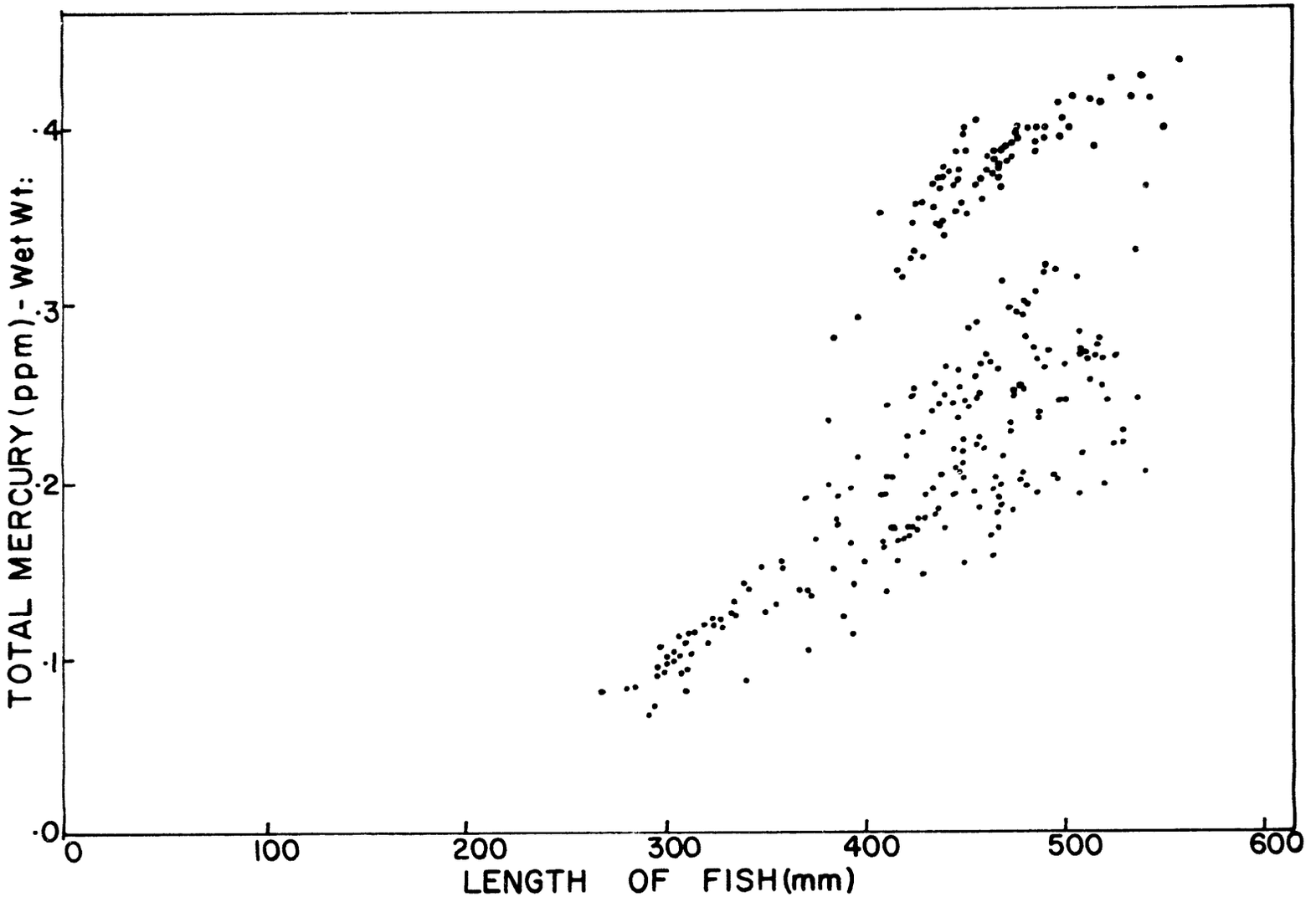

Fig. 25. Mercury concentration (μgHg/g. wet) in the Pacific Hake as a function of its length.

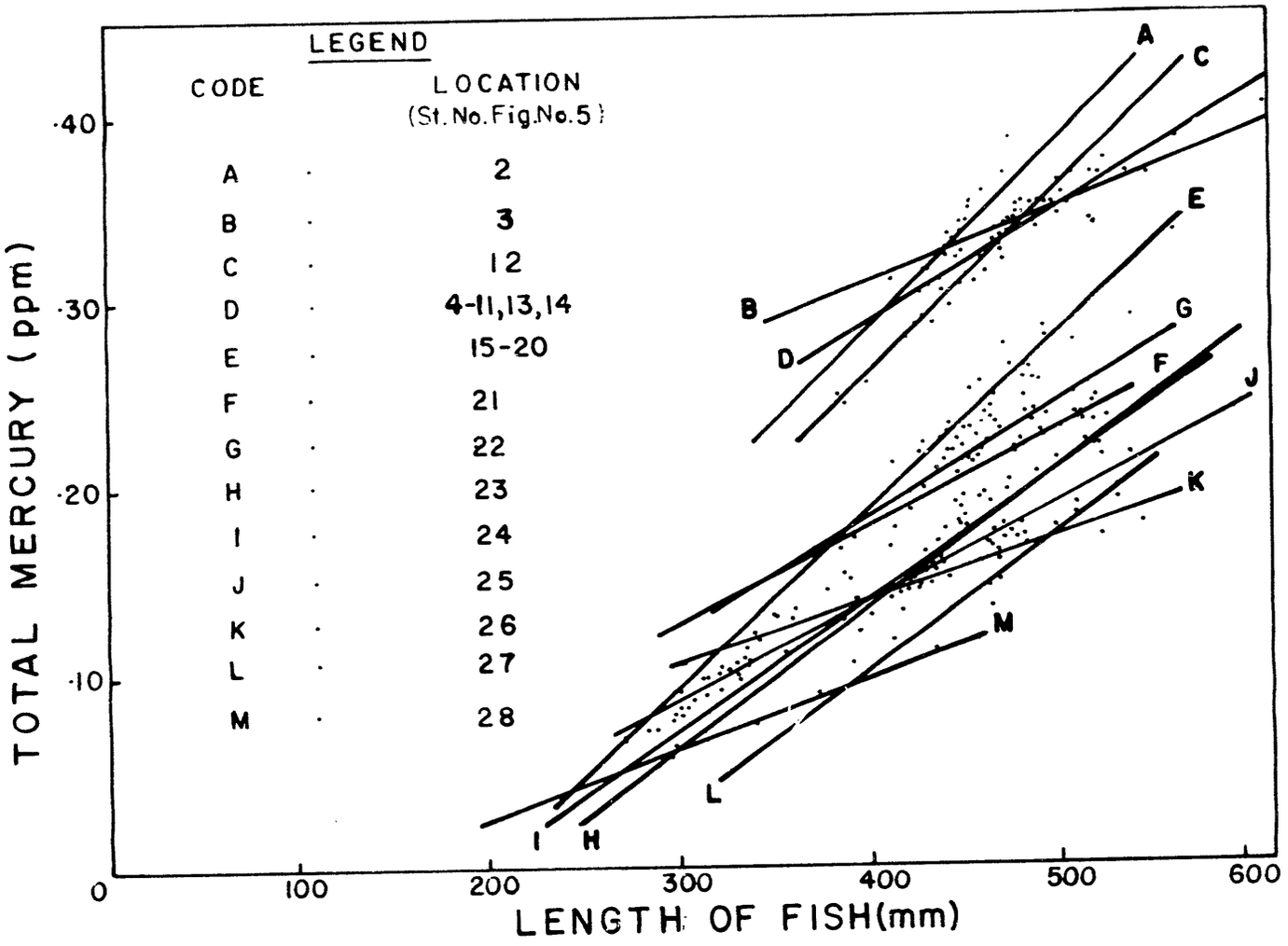

Fig. 26. Mercury concentration (μgHg/g. wet) in the Pacific hake as a function of its length, and also showing the regression lines drawn through the data points for specific locations (Lat. °N).

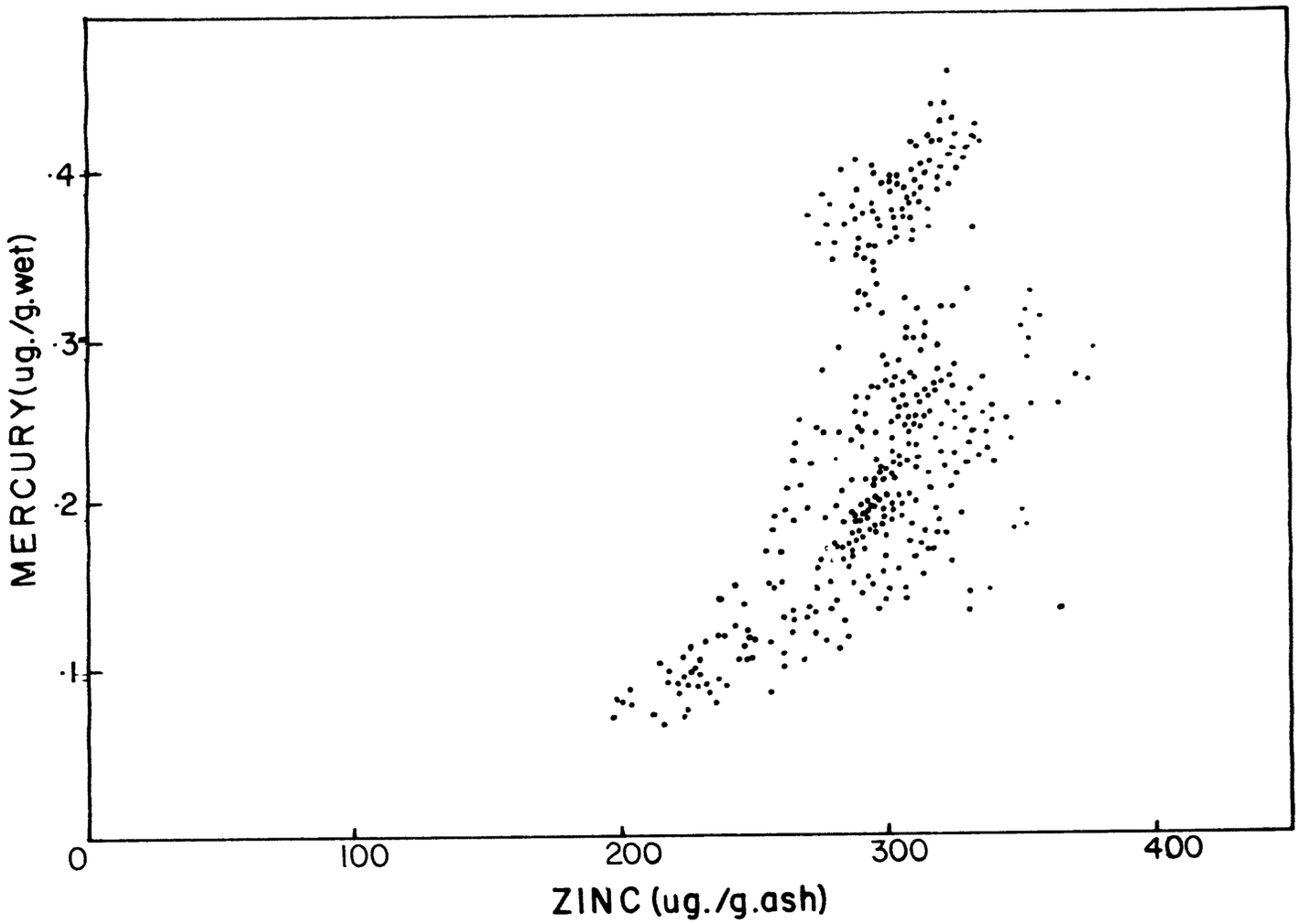

Fig. 27. Mercury concentration (μgHg/g. wet) in the Pacific Hake plotted in relation to its zinc concentration (μgZn/g. ash).

Table 10. Correlation coefficients (R), correlation coefficients at the 5% level of significance, and slopes for plots of Hg concentration (μg/g wet weight) as a function of Zn concentrations (μg/g ash) for specific locations (Lat. °N).

Location °N	R	Degree of freedom (n-2)	Correlation Coefficient at 5% level of Significance	Slope (X 10^{-3})
48	.7051	12	.6120	1.39
47	.7211	6	.7887	1.36
46	.8337	25	.4551	2.83
46*	.8672	52	.3204	2.44
45*	.7862	28	.4169	2.11
43	.7331	15	.4821	1.45
42	.8727	20	.4227	1.46
41	.9488	18	.4438	2.84
40	.8993	27	.4207	1.82
39	.9428	35	.3246	1.24
38	.9626	15	.4821	1.14
37	.8758	11	.5529	3.54
32	.9536	4	.8114	0.63

* Collection other than Russian (cf: Table 1 (Appendix)).

Based on the above results, the following observations can be made:

1. The concentration of Hg increases with the size of fish, irrespective of location.
2. A trend is seen towards increasing concentrations of Hg from Lat. 48°N to Lat. 46°N, but decreases beyond Lat. 46°N to Lat. 48°N. The slopes of these plots (Figure 26) were tested for significance. An analysis of covariance, indicates that the slopes also are distinctly different.

3. Fishes from Puget Sound have comparatively high Hg values.
4. There may be two groups of fishes, one group showing higher concentration than the other (for corresponding sizes). The fishes showing higher concentrations were collected from Lat. 46°, 47° and 48°N.
5. A positive correlation exists for Hg and Zn concentrations.
6. Correlation between Hg and Zn is significant at the $\alpha = .05$ level for all stations except Lat. 47°N. This exception could be the outcome of the small size of the sample for the location: Lat. 47° N, i.e., eight fishes. There is also the possibility, based on the correlation coefficient (R), that an arbitrary line of demarcation occurs between Lat. 41°N and Lat. 42°N, in that the higher R values being south of Lat. 42°N, and the lower R values being north of Lat. 41°N.

Mercury Concentration in Water Samples

Table 2 (Appendix) gives the type of sample (fresh water, or sea water), location of sample and date of collection of the sample, and the Hg concentration. Figure 6 indicates the sampling points. Figure 28 is a plot of Hg concentration in the Columbia River water (surface samples from different locations along its flow towards the sea, as a function of the data of collection (Table 2a, Appendix). These results imply that the Columbia River water cannot be the source of Hg as the

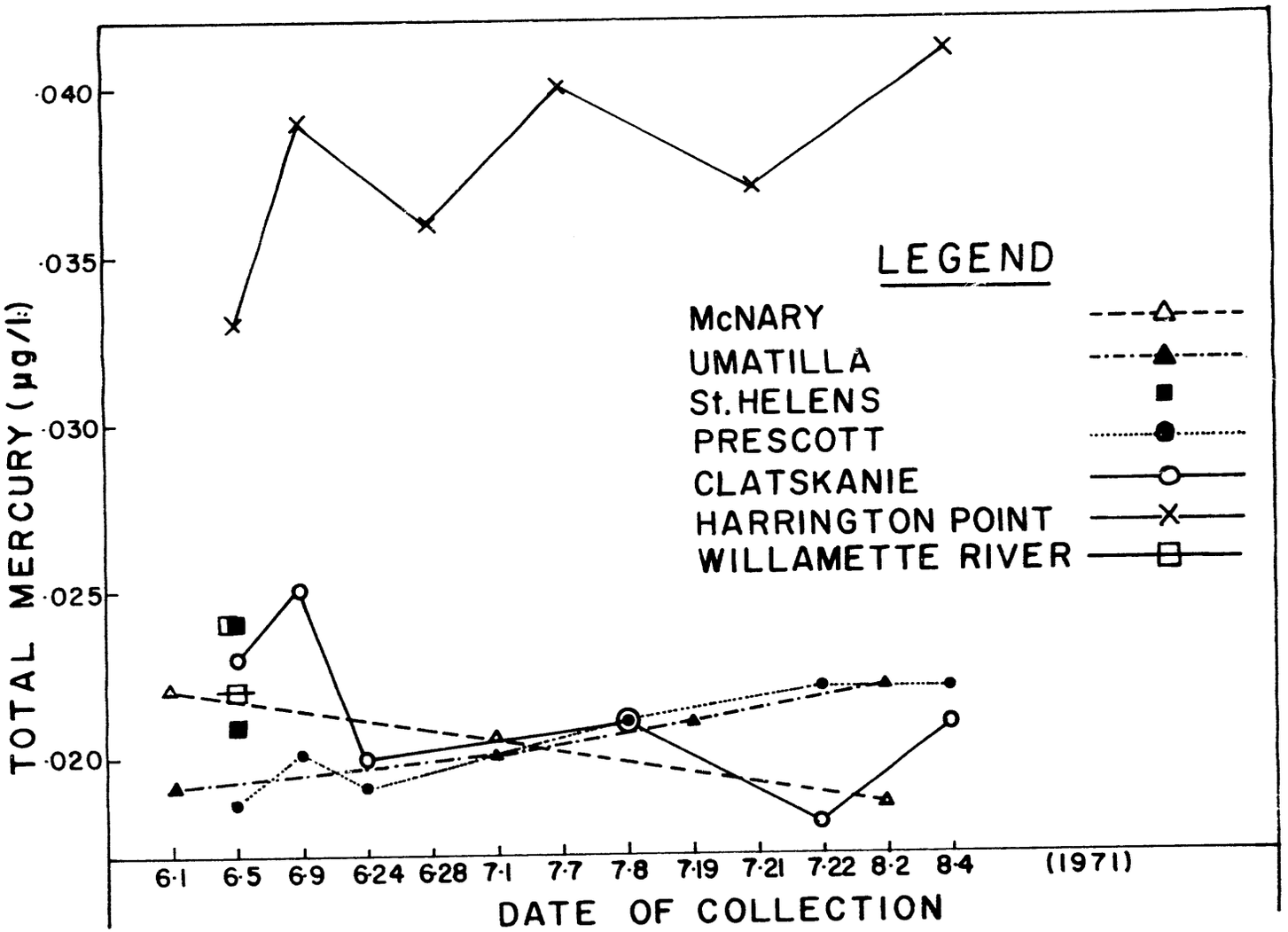

Fig. 28. Plot of mercury concentration (µgHg/liter) in the Columbia River water samples (surface) from different locations along its flow towards the sea, as a function of the date of collection.

values for the Columbia River water at stations away from the influence of the sea are much lower than the offshore values. Whereas all the other stations have values close to each other (0.018 to 0.25 μg/g), over the period of collection, Harrington Point is consistently higher (0.033 to 0.041 μg/g). The reason for this consistent difference in Hg values is not clear at present.

Surface water samples from Chinook Point, located very near the mouth of the Columbia River, were collected on a periodic basis from June 1971 to August 1972. The data is tabulated in Table 2b (Appendix) and plotted in Figure 29. The concentration of mercury varies in correspondence to river discharge. This relationship may indicate seasonal erosion of mercury from bed sediments during peak discharge periods.

Surface and mid-water depth sea water samples were collected over the continental shelf from locations ranging from Lat. 46°38'N to Lat. 40°05'N. The Hg contents of these samples, surface and mid-depth (Table 2c, d-Appendix) are shown in Figure 30. These single values for Hg in inshore sea water samples, as a function of latitude, indicate no distinct patterns of variations. However, for some river waters (Figure 30), especially the Umpqua, Smith and Siuslaw Rivers (rivers known to drain regions rich in Hg-bearing ores), concentrations are relatively high. These inputs probably vary seasonally. There is also the possibility that sediments may

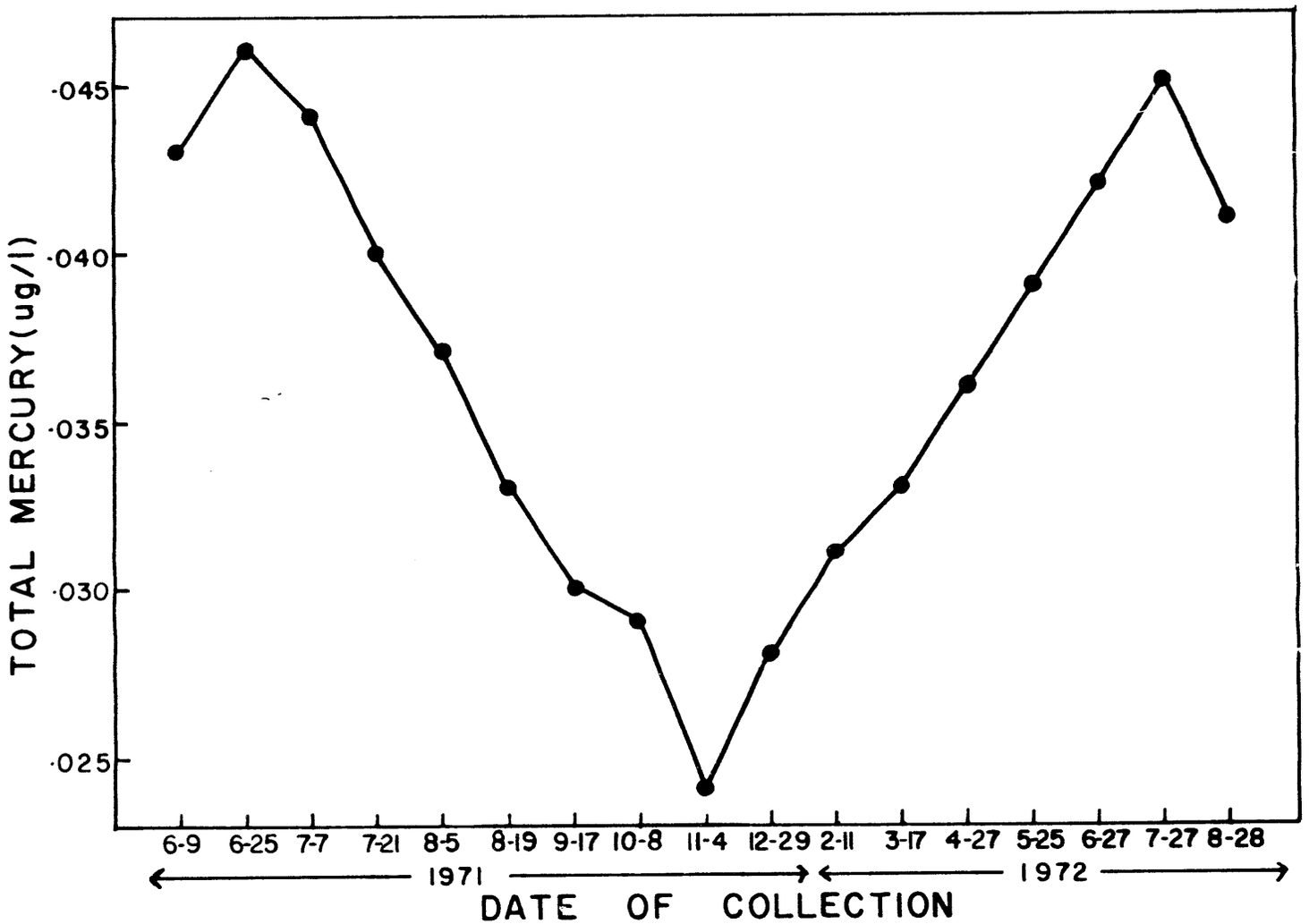

Fig. 29. Mercury concentration (μgHg/liter) in water samples collected at Chinook Point, Columbia River, plotted in relation to the date of collection of the sample.

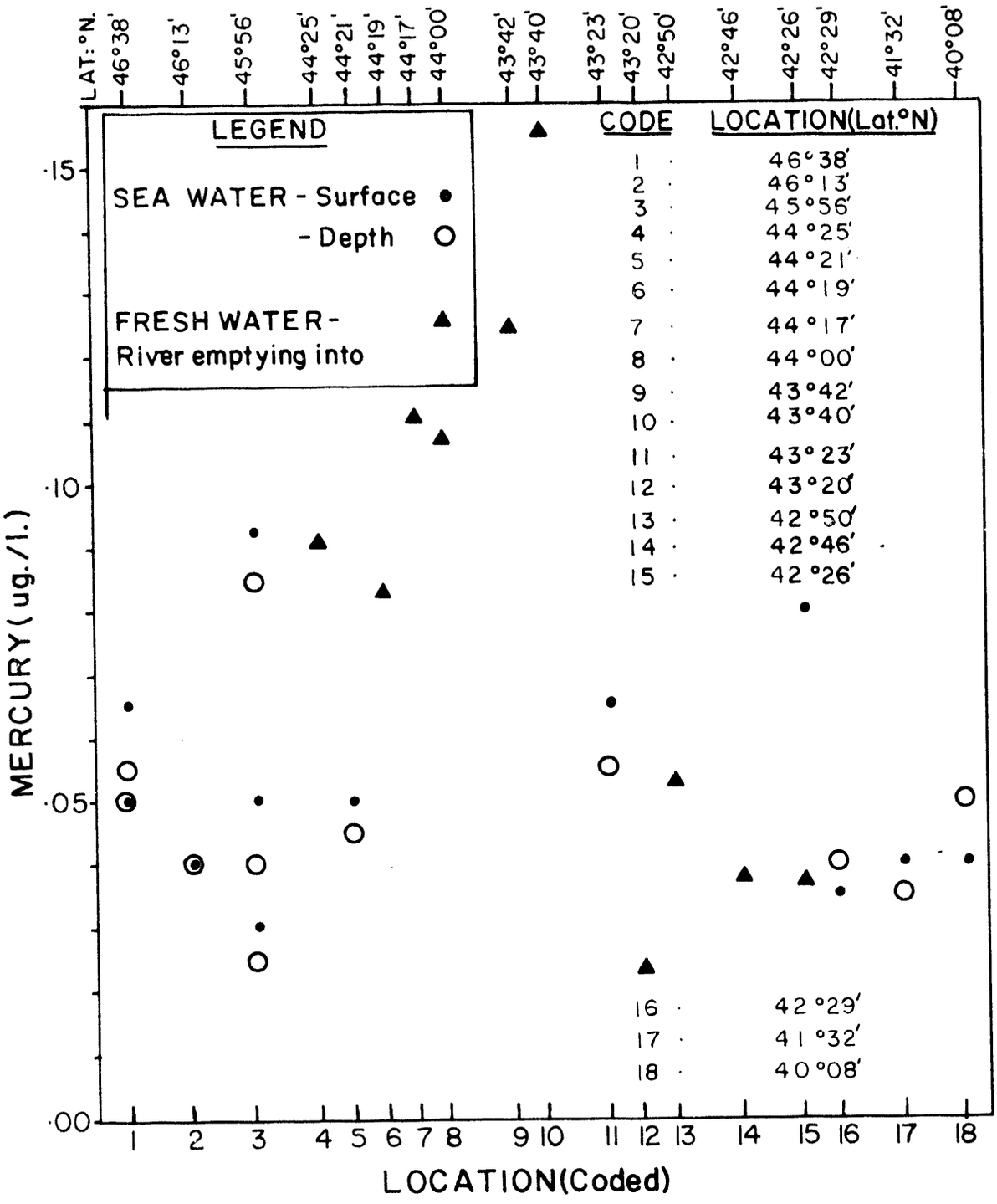

Fig. 30. Mercury concentration (μgHg/liter) in sea water samples collected off Oregon and Washington coast-line.

be a source, during periods of high runoff or, where the system has been polluted, after the original sources are removed (Jernelov, 1970).

The Pacific Hake moves north from its late winter spawning ground off California and appears off Oregon and Washington in June and July. In summer the fish are found at about 100 m or less, and in winter they are found in 350 m to 400 m. Thus, during the summer the fish might reside within the northward flowing the Davidson Current, and during winter, within the southward flowing California Current. A notable point is that they spawn in the south, when the larvae can take advantage of the upwelling and they migrate north to feed in the upwelling regions off Oregon and Washington much later on in the year, so the adults live in the upwelling regions for six months or more during the year. Knauer and Martin (1972) suggest that upwelled waters may carry heavy metals upward into the euphotic zone, based on their observation that high Hg levels in surface water samples correspond to periods of intense upwelling. This coupled with the local intensification of Hg concentrations due to river inputs could account for the variations in the slopes of Hg concentration vs. length in fish from different latitudes. Martin and Knauer (1972) found that the values of Hg in zooplankton off Coos Bay (.48 to .71 μg/g) are higher than that off Monterey Bay (0.09 to 0.17 μg/g). Thus, the concentration of Hg in the food of the hake, especially the

juveniles, is higher off Washington region and Oregon region than the Monterey region.

Tillman (1968) has indicated that older hake are found off the Washington coastline than those to the south. This could explain the occurrence of the two groups in the plot of Hg concentration as a function of length (Figure 25); that is, the higher mercury values in northern fish may reflect an older population structure.

Johnels *et al.* (1967) reported a positive correlation was observed between Hg content in the axial muscle and total weight of the fish (*Esox lucius* L.) or its age. Cross *et al.* (1973) observed a similar relationship for bluefish and morids. This corresponds to our observation that Hg concentration was related to length.

Concentration factors for zinc, cadmium and mercury in hake were calculated using values for sea water content of Zn = 3 μg/l, of Cd = 0.02 μg/l, and of Hg = 0.1 μg/l (IDOE, 1972). The concentration factors are: Zn = 800-1500, Cd = 150-1850, and Hg = 700-4500. The estimated concentration factor for Hg at the highest concentration noted was almost three times that of Zn or Cd.

The difference in the concentration factor pattern between Hg, and Zn or Cd, may be a function of the uptake and elimination rates of these elements, or dependent upon the environmental levels of biologically-available Hg. Because the concentration of Hg in flesh is dependent upon body weight, so is the concentration factor.

Mercury concentration factors were about 700 for juveniles and about 4500 in the largest fish analyzed in this study. The life expectancy of fish is therefore an important factor in determining the absolute levels of Hg attained.

An important factor that must not be overlooked from a public health aspect is that methyl-mercury cannot be readily removed from fish tissue. Westöö (1968c) reported that there was no demonstrable loss of methylmercury during cooking. The preparation of fish meal from pike produces losses amounting to only 15 to 20% of the Hg, even after the final drying temperatures are as high as 177°C (350°F). When fish is repeatedly extracted with isopropanol, the resulting powder still contains all the Hg. Beasley (1972) found the same when he extracted the fish protein concentrate (FPC) from the hake.

The Pacific Hake is used today mainly as a pet food (Best and Nitsos, 1966). However, a small number of fillets have appeared in the market. Also, efforts are being made to use the hake as a raw material for fish protein concentrate (FPC), a relatively cheap and odorless flour-like material that can be used as a food supplement to alleviate protein deficiencies in human diets. Alverson and Larkins (1969) estimate that the standing stock of hake off Washington and Oregon to be 550 to 1100 metric thousand metric tons, second only to the anchovy. This indeed substantiates its importance.

SUMMARY AND CONCLUSIONS

We set out to examine two propositions:

1. that the Pacific Hake, M. productus, be used as an indicator for ^{65}Zn, Zn, Cd, and Hg;
2. that the Columbia River is a dominant source for ^{65}Zn, Zn, Cd, and Hg in coastal waters off Oregon.

This study has indicated that:

The Pacific Hake could indeed be used as an indicator organism for ^{65}Zn, Zn, Cd, and Hg.

The hake is an important link in the food chain for transferring ^{65}Zn from the environment to man: ^{65}Zn in water → phytoplankton → euphausiids → to hake → man (as fish protein concentrate). Since the specific activity (^{65}Zn) of the stomach contents of the hake and that of euphausiids are similar, it seems likely that the uptake of ^{65}Zn by the hake is through food, especially since euphausiids are known to be important as food for the hake. A direct consequence of this is the rapid uptake of ^{65}Zn by the migratory hake off Oregon and Washington.

Detectable amounts of ^{65}Zn in the hake off California might be the result of exposure to the Columbia River off Oregon during a previous annual migration to the north. It is also possible that this could be a consequence of the ^{65}Zn being transported to the hake off California via the California current. The bathymetric movements of

the hake provide an avenue for the pelagic feeding hake to accelerate the transport of ^{65}Zn and possibly other elements and energy from the surface to the sea floor.

Zinc-65 activity has already decreased to levels very close to the levels of detection in the hake caught off the mouth of the Columbia River in January 1973, as compared to those caught in July/August 1969, from the same location. The same is, of course, true for the SA (^{65}Zn) as well, since in the ratio, the numerator (^{65}Zn) has declined while the denominator (total Zn) has remained constant.

Zinc is sufficiently concentrated by the hake to be estimated with the minimum of material (fish flesh). This was, also, the easiest of the elements analyzed. Attempts to provide an equation for predicting the concentration of Zn at any age of the hake resulted in the use of the exponential equation, $Y = B_1 + B_2 e^{B_3 X}$, as the equation that gave the best mathematical fit to the data (Zn concentration as a function of length and weight, hence age). Biological meanings for the parameters, B_1, B_2, and B_3, were looked for, but as of this moment, it remains an empirical equation, awaiting information on the physiology of Zn in fishes. Its predictability has also to be tested. Perhaps the most important conclusions that could be drawn is that the Zn concentrations showed a positive correlation with length, weight and age, and that most of the fish caught with the existing fishing gear would show the maximum or near maximum levels of Zn.

However, these values were far below the FDA limit (5 mg/kg).

The levels of Cd in the fish were very low, necessitating the use of the carbon cup technique to estimate Cd concentration in fish. The results are very similar to that of Zn, in almost every respect, and would only be repetitious if described. One would expect that the high level of Zn, nearly two orders of magnitude greater than Cd ($\sim$100), would act as an inhibiting effect on Cd uptake. However, based on results obtained in this study where the hake was exposed to "base-line" levels of Zn and Cd in its ambient medium, the degree of correlation between Zn and Cd is highly significant. The almost constant ratio of Zn to Cd ($\sim$100) bears this out.

It has clearly been demonstrated that Hg concentration increases with size of fish, thus apparently with age. It appears that local concentration of Hg may be variable especially along the coast line where rivers draining regions containing Hg bearing ores join the sea. The relatively long residence time of Hg within the biological system could result in erroneous conclusions from an observation, more so, if the past history of the fish is not known.

The size range of the fish normally harvested corresponds to high Hg levels. Furthermore, results pertaining to the concentration of Hg in the fish protein concentrate (FPC) will augment this fact in that the size range of fishes caught would have high Hg levels and that these levels would be further enhanced (even exceeding the FDA limit

of 0.5 μg/g) when the FPC is extracted from the fish tissue.

There is ample evidence from past studies and to some degree in this study that the Columbia River was indeed the source of ^{65}Zn. But with the phasing out of the nuclear reactors at Hanford, it can no longer be considered as a source of importance, barring an accident in the Hanford storage facility. Our studies also indicate that the Columbia River is not the source of Zn, Cd and Hg.

The concentration of Zn, Cd and Hg in the hake is rather uniformly distributed in the flesh, irrespective of the location of the muscle tissue. Furthermore, the pattern of concentration factors: Hg > Cd ≃ Zn in the hake reflects the tendency to form complexes (coordinate covalent bonds): Hg > Cd ≃ Zn. The chemical similarity between Zn and Cd has also been borne out by the trend in the Zn and Cd concentration with length, body-weight or age. Though all the three elements have shown a positive correlation with age, the pattern of Hg concentration is not the same as Zn or Cd. This seems to reflect the differences in the properties of Zn, and Cd from those of Hg, in that Hg forms strong complexes with organic compounds and is not under the regulatory influence of the organisms' physiology, whereas Zn, and to some extent Cd, are homeostatically regulated.

Finally, we note man's lack of control over the food of aquatic organisms, hence on the biological concentration of elements like Zn, Cd, and Hg in these organisms used as food by him.

In conclusion, one may reflect that the composition of the body as revealed by chemical analysis may be compared with the snapshot of a busy street, full of pedestrians and automobiles. It is essentially the static reproduction of a dynamic sense, full of individual and collective activity. The results must accordingly be interpreted with this in mind, but it must also be remembered that the composition of the body and of its tissues, usually expressed per unit weight of fresh or dry material, remains the foundation upon which most other biological studies must be built.

Future Plans

Since this study has helped lay down the base-line levels for ^{65}Zn, Zn, Cd and Hg, frequent sampling of the hake along the West Coast of U.S., especially during the period June to August, when the hake is migrating north, would help monitor the environment with reference to the established base-line. The hake used in this study could be examined for Co, Fe, Mn, and these elements could be added to the above list of elements in all future studies.

The exponential equation which was successfully fitted to the data (mathematically) should be tested by sampling fish of different sizes, especially at the same season as the original fish used in the curve fit analysis, and the concentration of Zn and Cd estimated. Comparison of predicted values and the determined values for Zn and

Cd would test the predictability of the model proposed.

The study of Hg in water could not be carried to fruition. More frequent sampling of the rivers known to have high Hg levels will help establish a means to calculate the input by such rivers into marine environment. It is important that the fish catch and the water sampling (marine and fresh water) be synoptic.

BIBLIOGRAPHY

Aberg, B., L. Ekman, R. Falk, U. Greitz, G. Persson, and J. O. Snihs. 1969. Metabolism of methylmercury (^{203}Hg) compounds in man. Arch. Environ. Health 19: 478-484.

Ahlstrom, E. H., and R. C. Counts. 1955. Eggs and larvae of the Pacific hake, Merluccius productus. U. S. Fish Wildl. Serv., Fish. Bull. 56: 295-329.

Aidin'yan, N. Kh. 1962. Content of mercury in some natural waters. Tr. Inst. Geol. Rudn. Mestorozhd., Petrogr., Mineralog. i Geokhim, Akad Nauk SSSR. 70: 9-14. [Chem. Abstr: 57:16336 3].

Aidin'yan, N. Kh. 1963. The mercury content of some waters in the Armenian SSR. Izv. Akad. Nauk Arm. SSR. Geol. Geogr. Nauki 16: 73-75. [Chem. Abstr: 58: 223121].

Alexander, G. V., and R. H. Rowland. 1966. Estimation of zinc-65 background levels for marine coastal waters. Nature 210: 155-157.

Alton, M. S. and M. O. Nelson. 1970. Food of the Pacific hake, Merluccius productus, in Washington and Northern Oregon Coastal waters. U. S. Fish Wildl. Serv., Circ. 332: 35-52.

Alverson, D. L. 1968. Fishery resources in the northeastern Pacific Ocean. Pages 86-101 in Gilbert DeWitt, ed. The future of the fishing industry of the United States. Univ. Wash. Publ. Fish., New Ser. 4.

Alverson, D. L., and H.A. Larkins. 1969. Status knowledge of the Pacific hake resource. Calif. Coop. Oceanic Fish. Invest. Rep. 13: 24-31.

Alverson, D. L., A. T. Pruter, and L. L. Ronholt. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. H. R. MacMillan Lectures in Fisheries. Univ. Brit. Columbia, Vancouver. 190 pp.

Anonymous. 1968. Cadmium and metabolism of albumin. [Editorial]. Lancet I: 133.

Anonymous. 1971. Cadmium pollution and Itai-Itai disease. [Editorial]. Lancet I: 382.

Bache, C. A., W. H. Gutenmann, and D. J. Lisk. 1971. Residues of total mercury and methylmercuric salts in lake trout as a function of age. Science 192: 951-952.

Barić, A., and M. Branića. 1967. Polarography of seawater, I: Ionic state of cadmium and zinc in sea water. J. Polarogr. Soc. 13: 4-8.

Barnes, C. A., A. C. Duxbury, and B. Morse. 1972. Circulation and selected properties of the Columbia River effluent at sea. Pages 41-80 in A. T. Pruter and D. L. Alverson, eds. The Columbia River Estuary and Adjacent Ocean Waters. University of Washington. Seattle.

Barnes, C. A., and M. G. Gross. 1966. Distribution at sea of Columbia River water and its load of radionuclides. Pages 291-302 in Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters. International Atomic Energy Agency, Vienna. [ST1/PUB/126].

Beasley, T. M. 1971. Mercury in selected fish protein concentrates. Environ. Sci. Technol. 5(7): 634-635.

Bertrand, G. 1938. Amount of zinc in sea water. Compt. Rend. H., 207: 1137-1141. [Chem. Abstr: 35:2089].

Best, E. A. 1963. Contribution to the biology of the Pacific hake, Merluccius productus (Ayres). Calif. Coop. Oceanic Fish. Invest. Rep. 9: 51-56.

Best, E. A., and R. J. Nitsos. 1966. Length frequencies of Pacific hake (Merluccius productus), landed in California through 1964. Calif. Fish Game 52: 49-53.

Bougis, P. 1961. The physiological effects of zinc in sea water. Compt. Rend. H., 253: 740-741.

Bowen, H. J. M. 1966. Trace Elements in Biochemistry. Academic Press, New York. 241 pp.

Bowen, H. J. M., and D. Gibbons. 1963. Radioactivation Analysis, Oxford University Press, Oxford. 295 pp.

Braman, R. S. 1971. Membrane probe-spectral emission type detection system for mercury in water. Anal. Chem. 43: 1462-1467.

Brody, S. 1945. Bioenergetics and growth. Reinhold, New York. 1023 pp.

Buffo, L. K. 1967. Extraction of zinc from sea water. M. S. thesis. Oregon State University, Corvallis. 49 numb. leaves.

Buhler, D. R., R. R. Claeys, and W. E. Shanks. 1973. Mercury in aquatic species from the Pacific northwest. Pages 11-16 in D. R. Buhler, ed. Proceedings of the Workshop on Mercury in the Western Environment, February 25-26, 1971. Oregon State University, Corvallis.

Butterworth, J., P. Lester, and G. Nickless. 1972. Distribution of heavy metals in Severn Estuary. Mar. Poll. Bull. 3: 72-74.

Byerrum, R. V., R. A. Anwar, and C. A. Hoppert. 1960. Toxicity of small quantities of cadmium and chromium in drinking water administered to dogs during a four year period. J. Amer. Water Works Ass. 52: 651-652.

California State Water Pollution Control Board. 1957. Water Quality Criteria, 2nd ed. Sacramento, California.

Carey, A. G., Jr. 1969. Zinc-65 in echinoderms and sediments in the marine environment off Oregon. Pages 380-388 in Symposium on Radioecology. Proceedings of the Second National Symposium, Ann Arbor, Michigan, May 15-17, 1967. (USAEC Report: Conf. 670503).

Carpenter, R. 1972. A study program to identify problems related to oceanic environmental quality in the North Pacific. Pages 83-103 in Baseline Studies of Pollutants in the Marine Environment, Brookhaven National Laboratory, New York. May 24-26, 1972. [No imprint].

Carroll, R. E. 1966. The relationship of cadmium in the air to cardiovascular disease death rates. J. Amer. Med. Ass. 198(3): 267-269.

Celeste, A. C., and C. G. Shane. 1970. Mercury in fish. FDA Pap. 4(9): 27-31.

Chang, T. L., T. A. Grover, and W. W. Harrison. 1966. Determination of magnesium and zinc in human brain tissue by atomic absorption spectroscopy. Anal. Chim. Acta 34: 17-23.

Chipman, W. A., T. R Rice, and T. J. Price. 1958. Uptake and accumulation of radioactive zinc by marine plankton, fish and shellfish. U.S. Fish Wildl. Serv., Fish. Bull. 135(20): 279-292.

Chow, T. J. and C. C. Patterson. 1966. Concentration profiles of barium and lead in Atlantic waters off Bermuda. Earth Planet. Sci. Lett. 1: 394-400.

Clark, D., R. M. Dagnall, and T. S. West. 1972. Determination of mercury by atomic absorption spectrophotometry with the Delves sampling cup technique. Anal. Chim. Acta 58: 339-346.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Page 443 in Fish. Res. Bd. Can., Bull. 68.

Cross, F. A., L. H. Hardy, N. Y. Jones, and R. T. Barber. 1973. Relation between total body weight and concentrations of Mn, Fe, Cu, Zn, and Hg in white muscle of bluefish (Pomatomus saltatrix) and a bathy-demersal fish (Antimora rostrata). J. Fish. Res. Bd., Canada 30: 1287-1291.

Crow, R. F., W. G. Hime, and J. D. Connolly. 1967. Analysis of Portland Cement by atomic absorption. J. PCA (Portland Cem. Ass.) Res. Develop. Lab. 9(2): 60-77. [Chem. Abstr: 67: 76040s].

Cutshall, N. H., and R. Holton. 1972. Metals analyses in IDOE baseline samples. Pages 69-81 in Baseline Studies of Pollutants in the Marine Environment. Brookhaven National Laboratory, New York. May 24-26, 1972. [No Imprint].

Delves, H. T. 1970. Microsampling method for the rapid determination of lead in blood by atomic absorption spectrophotometry. Analyst 95: 431-438.

DeWitt, J. W., Jr. 1952. An occurrence of the natural destruction of hake in Humboldt County. Calif. Fish Game. 38: 438.

Dow Chemical Co. 1970. Determination of mercury: Method CMS-AM-70.13. June 22, 1970. Midland, Michigan.

Dustman, E. H., L. F. Stickel, and J. B. Elder. 1971. Mercury in wild animals, Lake St. Clair 1970. Pages 145-152 in International Conference on Environmental Mercury Contamination. Ann Arbor, Michigan. Sept. 30-Oct. 2, 1970.

Erdey, L., G. Svehla, and L. Koltai. 1963. The accuracy of zinc determination by atomic absorption methods. Talanta 10: 531-536.

Fabricand, B. B., R. R. Sawyer, S. G. Unger, and S. Adler. 1962. Trace metal concentrations in the ocean by atomic absorption spectroscopy. Geochim. Cosmochim. Acta 26: 1023-1027.

Fairhall, L. T. 1957. Industrial Toxicology, 2nd ed. Williams and Wilkins Co., Baltimore, Maryland. 376 pp.

Fimreite, N. 1970a. Mercury uses in Canada and their possible hazards as sources of mercury contamination. Environ. Pollut. 1: 119-131.

Fimreite, N., R. W. Fyfe, and J. A. Keith. 1971. Mercury contamination of Canadian prairie seed eaters and their predators. Can. Field-Natur. 84(3): 269-276.

Flick, D. F., H. F. Kraybill, and J. M. Dimitroff. 1971. Toxic effects of cadmium: a review. Environ. Res. 4: 71-85.

Folsom, T. R., D. R. Young, V. F. Hodge, and R. Grismore. 1971. Variations of ^{54}Mn, ^{60}Co, ^{65}Zn, ^{110m}Ag, and ^{108m}Ag in tuna. Pages 721-730 in Third National Symposium on Radioecology, Vol. 2. May 10-12, 1971, Oak Ridge National Laboratory and Ecological Society of America, Oak Ridge, Tennessee. (Conf-71051).

Forster, W. O. 1972. Radioactive and stable nuclides in the Columbia River and adjacent northeast Pacific Ocean. Pages 663-700 in A. T. Pruter and D. L. Alverson, eds. The Columbia River Estuary and Adjacent Waters. University of Washington Press, Seattle.

Frederick, L. G. 1967. Dispersion of the Columbia River plume based on radioactivity measurements. Ph. D. Thesis. Oregon State University. 134 numb. leaves.

Friberg, L. 1957. Deposition and distribution of cadmium in man in chronic poisoning. Arch. Ind. Health 16: 27.

Gavis, J., and J. F. Ferguson. 1972. The cycling of mercury through the environment. Water Res. 6: 989-1008.

Goldberg, E. D. 1965. Minor elements in sea water. Pages 163-196 in J. P. Riley and G. Skirrow, eds. Chemical Oceanography, Vol. 1. Academic Press, New York.

_____. 1970. Chemical description of the oceans. Technology Review. 1970 (June): 24-29.

Goldberg, E. D., W. S. Broecker, M. G. Gross, and K. K. Turekian. 1971. Marine chemistry. Pages 137-146 in Radioactivity of the Marine Environment. Panel on Radioactivity in the Marine Environment, National Academy of Sciences, Washington, D. C.

Gorsuch, T. T. 1959. Radiochemical investigations on the recovery for analysis of trace elements in organic and biological materials. Analyst 85: 135-173.

Gotshall, D. W. 1969. Stomach contents of Pacific hake and arrow tooth flounder from northern California. Calif. Fish and Game 55(1): 75-82.

Guinn, V. P., and H. R. Lukens, Jr. 1965. Nuclear Methods. Pages 307-336 in G. H. Morrison, ed. Trace Analysis. Physical Methods. Interscience Publishers, New York.

Gunn, S. A., T. C. Gould, and W. A. D. Anderson. 1967. Specific response of mesenchymal tissue to cancerigenesis by cadmium. Arch. Pathol. 83: 493.

_____. 1968. Mechanism of zinc, cysteine and selenium protection against cadmium-induced vascular injury to mouse testis. J. Reprod. Fert. 15: 65.

Hamilton, G. A., and A. D. Ruthven. 1967. Residual mercury content of seed potatoes treated with organomercury disinfectant solutions. J. Sci. Food Agr. 18: 558-563.

Hammond, A. L. 1971. Mercury in the Environment. Natural and Human Factors. Science 171: 788-789.

Hanko, E., K. Erne, H. Wanntorp, and K. Borg. 1970. Poisoning in ferrets by tissues of alkyl mercury-fed chickens. Acta Vet. Scand. 11(2): 268-282. [Chem. Abstr: 73:96984e].

Hannerz, L. 1968. Experimental investigations on the accumulation of mercury in water organisms. Inst. Freshwater Res. Drottningholm 48: 120-176.

Harris, R. C., D. B. White, and R. B. Macfarlane. 1970. Mercury compounds reduce photosynthesis by plankton. Science 170: 736-738.

Hasselrot, T. B. 1969. Field investigations concerning the occurrence of mercury in fish, water, bottom sediment and bottom organisms [in Swedish, English summary]. Report to the Research Board of the National Environmental Protection Board, Sweden.

Hatch, W. R., and W. L. Ott. 1968. Determination of submicrogram quantities of mercury by atomic absorption spectrophotometry. Anal. Chem. 40: 2085-2087.

Her Majesty's Stationery Office. 1973. Survey of cadmium in food: Working party on the monitoring of foodstuffs for heavy metals. Fourth Report. Her Majesty's Stationery Office, London. 31 pp.

Hosohara, K. 1961. Mercury content of deep sea water. Nippon Kagaku Zasshi 82: 1107-1108. [Chem. Abstr: 56: 4535c].

International Decade of Oceanographic Exploration (IDOE). 1972. Baseline Studies of Pollutants in the Marine Environment and Research Recommendations: The IDOE Baseline Conference, May 24-26, 1972, New York, 1972.

Jacobs, E., M. Jacob, D. R. Sanadi, and L. B. Bradley. 1956. Uncoupling of oxidative phosphorylation by cadmium ion. J. Biol. Chem. 223: 147-156.

Jenkins, C. E. 1969. Radionuclide distribution in Pacific salmon. Health Physics 17: 507-512.

Jernelöv, A. 1969. Conversion of mercury compounds. Pages 68-74 in M. W. Miller and G. G. Berg, eds. Chemical Fallout: Current Research in Persistent Pesticides. Charles C. Thomas, Springfield, Illinois.

_____. 1970. Release of methyl mercury from sediments with layers containing inorganic mercury at different depths. Limnol. Oceanog. 15(6): 958-960.

Joensuu, O. I. 1971. Fossil fuels as a source of mercury pollution. Science 172: 1027-1028.

Johnels, A. G., and T. Westmark. 1969. Mercury contamination of the environment in Sweden. Pages 221-241 in M. W. Miller and G. G. Berg, eds. Chemical Fallout: Current Research in Persistent Pesticides. Charles C. Thomas, Springfield, Illinois.

Johnels, A. G., T. Westmark, W. Berg, P. I. Persson, and B. Sjöstrand. 1967. Pike (Esox lucius L.) and some other aquatic organisms in Sweden as indicators of mercury contamination in the environment. Oikos 18: 323-353.

Johnson, L. J., and W. L. High. 1970. Midwater trawling equipment and fishing technique for capturing hake off the coast of Washington and Oregon. U. S. Fish Wildl. Serv., Circ. 332: 77-101.

Kahn, H. L. 1968. Principles and practice of atomic absorption. Pages 183-229 in Trace inorganics in water. Symposium held at the 153rd meeting of the American Chemical Society, Miami Beach, Florida. (American Chemical Society, Washington, D. C. Advances in Chemistry Series No. 73).

Keilin, D., and T. Mann. 1940. Carbonic anhydrase: Purification and nature of the enzyme. Biochem. J. 34: 1163.

Kennedy, F. S. 1972. The role of heavy metals in biology. Pages 169-182 in Heavy metals in the environment. Seminar conducted by the Water Resources Research Institute, Oregon State University, Corvallis. Fall Quarter 1972.

Kim, M. K., K. D. Woo, S. S. Han, S. H. Lee, and U. H. Do. 1969. Mercury residues in polished rice grain. Nongsa Sihom Yon'gu Pogo 12(3): 55-61. [Chem. Abstr: 73: 97509r].

Knauer, G. A., and J. H. Martin. 1972. Mercury in the pelagic food chain. Pages 1-33 in Baseline Studies of Pollutants in the Marine Environment. Brookhaven National Laboratory, New York, May 24-26, 1972. [No Imprint].

Kopp, J. F., and R. C. Kroner. 1969. Trace metals in the waters of the United States. United States Department of the Interior. Federal Water Pollution Control Administration, Cincinnati. 28 pp.

Krauskopf, K. B. 1956. Factors controlling the concentrations of thirteen rare metals in seawater. Geochim. Cosmochim. Acta 9: 1-32.

Lee, D. H. K., ed. 1972. Mercury. Pages 17-55 in Metallic Contaminants and Human Health. Fogarty International Center Proceedings No. 9. Academic Press. New York.

Larsen, I. L., W. C. Renfro, and N. H. Cutshall. 1971. Zinc-65 specific activity in Mytilus californianus tissues. Pages 747-751 in Proceedings of the Third National Symposium on Radioecology. May 10-12, 1971. Oak Ridge, Tennessee.

Larsen, I. L. 1972. Determination of ^{65}Zn specific activity in various tissues of the California sea mussel, Mytilus californianus. M. S. thesis. Oregon State University, Corvallis. 66 numb. leaves.

Löfroth, G. 1970. Methylmercury: A review of health hazards and side effects associated with the emission of mercury compounds into natural systems. Swedish National Science Research Council, Ecological Research Committee Bulletin No. 4. 2nd ed. Stockholm. 59 pp.

Lukashev, K. I. 1958. The Main Principles of Lithology and Geochemistry of the Weathered Rocks. Izdatel'stvo Akademii Nauk Belorusskoi S. S. R., Minsk. (Translated from Russian: Israel Program for Scientific Translations, Ltd. 1970). 469 pp. [Chem. Abstr: 53: 1012b].

Lutz, R. E. 1926. The normal occurrence of zinc in biological materials. J. Ind. Hyg. 8: 177.

Margoshes, M., and B. L. Vallee. 1957. A cadmium protein from equine kidney cortex. J. Amer. Chem. Soc. 79: 4813-4814.

Marshall, N. B. 1966. The relationships of the anacanthine fishes, Macruronus, Lyconus, and Steindachneria. Copeia 1966: 275-280.

Martin, J. H., and G. K. Knauer. 1972. A comparison of inshore vs offshore levels of 21 trace and major elements in marine plankton. Pages 35-36 in Baseline Studies of Pollutants in the Marine Environment. Brookhaven National Laboratory, New York. May 24-26, 1972. [No Imprint].

Matousek, J. P., and B. J. Stevens. 1971. Biological applications of the carbon rod atomizer in atomic absorption spectroscopy. I. Preliminary studies on magnesium, iron, copper, lead, and zinc in blood and plasma. Clin. Chem. 17(5): 363-368.

McCance, R. A., and E. W. Widdowson. 1942. The absorption and excretion of zinc. Biochem. J. 36: 392.

McCaull, J. 1971. Building a shorter life. Environment 13(7): 3-14, 38-41.

McKee, J. E., and H. W. Wolf. 1963. Water Quality Criteria. Publication No. 3A, State of California Water Quality Control Board. Sacramento, California. 584 pp.

Medawar, P. B. 1944. The shape of the human being as a function of time. Proc. Roy. Soc. Ser. B: Biol. Sci. 132(867): 133-141.

Morris, A. W. 1968. The simultaneous determination of V, Cr, Mn, Fe, Co, Ni, Cu, and Zn in sea water by X-ray fluorescence spectrometry. Anal. Chim. Acta 42: 397-406.

Nagorzanski, R. 1968. Activity of some blood enzymes in workers exposed to mercury. Przegl. Lek. 24(2): 293-297. [Chem. Abstr: 69: 58104c].

Nakatani, R. E. 1966. Biological response of rainbow trout (Salmo gairdneri) ingesting zinc-65. Pages 809-823 in Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters: Proceedings of Symposium, Vienna; May 16-20, 1966. International Atomic Energy Agency, Vienna.

National Research Council. 1962. Disposal of low-level radioactive waste into Pacific coastal waters. National Academy of Sciences-National Research Council Publ. 985. Washington, D. C. 87 pp.

Nelson, M. O. 1967. Availability of Pacific hake (Merluccius productus) related to the harvesting process. Food and Agricultural Organization Conference on fish behaviour in relation to fishing techniques and tactics. Bergen, Norway. October 19-27, 1967. Experience Paper, FR:FB/67/E/34. 26 pp.

Nelson, M. O., and H. A. Larkins. 1970. Distribution and Biology of the Pacific hake: A synopsis. U. S. Fish Wildl. Serv., Circ. 332: 23-33.

Nicholls, G. D., H. C. Curl, Jr., and V. T. Bowen. 1959. Spectrographic analysis of marine plankton. Limnol. Oceanogr. 6(4): 472-478.

Norman, J. R. 1937. Coast Fishes. Part II: The Patagonian Region. Discovery Reports 16: 1-150.

O'Dell, B. L., P. M. Newberne, and J. E. Savage. 1958. Significance of dietary zinc for the growing chicken. J. Nutrition 65: 503-523.

Osterberg, C. L. 1963. Radioactivity in oceanic organisms. Ph. D. thesis. Oregon State University, Corvallis. 125 numb. leaves.

Osterberg, C. L., J. G. Pattullo, and W. G. Pearcy. 1964. Zinc-65 in euphausiids as related to Columbia River water off the Oregon coast. Limnol. Oceanogr. 9(2): 249-257.

Osterberg, C. L., W. G. Pearcy, and H. Curl, Jr. 1964. Radioactivity and its relationship to the oceanic food chains. J. Mar. Res. 22: 2-12.

Parisi, A. F., and B. L. Vallee. 1969. Zinc metalloenzymes: Characteristics and significance in biology and medicine. Amer. J. Clin. Nutrition 22(9): 1222-1239.

Parizek, J. 1964. Vascular changes at sites of oestrogen biosynthesis produced by parenteral injection of cadmium salts: The destruction of placenta by cadmium salts. J. Reprod. Fertility: 7(2): 263-265.

Parizek, J., I. Ostadalova, I. Benes, A. Babicky. 1968. Pregnancy and trace elements. J. Reprod. Fertility 16(3): 507-509.

Payne, P. R., and E. F. Wheeler. 1968. Models of the growth of organisms under nutrient limiting conditions. Pages 127-132 in A. Locker, ed. Quantitative Biology of Metabolism. 3rd International Symposium, Biologische Anstalt, Helgoland, September 26-29, 1967. Springer Verlag, New York, XVI. 296 pp.

Pearcy, W. G., and C. L. Osterberg. 1967. Depth, diel, seasonal, and geographic variation in zinc-65 of midwater animals off Oregon. Int. J. Oceano. Limnol. 1: 103-116.

Pearcy, W. G., and H. A. Vanderploeg. 1973. Radioecology of benthic fishes off Oregon. Pages 245-261 in International Atomic Energy Agency, Symposium on the Interaction of Radioactive Contaminants with the Constituents of the Marine Environment. Seattle, July 10-14, 1972. International Atomic Energy Agency, Vienna. (IAEA-SM-158/14).

Peden, J. D., J. H. Crothers, C. E. Waterfall, and J. Beasley. 1973. Heavy metals in Somerset marine organisms. Mar. Poll. Bull. 4: 7-9.

Pequegnat, J. E., S. W. Fowler, and L. F. Small. 1969. Estimates of the zinc requirements of marine organisms. J. Fish Res. Bd. Can. 26: 145-150.

Piro, A., M. Bernhard, M. Branića, and M. Verzi. 1972. Incomplete exchange reaction between radioactive ionic zinc and stable natural zinc in seawater. International Atomic Energy Agency, Symposium on the Interaction of Radioactive Contaminants with the Constituents of the Marine Environment. Seattle, July 10-14, 1972. International Atomic Energy Agency, Vienna. (IAEA-SM-158/2).

Platte, J. A., and V. M. Marcy. 1965. Atomic absorption spectrophotometry as a tool for the water chemist. At. Absorption Newslett. 4: 289-292.

Polikarpov, G. G. 1966. Radioecology of aquatic organisms. Reinhold, New York. 314 pp.

Preston, A. 1973. Heavy metals in British waters. Nature 242: 95-97.

Preston, A., D. F. Jefferies, J. W. R. Dutton, B. R. Harvey, and A. K. Steele. 1972. British Isles coastal waters: the concentrations of selected heavy metals in sea water, suspended matter and biological indicators--a pilot survey. Environ. Poll. 3: 69-82.

Pulido, P., J. H. R. Kagi, and B. L. Vallee. 1966. Isolation and some properties of human metallothionen. Biochemistry 5: 1768-1777.

Raeder, M. G., and E. Snekvik. 1941. Quecksilbergehalt mariner organismen. Kgl. Norske Videnskab Selskabs, Forh. 13: 169-172 (1940). [Chem. Abstr: 41: 2175a].

Ramierz Muñoz, J. 1968. Atomic Absorption Spectroscopy. Elsevier Publishing Co., Amsterdam. 493 pp.

Reigo, J. 1970. Mercury and fluorine content in Swedish milk. Sv. Mejeritidn 62(17): 312. [Chem. Abstr: 73: 108419g].

Renfro, W. C. 1970. Radioecology Lectures. Assistant Professor, School of Oceanography, Oregon State University, Corvallis, Oregon.

Renfro, W. C., and C. L. Osterberg. 1969. Radiozinc decline in starry flounders after temporary shutdown of Hanford reactors. Pages 372-379 in D. J. Nelson and F. C. Evans, eds. Symposium on Radioecology Proceedings of the 2nd National Symposium, May 15-17, 1967, Ann Arbor, Michigan. (Oak Ridge, Tennessee, U. S. Atomic Energy Commission Conf: 670503).

Renfro, W. C., J. E. McCauley, B. Glenne, R. H. Bourke, D. R. Hancock, and S. W. Hager. 1971. Oceanography of the near-shore coastal waters of the Pacific Northwest relating to possible pollution. WPCR Series 16070. I: 202, 206-208.

Rice, T. R. 1963. Review of zinc in ecology. Pages 619-631 in V. Schultz and A. W. Klement, eds. Proceedings of the 1st National Symposium on Radioecology. September 10-15, 1961, Collins, Colorado. Reinhold, New York.

Ricker, W. E. 1958. Handbook of Computations for Biological Statistics of Fish Populations. Fish. Res. Bd. Can. Bull. No. 119: 191-194.

Riley, J. P. 1965. Historical Introduction. Page 24 in J. P. Riley and G. Skirrow, eds. Chemical Oceanography. Vol. 1. Academic Press, New York.

Robertson, D. E., L.A. Rancitelli, J. C. Langford, and R. W. Perkins. 1972. Battelle-Northwest contribution to the IDOE Baseline Study. Pages 231-273 in Baseline Studies of Pollutants in the Marine Environment, Brookhaven National Laboratory, New York. May 24-26, 1972. [No Imprint].

Robinson, J. W. 1966. Atomic Absorption Spectroscopy. Marcel Dekker, Inc., New York. 204 pp.

Rona, E., D. W. Hood, L. Muse, and B. Buglio. 1962. Activation analysis of Mn and Zn in sea water. Limnol. Oceanogr. 7: 201-206.

Ryan, V. A., ed. 1973. Contemporary Activation Analysis, Marcel Dekker, Inc., New York. 443 pp.

Schelske, C. L. 1966. Fallout radioactivity in an estuary. The American Biology Teacher 28: 373-380.

Schroeder, H. A. 1965. The biological trace elements or peripatetics through the periodic table. J. Chronic Dis. 18: 217-228.

Schroeder, H. A., and J. J. Balassa. 1961. Abnormal trace metals in man: cadmium. J. Chronic Dis. 14: 236-258.

Schroeder, H. A., A. P. Nason, I. H. Tipton, and J. J. Balassa. 1967. Essential trace elements in man: zinc relation to environmental cadmium. J. Chronic Dis. 20(4): 179-210.

Seigbahn, K., ed. 1966. Alpha, beta and gamma-ray spectroscopy. Vol. I. North-Holland Publishing Co., Amsterdam. 862 pp.

Seymour, A. H. 1960. A program to study the radionuclides in water, bottom and biological samples from near the mouth of the Columbia River. Laboratory of Radiation Biology, University of Washington, Seattle. November 10, 1960.

Seymour, A. H. and G. B. Lewis. 1964. Radionuclides of the Columbia River origin in marine organisms, sediments, and water collected from the coastal and offshore waters of

Washington and Oregon, 1961-1963. Page 78 in U. S. Atomic Energy Commission Report UWFL-86.

Shippen, H. H., and M. S. Alton. 1967. Predation upon Pacific Hake, Merluccius productus, by Pacific dogfish, Squalus acanthias. Calif. Fish Game 53: 218-219.

Shubik, P., and J. L. Hartwell. 1971. Survey of compounds which have been tested for carcinogenic activity. In J. A. Peters, ed. Public Health Service Publication No. 149. (1968-1969 Volume).

Sidgwick, N. V. 1950. The Chemical Elements and their Compounds. Oxford University Press, New York. 2 vols.

Simon, F. P., A. M. Potts, and R. W. Gerard. 1947. Action of cadmium and thiols on tissues and enzymes. Arch. Biochem. 12: 283-291.

Skerfving, S. K., K. Hansson, and J. Lindsten. 1970. Chromosome breakage in humans exposed to methylmercury through fish consumption. Arch. Environ. Health 21: 133-139.

Slavin, W. 1966. Atomic absorption spectroscopy--a critical review. Appl. Spectrosc. 20: 281-288.

_____. 1968. Atomic absorption spectroscopy. John Wiley and Sons. New York. 307 pp.

Smart, N. A., and A. R. C. Hill. 1968. Pesticide residues in foodstuffs in Great Britain. 4. Mercury. J. Sci. Food Agr. 19: 315-316.

Stock, A., and F. Cucuel. 1934. Die Verbreitung des Quecksilbers. Naturwissenschaften 22/24: 390-393. [Chem. Abstr: 32: 4099].

Stokinger, H. E. 1963. The Metals (exluding Lead (Pb)). Pages 987-1194 in F. A. Patty, D. W. Fassett, and D. D. Irish, eds. Industrial Hygiene and Toxicology. Vol. 2. John Wiley and Sons, New York.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The Oceans. Prentice-Hall. 1087 pp.

Tejning, S. 1967b. Mercury in pheasants (Phasanus colchicus L.) derived from seed grain dressed with methyl and ethyl mercury compounds. Oikos 18: 334-344.

Tillman, M. F. 1968. Tentative recommendations for management of the coastal fishery for Pacific hake, Merluccius productus (Ayres), based on a simulation study of the effects of fishing upon a virgin population. M. S. Thesis. University of Washington, Seattle. 197 numb. leaves.

Tsuchuga, K. 1969. Cause of ouch-ouch disease (Itai-Itai Byo): An introductory review. Kobe J. Med. Sci. 18: 181-184.

Turney, W. G. 1970. The mercury pollution in Michigan. Report of the Michigan Water Resources Commission, 1970.

Underdal, B. 1968. Mercury in food determined by activation analysis: 1. Eggs. Nord Veterinaermed. 20(1): 9-13. [Chem. Abstr: 68: 86231g].

Underwood, E. J. 1971. Trace Elements in Human and Animal Nutrition. 3d ed. Academic Press, New York. 543 pp.

United States Atomic Energy Commission. 1960. Standards for protection against radiation. Pages 63-76 in Rules and Regulations. Title 10--Atomic Energy, Part 20. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.

United States Department of the Interior. 1968a. Minerals Yearbook. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 1142 pp.

_____. 1968b. Water Quality Criteria. Federal Water Pollution Control Administration. Washington, D. C. 234 pp.

_____. 1969. Minerals Yearbook. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 1216 pp.

_____. 1970. Mineral facts and problems. Bureau of Mines Bull. No. 650. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 1291 pp.

_____. 1970. Pacific hake. U. S. Fish Wildl. Serv., Circ. 332. 152 pp.

United States Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. National Environmental Research Center. Cincinnati, Ohio No.: 16020:121-130.

United States Geological Survey. 1970. Mercury in the environment. Geological Survey Professional Paper No. 713. 67 pp.

Uthe, J. F., and E. G. Bligh. 1971. Preliminary survey of heavy metal contamination of Canadian freshwater fish. J. Fish. Res. Bd. Can. 28(5): 786-788.

Vallee, B. L. 1962. Zinc. Pages 443-482 in C. L. Comar and F. Bonner, eds. Mineral Metabolism--An Advanced Treatise. Vol. 2, Part B, Ch. 24, The Elements. Academic Press, New York.

Vallee, B. L., and M. D. Altschule. 1949. Zinc in mammalian organisms with particular reference to carbonic anhydrase. Physiol. Rev. 29: 370-388.

Vallee, B. L., R. G. Fluharty, and J. G. Gibson, II. 1949a. Distribution of zinc in normal blood and organs studied by means of ^{65}Zn. Acta Unio. Int. contra Cancrum 6: 869-873. [Chem. Abstr: 46: 3631h].

Wallace, R. A., W. Fulkerson, W. D. Shults, and W. S. Lyon. 1971. Mercury in the environment: the human element. Oak Ridge National Laboratory. Report No: ORNL. NSF-EP-1. Oak Ridge, Tennessee. 61 pp.

Walsh, A. 1969. Physical aspects of atomic absorption. Pages 3-18 in Atomic Absorption Spectroscopy. American Society for Testing and Materials. Philadelphia. (ASTM: STP-443).

Weitzel, G., F. J. Strecker, U. Roester, A. M. Fretzdorff, and E. Buddecke. 1953b. Zinc und Insulin im Pankreas von Knockenfishen. [in German]. Physiol. Chem. 295: 83-86.

Wershaw, R. L. 1970. Source and behavior of mercury in surface waters. U. S. Geol. Surv. Professional Paper 173: 29-31.

Westöö, G. 1966. Determination of methylmercury compounds in foods: I: Methylmercury compounds in fish; identification and determination. Acta Chem. Scand. 20(8): 2131-2137. [Chem. Abstr: 66: 36635n].

_____. 1967a. Determination of methylmercury compounds in food stuffs: II. Determination of methylmercury in fish, eggs, meat and liver. Acta Chem. Scand. 21(7): 1790-1800. [Chem. Abstr: 68: 28546k].

_____. 1967b. Kwicksilver i fisk. Var Föeda 19(1): 1-7. [Chem. Abstr: 66: 102796u].

_____. 1968. Determination of methylmercury salts in various kinds of biological material. Acta Chem. Scand. 22(7): 2277-2280. [Chem. Abstr: 70: 36459r].

_____. 1969a. Methylmercury compounds in animal foods. Pages 75-96 in M. W. Miller and G. G. Berg, eds. Chemical Fallout. Charles C. Thomas, Springfield, Illinois.

Westöö, G., and K. Nören. 1967a. Kvicksilver och metylkvicksilver i fisk. Var Föeda 19(10): 138-178. [Chem. Abstr: 69: 9116z].

Westöö, G., M. Rydalv. 1969. Kvicksilver och Metylkvicksilver i fisk och krafton. Vor Föeda 21(3): 18-111. [Chem. Abstr: 73: 44026z].

Widdowson, E. M., R. A. McCance, and C. M. Spray. 1951. The chemical composition of the human body. Clin. Sci. 10: 113-125.

Windom, H. L. 1972. Arsenic, cadmium, copper, lead, mercury, and zinc in marine biota-North Atlantic Ocean. Pages 121-147 in Baseline Studies of Pollutants in the Marine Environment. Brookhaven National Laboratory, New York. May 24-26, 1972. [No Imprint].

Wobeser, G., N. O. Nielson, R. H. Dunlop, and F. M. Alton. 1970. Mercury concentrations in tissues of fish from Saskatchewan River. J. Fish Res. Bd. Can. 27: 830-834.

Wisely, B., and R. A. Blick. 1967. Mortality of marine invertebrate larvae in Hg, Cu, and Zn solutions. Aust. J. Mar. Freshwater Res. 18: 63-72.

APPENDIX: TABLE 1: Summary of Data on the Pacific Hake, Merluccius productus.

Location: Lat. 32° 50.4'N, Long. 117° 26.2'W (Start of Tow);
Lat. 32° 54.7'N, Long. 117° 26.5'W (End of Tow);
Date of Collection: June 11, 1970;

Cruise Data:
Cruise #50; Tow #16;
Time: 1330 to 1700 hrs PDT;
Depth: 610 to 640 m;
Depth of net: 325 m;

Length of fish (mm) (1)	Wet weight (g) (2)	Dry weight (g) (3)	Ash weight (g) (4)	Ratio of weights: Wet/Ash (5)	Ratio of weights: Dry/Ash (6)	^{65}Zn (pCi/g. ash) (7)	Total Zinc (ug/g. ash) (8)	Specific Activity: (^{65}Zn/g. Zn) (9)	Cadmium (ug/g. ash) (10)	Mercury (ug/g. wet) (11)	Part of Fish (12)
277	75.0412	15.1496	2.5194	29.79	6.01	Not Detectable	256.67	NIL	1.66	Not Determined	Entire Fish
282	106.2674	20.6776	3.1761	33.46	6.51		300.61		2.00		
300	126.5028	29.5597	4.0013	31.62	7.39		316.44		2.52		
319	178.8134	36.8893	4.7109	37.96	7.83		340.96		3.44		
332	211.6411	42.1988	5.7703	36.68	7.31		350.12		3.42		
352	349.4865	77.3281	9.1513	38.19	8.45		365.03		3.41		
375	395.3155	86.5228	12.6866	31.16	6.82		369.92		3.92		
384	355.3857	60.7855	10.0203	35.47	6.07		382.61		3.86		
402	375.4126	75.0931	10.9901	34.25	6.83		387.77		4.10		
294	93.5927	17.1847	1.3574	68.95	12.66	Not Detectable	217.32	NIL	1.08	.066	Flesh
298	62.5927	11.3997	0.8769	71.29	13.00		213.14		1.19	.070	
312	103.5471	20.9420	1.4008	73.92	14.95		235.63		1.14	.079	
341	135.7933	28.1770	1.9142	70.94	14.72		257.11		1.72	.084	
374	205.4848	44.6149	2.9122	70.56	15.32		262.39		1.90	.102	
396	219.7930	45.3470	3.0051	73.14	15.09		282.17		2.15	.111	

Location: Lat. 37° 03.0'N, Long. 122° 38.0'W
Date of Collection: August 3, 1969;

Cruise Data:
Russian Collection,
Research Vessel:
"PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
400	425.5252	91.5290	13.0569	32.59	7.01	1.98	400.11	.0049	4.09	Not Determined	Entire Fish
415	586.8115	132.3031	17.4542	33.62	7.58	1.22	397.22	.0031	4.10		
430	667.1970	143.4530	18.7520	35.58	7.65	1.12	408.11	.0027	4.24		
441	690.8706	158.7896	20.8659	33.11	7.61	1.47	402.31	.0036	4.35		
454	686.8924	165.0368	21.7440	31.59	7.59	1.07	410.41	.0026	4.43		
461	650.9979	136.5916	19.0239	34.22	7.18	0.91	408.19	.0022	4.73		
465	682.0966	137.9865	19.1117	35.69	7.22	1.11	409.21	.0027	4.44		
466	654.3441	144.7089	19.1161	34.23	7.57	1.09	412.40	.0026	4.31		
484	962.9818	223.8368	29.0203	33.18	7.71	0.88	413.16	.0021	4.83		
490	971.5142	224.1563	29.0841	33.40	7.71	0.77	415.61	.0018	4.62		

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
492	930.0752	211.3552	28.0312	33.18	7.54	0.91	411.68	.0022	4.80	Not Determined	Entire Flesh
492	998.1235	224.3242	31.5144	31.67	7.12	0.88	418.54	.0021	4.54		
496	1001.8675	225.7088	31.4518	31.85	7.18	0.65	415.11	.0016	4.73		
500	1004.5232	226.1123	29.0251	34.61	7.79	0.49	415.64	.0012	4.81		
500	962.8772	222.5428	31.6112	30.46	7.04	0.68	420.11	.0016	4.59		
414	283.2124	59.4791	3.7128	76.28	16.02	0.54*	280.32	.0019	1.82	.134	Flesh
431	218.7795	45.7329	2.9124	75.12	15.72	0.49	291.11	.0016	2.00	.144	
451	297.7697	61.4765	3.8762	76.82	15.86	0.47	297.14	.0016	2.15	.150	
465	316.8343	66.5936	4.1158	76.98	16.18	0.48	300.39	.0016	2.04	.165	
467	228.4644	45.4336	3.1617	72.26	14.37	0.44	294.11	.0015	2.05	.153	
469	304.9540	60.6390	3.9973	76.29	15.17	0.49	293.68	.0017	2.10	.170	
470	304.9848	60.4874	4.1092	74.22	14.72	0.39	297.54	.0013	2.19	.181	
477	401.7919	84.9696	5.6234	71.45	15.11	0.35	300.16	.0012	2.40	.179	
485	432.7480	88.4322	5.9954	72.18	14.75	0.40	302.68	.0013	2.06	.192	
498	408.0352	80.0926	5.3324	76.52	15.02	0.41	300.91	.0140	2.05	.200	
512	450.8415	88.2454	6.1239	73.62	14.41	0.29	303.65	.0009	2.36	.212	
528	354.4236	69.6079	4.7288	74.95	14.72	0.22	305.22	.0007	2.27	.218	
532	384.0810	77.0010	5.1334	74.82	15.00	0.15	308.41	.0005	2.34	.224	

Location: Lat. 38° 41.0'N, Long. 123° 45.0'W
Date of Collection: August 1, 1969;

Cruise Data:
Russian Collection, Research Vessel:
"PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
305	148.6594	29.3567	4.3621	34.08	6.73	2.25	325.69	.0069	2.86	Not Determined	Entire Flesh
309	196.0156	35.4813	5.4133	36.21	6.55	2.09	326.22	.0064	3.00		
311	219.3414	46.0223	5.9715	36.73	7.71	2.18	325.95	.0067	2.92		
317	227.4574	48.0250	6.5400	34.78	7.34	1.95*	335.11	.0058	3.10		
320	321.6861	47.5122	5.9827	38.73	7.94	1.75*	345.18	.0051	3.12		
323	249.3850	50.2651	6.6234	37.65	7.59	1.90	342.33	.0056	3.20		
325	245.4144	44.6334	6.5000	37.76	7.86	1.69*	345.79	.0049	3.11		
343	303.3891	59.5662	8.3652	36.27	7.13	1.55*	359.62	.0043	3.44		
351	339.4120	71.2250	10.1028	33.61	7.05	1.40*	362.63	.0039	3.80		
370	363.0781	81.2831	9.9533	36.48	8.17	1.25*	382.61	.0033	3.61		
385	398.1072	93.3254	12.1011	32.89	7.71	1.22*	390.52	.0031	3.76		
415	524.8075	107.1519	15.1232	34.70	7.59	1.00*	402.11	.0025	4.00		
450	683.7542	154.8154	19.9011	34.36	7.74	0.95*	407.65	.0023	4.14		
492	927.4254	192.2611	25.9112	35.79	7.42	1.02*	417.81	.0024	4.36		
511	1051.1858	229.9561	29.5194	35.61	7.79	0.88*	421.54	.0021	4.60		
311	85.3387	17.8277	1.1379	75.00	15.67	0.96	225.22	.0042	1.30	.111	Flesh
328	133.9305	27.3253	1.9122	70.04	14.29	0.76	248.61	.0031	1.36	.119	
337	125.5450	27.1734	1.7889	70.18	15.19	0.69*	247.54	.0028	1.35	.122	
350	153.3960	31.5424	2.1472	71.44	14.69	0.64*	256.22	.0025	1.71	.149	
361	177.4889	36.5374	2.5233	70.34	14.48	0.59	262.24	.0023	1.57	.152	
378	196.0967	42.5642	2.6421	74.22	16.11	0.54	275.14	.0020	2.00	.164	
390	186.0757	38.8017	2.4636	75.53	15.75	0.52*	277.22	.0019	1.71	.171	
411	253.8525	55.1038	3.4722	73.11	15.87	0.49*	283.11	.0017	2.14	.162	

* Values with 25-30% error.

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
424	133.0340	28.5163	1.7980	73.99	15.86	0.44*	287.65	.0015	2.01	.170	Flesh
447	123.8405	25.2693	1.6430	75.37	15.38	0.41*	288.15	.0014	2.43	.190	
458	256.7368	55.8964	3.5153	73.03	15.90	0.43*	293.11	.0015	2.27	.191	
470	284.0646	55.3337	3.8722	73.36	14.29	0.40*	300.63	.0013	2.25	.194	
481	265.0862	55.1594	3.2755	80.93	16.84	0.39*	296.11	.0013	2.23	.196	
490	405.9550	82.8103	5.1244	79.22	16.16	0.36*	304.91	.0012	2.34	.190	
510	392.4384	77.6524	5.1562	76.11	15.06	0.39*	305.01	.0013	2.60	.188	
522	334.6440	65.0143	4.3314	77.26	15.01	0.29*	306.11	.0009	2.64	.195	
544	344.2520	70.4122	4.3384	79.35	16.23	0.32*	308.67	.0010	2.41	.202	

Location: Lat. 39° 16.0'N, Long. 123° 56.5'W
Date of Collection: July 31, 1969;

Cruise Data:
Russian Collection, Research Vessel: "PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
270	86.1918	18.7153	2.6660	32.33	7.02	1.97	200.17	.0098	1.80	Not Determined	Entire Fish
286	105.5986	21.4908	3.0922	34.15	6.95	2.03	290.64	.0070	2.50		
295	121.3813	25.5253	3.6660	33.11	6.99	2.17	315.22	.0067	2.42		
298	136.5603	27.2654	3.8895	35.11	7.01	2.06	311.14	.0066	3.00		
298	133.8960	27.8200	3.9128	34.22	7.11	2.27	308.69	.0073	2.67		
309	159.9496	34.1539	4.7044	34.00	7.26	2.33	321.88	.0072	2.86		
312	162.9611	32.0914	5.1101	31.89	6.28	2.37	333.75	.0071	3.20		
315	184.7162	41.5743	5.8473	31.59	7.11	2.17	329.11	.0066	2.75		
325	208.5131	47.0315	6.7284	30.99	6.99	2.20	348.33	.0063	3.50		
332	246.5290	53.3016	7.2916	33.81	7.31	2.11	356.14	.0059	3.22		
335	267.0253	56.3034	7.9189	33.72	7.11	2.07	347.33	.0060	3.51		
336	271.7867	57.7997	8.0055	33.95	7.22	2.10	363.17	.0058	3.37		
342	328.6937	67.2916	9.5857	34.29	7.02	2.02	357.39	.0057	3.60		
352	336.7450	71.2672	9.9954	33.99	7.13	1.95	373.16	.0052	3.56		
365	379.5648	82.2824	11.8392	32.06	6.95	1.88	373.39	.0050	3.85		
400	484.7850	99.3447	14.2124	34.11	6.99	1.70*	388.71	.0044	4.20		
409	551.0846	119.9584	16.4552	33.49	7.29	1.62	400.57	.0040	4.16		
421	611.1343	127.6536	18.2102	33.56	7.01	1.70	395.75	.0043	4.02		
437	645.2107	135.5919	19.1514	33.69	7.08	1.65*	410.55	.0040	4.36		
454	657.0998	134.6233	20.2746	32.41	6.64	1.22*	404.61	.0030	4.30		
470	765.2277	164.2744	23.1047	33.12	7.11	1.20*	411.75	.0029	4.20		
486	902.1811	206.5950	29.7259	30.35	6.95	1.15*	417.88	.0028	4.35		
509	1021.2131	214.5658	30.0092	34.03	7.15	0.99*	414.65	.0024	4.36		
521	1039.1703	218.2506	31.0015	33.52	7.04	1.07*	423.81	.0025	4.60		
270	74.4338	14.4615	1.1432	65.11	12.65	0.88	177.39	.0049	0.21	.079	Entire Fish
282	92.2387	18.6682	1.3440	68.63	13.89	0.92	198.44	.0046	0.50	.082	
286	65.0267	12.3063	0.9736	66.78	12.64	0.89	200.75	.0044	0.75	.081	
298	87.0612	15.9568	1.2265	70.99	13.01	0.89	222.55	.0040	0.92	.089	
298	61.7992	11.1923	0.8636	71.56	12.96	0.85	217.36	.0039	1.00	.092	
299	98.7269	19.6307	1.3982	70.61	14.04	0.87	221.53	.0039	0.80	.090	
302	97.9294	20.1233	1.4446	67.79	13.93	0.99	218.51	.0045	1.10	.099	
303	100.7722	18.9525	1.3703	73.54	13.83	0.85	225.00	.0038	1.15	.089	
304	94.7562	19.6847	1.2959	73.12	15.19	0.87	222.85	.0039	1.06	.095	

*Values with 25-30% error.

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
306	106.4256	21.9946	1.4873	71.56	14.79	0.92	228.11	.0040	0.94	.101	Flesh
306	100.9816	20.5120	1.4114	71.45	14.53	0.83	230.02	.0036	1.20	.095	
309	111.4418	22.4332	1.5626	71.31	14.35	0.81	227.69	.0036	1.05	.099	
310	103.3942	21.7031	1.5201	68.02	14.28	0.77	232.31	.0033	1.22	.089	
312	81.3403	16.7537	1.0986	70.04	15.25	0.94	229.61	.0041	1.00	.105	
314	104.1212	20.5292	1.4566	71.48	14.09	0.93	226.18	.0041	1.30	.112	
316	93.3697	20.0413	1.3371	69.83	14.99	0.93	241.95	.0038	1.03	.101	
316	103.8124	21.4317	1.4031	73.99	15.27	0.88	233.88	.0038	1.20	.112	
322	290.8650	59.6250	4.1725	69.71	14.29	0.97	232.91	.0042	1.40	.117	
324	104.5303	21.3278	1.5062	69.40	14.16	0.82	247.63	.0033	1.51	.105	
324	132.9498	27.7437	1.8657	71.26	14.87	0.86	237.64	.0036	1.27	.120	
326	128.8483	26.4304	1.8457	69.81	14.32	0.89*	250.16	.0036	1.60	.117	
326	140.2358	27.6834	1.9988	70.16	13.85	0.92	243.29	.0038	1.49	.123	
337	127.9782	28.0387	1.8386	69.63	15.25	0.86	260.12	.0033	1.58	.129	
342	293.4469	59.8965	4.1915	70.01	14.29	0.85	246.30	.0034	1.40	.138	
345	143.0943	29.8741	2.0378	70.22	14.66	0.81*	260.91	.0031	1.50	.135	
352	148.8749	28.7134	1.9232	77.41	14.93	0.86	265.85	.0032	1.81	.122	
363	175.1532	35.7149	2.4614	71.16	14.51	0.83	257.56	.0032	1.90	.148	
389	194.2211	42.2753	2.6112	74.38	16.19	0.79*	284.36	.0028	2.06	.175	
412	273.3735	57.2969	3.6218	75.48	15.82	0.73*	277.67	.0026	2.25	.188	
430	250.0562	52.3248	3.2855	76.11	15.92	0.74	280.49	.0026	1.92	.175	
449	234.9441	43.6524	2.9736	79.01	14.68	0.68*	283.74	.0024	2.33	.204	
452	196.1091	39.8105	2.7380	71.62	14.54	0.53*	290.31	.0018	2.20	.196	
469	267.5530	54.7457	3.8418	69.64	14.25	0.52*	295.39	.0018	2.26	.188	
482	297.9666	62.5411	4.3735	68.13	14.30	0.52*	304.54	.0017	2.43	.201	
499	326.1399	67.3752	4.2268	77.16	15.94	0.41*	311.27	.0014	2.20	.198	
512	396.3369	77.1777	5.3857	73.59	14.33	0.43*	296.17	.0015	2.55	.211	
532	338.2141	64.2894	4.5563	74.23	14.11	0.45*	312.65	.0014	2.59	.218	

Location: Lat. 40° 08'N, Long. 124° 20.0'W;
Date of Collection: July 30, 1969;

Cruise Data:
Russian Collection, Research Vessel:
"PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
315	237.4642	50.4857	7.2641	32.69	6.96	9.85	327.18	.030	3.00	Not Determined	Entire Fish
342	318.9281	70.5532	9.9231	32.14	7.11	6.78	362.39	.019	3.75		
366	380.1743	79.2077	11.3316	33.55	6.99	4.81	377.82	.013	3.66		
384	480.8536	108.1227	15.4021	31.22	7.02	4.92	385.19	.013	4.10		
399	514.4940	106.1019	15.3994	33.41	6.89	4.08	392.44	.010	3.86		
415	519.8526	120.8288	16.9942	30.59	7.11	3.72	400.17	.009	4.20		
417	583.8111	128.7951	18.0133	32.41	7.15	4.01	396.89	.010	4.25		
422	598.6169	126.8836	17.5496	34.11	7.23	3.59	404.85	.0089	4.27		
432	632.1126	131.2645	18.9142	33.42	6.94	3.67	403.54	.0091	4.20		
440	664.4688	131.7212	19.5432	34.00	6.74	3.28	408.15	.0080	4.50		
448	667.3320	132.4893	19.5412	34.15	6.78	3.31	409.22	.0081	4.21		
457	738.7686	155.2276	21.1122	33.41	7.02	3.30	407.16	.0081	4.33		
462	646.7228	135.4691	20.2798	32.75	6.68	3.18	412.54	.0077	4.45		
494	944.7221	207.6670	29.6244	31.89	7.01	3.19	418.16	.0076	4.30		
515	1056.3792	223.8275	30.9154	34.17	7.24	2.98	419.51	.0071	4.35		

*Values with 25-30% error.

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
528	1077.4813	221.8437	31.7373	33.95	6.99	2.83	423.19	.0067	4.50		
299	96.4251	19.7962	1.4324	67.32	13.82	6.01	215.23	.028	1.00	.104	Flesh
315	103.3697	21.4317	1.4031	73.99	15.27	4.33	237.36	.018	1.00	.092	
332	157.9865	29.8590	2.3160	68.22	12.89	3.59	248.11	.014	1.52	.114	
358	185.5305	38.0216	2.6459	70.12	14.37	3.03	266.54	.011	1.65	.128	
374	200.5270	42.7127	2.8156	71.22	14.17	2.00	265.59	.008	1.77	.133	
392	189.5505	38.3925	2.5126	75.44	15.28	1.98	273.51	.007	1.80	.120	
396	214.7679	45.2594	2.9562	72.65	15.31	1.95	282.49	.007	1.74	.139	
402	213.0176	44.9763	2.9512	72.18	15.24	1.78	279.56	.006	1.90	.150	
412	234.3608	45.0321	3.1294	74.89	14.39	1.81	286.61	.006	2.04	.159	
418	249.1409	52.1067	3.5714	69.76	14.59	1.72	287.59	.006	2.15	.151	
418	291.9021	63.3021	4.0014	72.95	15.82	1.76	280.41	.006	2.00	.162	
425	167.6849	35.7480	2.2654	74.02	15.78	1.75	285.63	.006	2.30	.170	
425	231.2211	44.9137	3.0103	76.81	14.92	1.71	288.55	.006	2.17	.166	
432	172.1297	34.4888	2.2439	76.71	15.37	1.65	295.15	.005	2.15	.188	
437	283.8718	55.5960	3.7769	75.16	14.72	1.78	286.94	.006	1.96	.192	
439	255.8429	50.3284	3.[illegible]758	75.79	14.91	1.80	295.15	.006	2.20	.181	
440	309.8622	63.0718	4.0[illegible]2	77.23	15.72	1.70	293.91	.006	2.40	.199	
449	368.3433	72.1289	4.8118	76.55	14.99	1.65	296.31	.006	2.45	.201	
450	270.1323	53.3308	3.4099	79.18	15.64	1.60	292.59	.005	2.40	.211	
450	299.6354	61.6954	3.9122	76.59	15.77	1.63	298.65	.005	2.50	.219	
452	351.1479	73.1648	4.5444	77.27	16.10	1.56	295.51	.005	2.44	.206	
459	281.3149	60.0839	3.8652	72.78	15.54	1.52	303.11	.005	2.37	.218	
461	308.1517	64.5792	4.2126	73.15	15.33	1.61	304.19	.005	2.50	.222	
464	301.1785	58.9949	3.8376	78.48	15.37	1.55	299.29	.005	2.41	.215	
475	267.7981	54.7921	3.7122	72.14	14.76	1.49	303.47	.005	2.55	.228	
489	331.5546	66.9101	4.4037	75.29	15.19	1.52	309.56	.005	2.40	.232	
500	317.0668	60.3053	3.9520	80.23	15.26	1.43	308.95	.005	2.52	.241	
521	303.1303	59.2005	3.9599	76.55	14.95	1.23	311.51	.004	2.60	.249	
538	409.6845	87.2821	5.2490	78.05	16.63	1.20	312.15	.004	2.35	.243	

Location: Lat. 41° 32.0'N, Long. 124° 16.0'W;
Date of Collection: July 29, 1969;

Cruise Data:
Russian Collection; Research
Vessel: "PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
375	373.0742	84.0646	11.9921	31.11	7.01	14.05	381.22	.037	3.70	Not Determined	Entire Fish
388	420.9705	92.5008	13.1021	32.13	7.06	10.76	390.65	.028	3.84		
397	470.1028	106.0348	15.1695	30.99	6.99	10.00	391.54	.026	4.10		
409	553.6560	120.6970	18.4552	30.00	6.54	9.15	393.60	.023	4.01		
417	546.0119	115.3207	17.1864	31.77	6.71	8.22	404.93	.022	4.13		
421	552.4474	117.2015	17.2102	32.10	6.81	7.78	401.56	.019	4.06		
426	551.6215	118.1009	16.1340	34.19	7.32	8.47	402.39	.021	4.20		
430	628.5156	136.2003	18.8122	33.41	7.24	7.50	401.55	.019	4.24		
430	638.1379	139.0229	18.9922	33.60	7.32	7.73	402.15	.019	4.03		
430	639.8258	139.4492	19.0765	33.54	7.31	8.17	410.12	.020	4.12		
433	676.4716	135.7143	19.0878	35.44	7.11	8.01	405.61	.020	4.16		
435	678.5208	137.3470	19.1025	35.52	7.19	7.59	401.56	.019	4.30		

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
435	637.5798	137.9121	19.1811	33.24	7.19	8.11	412.69	.020	4.44	Not Determined	Entire Fish
445	678.4393	155.2157	21.8922	30.99	7.09	7.04	408.53	.017	4.46		
452	755.4803	168.5959	23.7125	31.86	7.11	7.51	406.61	.018	4.45		
467	698.5141	153.2844	21.8354	31.99	7.02	7.02	405.91	.017	4.53		
473	854.0781	189.5842	27.1222	31.49	6.99	6.77	415.33	.016	4.55		
488	931.9070	205.7032	29.7259	31.35	6.92	6.29	411.71	.015	4.62		
503	963.5364	218.6728	29.9142	32.21	7.31	6.47	416.59	.016	4.65		
510	1061.1779	217.6298	31.0014	34.23	7.02	6.23	422.37	.015	4.46		
514	1042.6360	213.2873	30.5132	34.17	6.99	5.85	417.21	.014	4.55		
522	1043.0490	221.5739	31.1637	33.47	7.11	6.18	420.16	.015	4.55		
526	1067.2963	220.3755	31.4373	33.95	7.01	6.17	419.55	.015	4.65		
369	81.0284	16.4017	1.1398	71.09	14.39	9.15	272.51	.034	1.95	.135	Flesh
375	198.4454	41.8518	2.7516	72.12	15.21	7.56	273.64	.028	1.86	.132	
387	203.6400	43.3074	2.7152	75.00	15.95	7.01	272.15	.026	1.96	.147	
395	206.7148	43.5745	2.8536	72.44	15.27	6.25	275.49	.023	1.94	.160	
415	272.1676	56.1050	3.5264	77.18	15.91	5.06	282.55	.018	2.04	.171	
422	278.6162	60.8876	3.8198	72.94	15.94	5.51	283.66	.019	2.00	.165	
428	324.6101	63.3713	4.3316	74.94	14.63	4.98	288.17	.017	2.10	.168	
438	274.8750	64.8517	3.8193	71.97	16.98	4.97	287.62	.017	2.15	.179	
443	266.5782	56.1589	3.7216	71.63	15.09	4.78	293.39	.016	2.04	.170	
459	390.4293	78.8337	5.1224	76.22	15.39	4.40	290.85	.015	2.32	.180	
467	326.1771	65.4683	4.3128	75.63	15.18	4.02	300.15	.013	2.10	.191	
467	362.7924	72.8040	4.7214	76.84	15.42	4.11	291.98	.014	2.40	.178	
468	318.6833	61.3798	4.0614	78.47	15.11	4.50	297.55	.015	2.02	.199	
473	314.8790	61.9844	4.2368	74.32	14.63	4.00	296.11	.014	2.15	.210	
475	311.7362	62.2629	4.2155	73.95	14.77	4.35	305.32	.014	2.35	.224	
490	398.6596	81.6784	4.9759	80.12	16.41	4.22	303.91	.014	2.10	.234	
501	317.0668	60.3053	3.9520	80.23	15.26	3.88	310.01	.013	2.30	.241	
514	412.6616	81.6223	5.6175	73.46	14.53	4.09	306.89	.013	2.31	.252	
514	357.5777	73.3197	5.0116	71.35	14.63	3.79	312.64	.012	2.26	.269	
524	257.8209	49.8041	3.3961	78.22	15.11	3.82	314.22	.012	2.27	.242	

Location: Lat. 42° 23.0'N, Long. 124°43.0'W; Cruise Data:
Date of Collection: July 27, 1969; Russian Collection: Research Vessel: "PROF. DERYUGIN"

369	352.5801	77.7664	11.6942	30.15	6.65	17.94	387.56	.046	4.00	Not Determined	Entire Fish
374	374.8086	79.1156	12.0054	31.22	6.59	15.52	375.51	.041	3.85		
376	402.8452	87.3546	12.9992	30.99	6.72	14.68	390.22	.038	4.01		
384	453.9054	100.4063	14.3233	31.69	7.01	13.81	395.16	.035	3.90		
398	494.9886	108.2161	15.4154	32.11	7.02	11.78	386.54	.030	4.28		
412	519.6010	112.6748	16.2122	32.05	6.95	11.49	390.33	.029	4.22		
422	605.3164	125.8812	18.1124	44.42	6.95	11.22	413.11	.027	4.16		
430	618.1891	123.1194	18.5142	33.39	6.65	10.31	414.56	.025	4.30		
435	632.1126	125.2120	18.9142	33.42	6.62	10.44	393.94	.026	4.51		
440	616.7688	126.1702	19.0302	32.41	6.63	10.00	416.54	.024	4.27		
443	672.1444	128.4779	19.7052	34.11	6.52	10.02	402.51	.025	4.33		
446	681.7645	143.8767	21.9995	30.99	6.54	10.19	420.11	.024	4.30		

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
448	692.4092	142.9760	22.0302	31.43	6.49	10.00	416.14	.024	4.44	Not Determined	Entire Fish
453	725.8473	157.3829	22.4512	32.33	7.01	9.58	420.14	.023	4.39		
468	748.7562	157.1687	22.6142	33.11	6.95	9.92	419.51	.024	4.35		
470	789.0155	159.6535	23.1047	34.15	6.91	9.66	417.63	.023	4.52		
478	812.4009	166.8715	23.1124	35.15	7.22	9.22	427.11	.022	4.46		
485	958.6392	196.6158	27.4603	34.91	7.16	9.75	416.71	.023	4.50		
496	1029.7308	205.8891	28.5165	36.11	7.22	9.28	425.00	.022	4.61		
511	1022.2187	212.7652	30.1002	33.96	7.07	9.33	418.11	.022	4.42		
524	1136.6791	228.4879	32.0011	35.52	7.14	9.51	431.22	.022	4.56		
386	202.1349	44.2811	2.7334	73.95	16.20	10.98	265.12	.041	1.86	.188	Flesh
394	196.0282	41.5500	2.6165	74.92	15.88	9.18	281.14	.033	2.04	.194	
415	294.9586	61.5630	3.8841	75.94	15.85	8.85	292.22	.030	2.14	.199	
423	293.3319	63.8341	4.0122	73.11	15.91	7.78	286.41	.027	2.09	.211	
431	221.0245	45.8960	2.8956	76.33	15.85	7.75	296.51	.026	2.23	.224	
447	268.9582	53.0951	3.5539	75.68	14.94	7.50	301.13	.025	2.31	.215	
449	357.3824	70.7368	4.6815	76.34	15.11	7.02	291.65	.024	2.20	.232	
453	252.6731	51.1789	3.5759	70.66	14.31	7.25	288.94	.025	2.34	.241	
455	268.2128	55.0992	3.7179	72.41	14.82	7.50	295.67	.025	2.40	.239	
459	335.4344	67.3902	4.4600	75.21	15.11	7.31	306.93	.024	2.26	.244	
461	285.3174	59.1865	3.9170	72.84	15.11	6.98	299.95	.023	2.11	.247	
478	474.9878	95.6038	6.3146	75.22	15.14	7.11	312.56	.023	2.40	.248	
478	310.4804	61.7472	4.0570	76.53	15.22	6.54	298.65	.022	2.12	.244	
482	403.1996	84.2508	5.3661	75.14	15.70	7.01	308.51	.023	2.40	.249	
482	306.5969	64.0257	4.1765	73.41	15.33	7.11	315.44	.023	2.53	.251	
492	392.3008	77.8625	5.3267	73.51	14.59	6.81	303.85	.022	2.27	.258	
503	326.8489	65.0218	4.3493	75.15	14.95	7.00	306.49	.023	2.31	.261	
511	374.1220	73.9913	4.9592	75.44	14.92	6.80	320.01	.021	2.50	.270	
513	345.1313	71.4760	4.9057	70.35	14.57	6.99	317.90	.022	2.44	.268	
515	392.3216	75.2742	5.0317	77.97	14.96	6.48	315.65	.021	2.52	.265	
520	311.2827	60.8254	4.7126	75.69	14.79	6.32	325.91	.019	2.35	.264	
528	446.5135	86.3287	5.9008	75.67	14.63	7.02	322.14	.022	2.50	.266	

Location: Lat. 43°23.0'N, Long. 124°09.0'W;
Date of Collection: July 26, 1969;

Cruise Data:
Russian Collection: Research
Vessel: "PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
379	376.9885	80.4787	12.1569	31.01	6.62	20.14	375.49	.054	3.25	Not Determined	Entire Fish
385	405.7034	86.5871	13.2194	30.69	6.55	18.44	379.65	.049	4.00		
399	434.7512	91.2423	14.2122	30.59	6.42	17.88	392.64	.045	3.96		
417	484.2513	101.5664	15.4122	31.42	6.59	16.39	410.33	.040	4.30		
430	619.6703	123.1194	18.5142	33.47	6.65	16.12	412.65	.039	4.22		
446	664.1649	132.4370	21.9995	30.19	6.02	14.75	409.94	.036	4.50		
450	670.3790	132.4015	22.0302	30.43	6.01	15.00	408.66	.037	4.50		
459	653.2333	135.8467	20.1553	32.41	6.74	15.00	416.95	.036	4.65		
460	628.7135	133.9567	19.1915	32.76	6.98	14.56	403.19	.036	4.51		
462	632.9624	138.4907	19.3153	32.77	7.17	14.74	417.55	.035	4.40		
465	658.5703	147.8724	21.0945	31.22	7.01	14.15	417.11	.034	4.55		

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
470	684.2853	147.5827	21.1134	32.41	6.99	14.88	431.65	.034	4.70	Not Determined	Entire Fish
470	738.5393	162.7924	22.6415	32.61	7.19	14.51	409.55	.035	4.61		
470	785.9445	176.0476	25.0780	31.34	7.02	14.18	413.63	.034	4.64		
481	939.3654	199.9191	28.2771	33.22	7.07	13.95	435.11	.032	4.56		
485	902.1571	187.5866	29.7259	30.35	6.31	14.16	413.85	.034	4.65		
490	976.5921	210.0105	30.0015	32.55	7.00	14.09	432.51	.033	4.54		
491	962.6196	215.8112	29.9322	32.16	7.21	14.39	408.66	.035	4.70		
511	1083.6575	236.7889	30.9528	35.01	7.65	13.91	437.11	.032	4.64		
523	1054.2692	235.2809	30.9988	34.01	7.59	13.66	418.61	.033	4.65		
372	197.4878	42.4582	2.7878	70.84	15.23	18.25	275.12	.066	1.65	.188	Flesh
384	199.8116	43.2335	2.6638	75.01	16.23	16.31	267.51	.061	1.80	.195	
399	206.8327	43.2913	2.8536	72.39	15.26	15.22	284.13	.054	2.01	.210	
414	277.4677	60.1186	3.8098	72.83	15.78	13.81	297.19	.046	1.96	.199	
423	219.5428	45.0529	3.1265	70.22	14.41	13.68	277.64	.049	1.95	.222	
436	233.9593	47.0612	3.2841	71.24	14.33	12.59	283.59	.044	2.05	.234	
443	289.9976	59.6001	4.0216	72.11	14.82	12.96	301.23	.043	2.10	.246	
446	314.7239	68.0629	4.2913	73.34	15.86	12.49	279.18	.045	2.10	.239	
450	317.4002	65.6122	4.1162	77.11	15.94	12.14	306.54	.040	2.29	.249	
458	320.2050	66.4049	4.5112	70.98	14.72	12.22	305.69	.040	2.00	.255	
466	317.0471	69.1567	4.5114	70.28	15.23	12.00	292.15	.041	2.15	.264	
470	283.6847	57.6966	3.9654	71.54	14.55	12.31	312.44	.039	2.44	.259	
488	402.3394	60.6754	4.2615	77.91	14.39	11.29	291.39	.039	2.35	.264	
496	359.3057	71.4121	4.7767	75.22	14.95	12.01	317.25	.038	2.48	.268	
510	297.9075	58.3628	3.9568	75.29	14.75	11.31	302.15	.037	2.41	.281	
519	294.5549	56.6406	3.7963	77.59	14.92	11.64	316.22	.037	2.50	.275	

Location: Lat. 45°56.8'N; Long. 124°12.2'W, to
Lat. 45°56.8N; Long. 124°15.4'W;
Date of Collection: May 20, 1969:

Cruise Data:
69-6; AEC "BARON" #20;

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
445	657.8078	141.0488	20.9894	31.34	6.72	20.04	426.32	.047	4.37	Not Determined	Entire Fish
448	664.1649	132.4370	21.9995	30.19	6.02	18.79	397.85	.047	4.30		
461	728.7135	155.2631	22.2440	32.76	6.98	19.22	402.34	.048	4.65		
474	785.9445	176.0476	25.0780	31.34	7.02	18.69	404.59	.046	4.50		
460	290.6854	62.1507	4.3414	66.96	14.32	15.55	312.26	.050	2.44	.261	Flesh
463	290.2016	63.8485	4.1487	79.95	15.39	14.06	306.49	.049	2.26	.268	
464	304.8448	61.3272	4.0127	75.97	15.28	15.12	310.11	.049	2.30	.272	
473	256.5341	53.5902	3.6015	71.23	14.88	14.78	308.27	.048	2.50	.295	

Location: Lat. 45°51.0'N; Long. 124°15.4'W;
Date of Collection: May 22, 1969:

Cruise Data:
69-6; AEC "BARON" #28

465	632.9624	138.4907	19.3153	32.77	7.17	17.62	410.23	.043	4.40	Not Determined	Entire Fish
496	684.2853	147.5827	21.1134	32.41	6.99	17.51	397.21	.044	4.31		
470	748.7562	157.1687	22.6142	33.11	6.95	17.81	418.55	.043	4.50		
472	789.0255	150.6535	23.1047	34.15	6.91	16.79	422.51	.040	4.41		
475	812.4009	166.8715	23.1124	35.15	7.22	18.00	400.11	.045	4.65		

TABLE 1: Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
480	900.1422	186.2156	29.6144	30.40	6.29	16.26	429.21	.038	4.59	N.D.	
426	310.7197	59.6965	4.1308	75.22	14.45	16.51	301.31	.055	1.86	.244	
452	293.8498	59.2578	3.9985	73.49	14.82	15.31	303.22	.050	2.24	.259	
463	312.0461	61.7988	3.8971	80.07	15.86	14.78	302.95	.049	2.15	.267	Flesh
482	267.7212	55.2934	3.7086	72.19	14.91	14.51	310.17	.047	2.14	.295	
509	312.6433	60.2404	4.1008	76.24	14.69	14.48	312.25	.046	2.26	.311	

Location: Lat. 45°50.9'N; Long. 124°22.6'W, to Lat. 45°51.2'N; Long. 124°23.2'W:
Cruise Data: C6910C; BMT #132
Date of Collection: October 12, 1969:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
488	905.1422	189.1120	29.8142	30.36	6.34	17.52	426.14	.041	4.60		
490	906.0114	189.2132	29.8915	30.41	6.33	17.10	431.59	.041	4.51	Not Det.	Entire Fish
500	1002.4687	226.3739	30.8832	32.46	7.33	17.56	434.62	.040	4.50		
439	289.6483	63.9379	4.0162	72.12	15.92	16.25	276.12	.059	1.85	.240	
449	268.9582	53.0951	3.5639	75.68	14.94	15.12	292.41	.052	2.22	.259	
458	317.0488	64.6587	4.3366	73.11	14.91	15.76	298.64	.053	2.34	.285	Flesh
471	358.1069	64.4591	4.8295	74.15	14.49	15.48	300.11	.052	2.11	.309	
492	461.7462	92.1434	6.0541	76.27	15.22	15.00	307.65	.049	2.35	.318	

Location: Lat. 45°50.9'N; Long. 124°20.2'W, to Lat. 45°50.8'N; Long. 124°22.6'W;
Cruise Data: C6910C, OFC #14, OTB#300
Date of Collection: October 14, 1969:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
475	854.0781	189.5842	27.1222	31.49	6.99	17.51	417.52	.042	4.35		
480	906.6808	203.1567	28.9397	31.33	7.02	18.06	426.11	.042	4.50		
492	991.5326	215.7079	30.0011	33.05	7.19	17.78	425.69	.042	4.40	Not Det.	Entire Fish
503	966.0658	210.7943	29.8999	32.31	7.05	17.18	431.61	.040	4.51		
412	269.5670	55.3349	3.4671	77.75	15.96	17.51	290.11	.060	1.85	.239	
427	314.7429	61.8584	4.1294	76.22	14.98	16.78	292.46	.057	1.90	.249	
437	277.8818	59.5270	3.8281	72.59	15.55	15.66	288.17	.054	2.10	.251	
442	259.4927	54.3880	3.6502	71.09	14.90	15.76	287.69	.055	2.15	.261	Flesh
453	258.4203	52.5828	3.6239	71.31	14.51	14.81	300.22	.049	2.00	.281	
470	336.2660	67.9979	4.6542	72.25	14.61	14.51	305.64	.047	2.06	.259	
482	324.5606	59.3143	4.1557	78.10	14.27	13.92	302.23	.046	2.30	.278	
482	367.5991	70.4002	4.6561	78.95	15.12	14.21	312.67	.045	2.49	.288	

Location: Lat. 45°49.1'N, Long. 124°16.7'W;
Cruise Data "COMMANDO" Haul #1:
Date of Collection: July 1, 1970:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(1)	(11)	(12)
459	699.0980	147.7751	20.6102	33.92	7.17	16.20	411.24	.039	4.50		
468	717.2628	149.1318	21.0341	34.10	7.09	15.26	441.63	.034	4.61	Not Det.	Entire Fish
482	857.3292	174.0807	24.2115	35.41	7.19	15.01	427.55	.035	4.40		
484	333.8246	70.7132	4.5592	73.22	15.51	13.12	314.68	.042	2.55	.295	
488	445.4754	89.8413	5.9223	75.22	15.17	12.51	306.95	.041	2.46	.302	Flesh
492	336.6404	67.5211	4.5964	73.24	14.69	12.75	320.61	.040	2.41	.314	

Location: Lat. 45°59.0'N, Long. 124°12.0'W
Date of Collection: July 7, 1970:

Cruise Data:
"COMMANDO" Haul # 17"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
471	785.7642	166.1264	23.0092	34.15	7.22	16.31	436.17	.037	4.25	Not Determined	Entire Fish
482	965.3467	208.7863	28.9981	33.29	7.20	16.22	444.62	.036	4.50		
491	996.7866	211.8730	29.7993	33.45	7.11	15.79	441.55	.036	4.65		
515	1054.9776	219.7999	31.0014	34.03	7.09	15.51	443.22	.035	4 66		
477	284.1421	57.9250	3.9165	72.55	14.79	13.22	319.33	.041	2.50	.291	Flesh
499	317.0668	60.3053	3.9520	80.23	15.26	12.53	325.41	.039	2.53	.314	
538	444.0694	85.5762	5.8654	75.71	14.59	12.61	330.65	.038	2.60	.325	
543	329.6935	66.4311	4.3965	74.99	15.11	11.98	332.22	.036	2.65	.361	
552	468.7861	98.9673	6.2322	75.22	15.88	11.23	326.41	.034	2.61	.395	

Location: Lat. 46°17.0'N; Long. 124°21.0'W:
Date of Collection: July 16, 1969:

Cruise Data:
Russian Collection: Research
Vessel: "PROF. DERYUGIN"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
369	379.5344	76.7351	11.8392	32.06	6.48	31.62	373.12	.085	3.88	Not Determined	Entire Fish
378	406.4391	90.1926	12.7211	31.95	7.09	30.02	390.02	.077	4.10		
399	504.2126	109.7895	15.1643	33.25	7.24	30.06	397.52	.076	4.13		
415	589.3165	128.4724	17.6231	33.44	7.29	27.55	398.11	.069	4.40		
440	610.2122	130.1221	19.6511	31.05	6.62	25.21	421.16	.060	4.32		
445	614.2149	1 1.4654	19.7488	31.10	6.66	23.81	412.16	.058	4.60		
460	700.1222	145.1118	21.3895	32.73	6.78	23.66	413.22	.057	4.30		
464	702.9164	146.6996	21.4316	32.80	6.85	23.00	407.85	.056	4.60		
471	700.0942	142.2839	23.0780	30.34	6.17	23.72	415.22	.057	4.48		
480	882.1428	168.7951	26.8782	32.82	6.28	22.48	413.16	.054	4.68		
509	1023.6419	218.5440	30.5656	33.49	7.15	20.38	423.62	.048	4.55		
519	1094.0927	238.3269	32.5139	33.65	7.33	21.22	425.10	.050	4.65		
386	204.4595	44.6226	2.7924	73.22	15.98	26.22	277.11	.095	2.00	.275	Flesh
399	194.8327	41.2913	2.7317	71.32	15.11	23.78	282.54	.084	1.91	.289	
418	286.3353	61.5674	3.9165	73.11	15.72	22.51	295.61	.076	1.85	.314	
420	217.9915	44.5959	2.9691	73.42	15.02	22.54	290.18	.078	2.02	.309	
423	211.9428	43.2208	3.0373	69.78	14.23	23.22	293.41	.079	2.18	.321	
426	235.9301	47.8194	3.1357	75.24	15.25	22.51	297.54	.076	2.01	.326	
426	242.2015	47.8194	3.1357	77.24	15.25	22.61	280.22	.077	2.04	.341	
440	267.2184	53.4698	3.3677	79.35	15.88	21.26	290.13	.073	1.96	.342	
440	289.3560	58.7143	3.8076	75.99	15.42	21.49	296.74	.072	2.14	.339	
447	287.3349	62.9225	3.8344	74.91	16.41	20.05	290.21	.069	2.00	.347	
450	293.8604	61.7324	3.8554	76.22	16.01	21.02	302.61	.069	2.03	.351	
454	307.1666	68.2497	4.2763	71.83	15.96	20.01	291.52	.069	2.15	.346	
458	290.6854	62.1507	4.3414	66.96	14.32	20.56	300.11	.069	2.24	.362	
460	257.0559	51.8154	3.2668	78.69	15.86	19.76	297.50	.066	2.17	.366	
463	281.4243	64.1314	4.1101	68.64	15.64	20.20	307.71	.066	2.10	.371	
464	287.2443	62.1339	3.6864	77.92	16.85	19.42	305.17	.064	2.36	.379	
467	316.6376	64.7822	4.2286	74.88	15.32	19.02	307.56	.062	2.20	.369	
470	265.8130	54.3124	3.7822	70.28	14.36	18.88	302.61	.062	2.15	.382	
472	217.8557	44.5634	3.0070	72.45	14.82	18.72	307.56	.061	2.40	.384	
476	290.5129	61.9628	4.1419	79.59	14.96	18.81	310.66	.062	2.27	.379	
476	268.0260	57.2979	3.8213	70.14	14.99	18.52	300.11	.062	2.17	.386	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
477	317.8248	60.9575	4.0752	77.99	14.96	18.70	296.54	.063	2.30	.391	Flesh
479	313.9226	63.8739	4.0548	77.42	15.75	18.80	311.22	.060	2.01	.388	
485	498.0008	101.4575	6.9207	71.96	14.66	18.00	310.46	.058	2.36	.394	
492	337.0746	67.5068	4.6118	73.09	14.64	17.72	315.18	.056	2.45	.395	
499	363.7819	76.0737	4.6383	78.43	16.40	17.85	312.22	.057	2.40	.389	
515	36 .6938	71.7598	4.5504	79.71	16.77	16.74	310.64	.054	2.55	.411	

Location: Lat. 46°23.8'N; Long. 124°15.4'W; Cruise Data:
Date of Collection: May 15, 1969: 69-6: AEC "BARON" #1

518	1039.6314	224.9609	32.5088	31.98	6.92	0.21	422.14	.048	4.71	N.Det.	Entire Fish
530	1087.3729	239.9305	33.4165	32.54	7.18	20.01	428.94	.047	4.66		
437	239.7903	49.8063	3.2426	73.95	15.36	21.21	292.56	.071	1.90	.349	Flesh
470	271.2142	55.4712	3.8629	70.21	14.36	20.04	302.61	.070	2.35	.359	
487	286.5291	59.3882	4.0046	71.55	14.83	18.72	307.59	.067	2.18	.379	
517	326.1728	68.2492	4.6523	70.11	14.67	17.53	312.22	.065	2.44	.384	

Location: Lat. 46°21.2'N; Long. 124°14.0'W; Cruise Data:
Date of Collection: May 17, 1969: 69-6; AEC "BARON" #6

430	665.3816	143.0538	21.3195	31.21	6.71	25.01	405.22	.062	4.36	Not Determined	Entire Fish
443	680.5063	147.3975	20.9968	32.41	7.02	25.31	414.26	.061	4.31		
469	703.2872	148.2949	21.2153	33.15	6.99	23.78	416.29	.057	4.56		
495	982.6325	196.4271	27.2122	36.11	7.22	22.34	419.54	.053	4.46		
514	1020.0207	206.6590	30.1692	33.81	6.85	21.22	420.23	.050	4.62		
516	1085.5269	229.7714	31.8243	34.11	7.22	20.10	416.21	.048	4.51		
522	1060.7002	228.7542	30.9964	34.22	7.38	21.24	426.34	.050	4.78		
534	1089.4096	233.8809	32.1265	33.91	7.28	20.61	430.26	.048	4.74		
439	275.9724	57.1644	3.7168	74.25	15.38	20.51	283.15	.077	2.36	.361	Flesh
449	294.3885	62.4235	3.9137	75.22	15.95	20.25	296.26	.075	2.41	.365	
468	312.3197	62.1595	4.1138	75.92	15.11	18.75	298.15	.068	2.16	.371	
485	345.8825	70.3586	4.7284	73.15	14.88	17.65	312.66	.064	2.40	.395	
499	355.3400	72.2521	4.8136	73.82	15.01	18.23	310.19	.060	2.46	.408	

Location: Lat. 46°13.7'N; Long. 124°28.3'W: Cruise Data:
Date of Collection: May 17, 1969: 69-6; AEC "BARON" #7

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
400	501.4292	113.8888	15.9285	31.48	7.15	30.34	402.22	.075	4.02	Not Determined	Entire Fish
424	553.8338	125.3703	17.2212	32.16	7.28	29.02	398.41	.073	4.40		
444	701.6936	147.4376	21.0025	33.41	7.02	27.51	403.11	.068	4.49		
444	691.3098	153.9271	20.9996	32.92	7.33	28.81	410.29	.070	4.28		
459	707.3450	149.8295	22.0014	32.15	6.81	26.25	415.33	.063	4.58		
460	666.3848	142.5051	20.4162	32.64	6.98	25.63	409.92	.060	4.57		
432	294.0410	59.6611	3.9122	75.16	15.25	22.21	288.13	.084	1.96	.322	Flesh
438	317.3879	64.1264	4.2133	75.33	15.22	22.02	290.62	.081	2.07	.341	
442	291.5652	58.7250	3.8865	75.02	15.11	21.24	295.33	.076	2.02	.333	
461	308.8749	62.4247	4.1123	75.11	15.18	20.11	302.46	.072	2.14	.354	
469	298.7510	60.1729	3.9876	74.92	15.09	19.54	308.46	.067	2.20	.365	
475	309.1909	62.4244	4.1286	74.89	55.12	20.22	307.75	.071	2.22	.377	
479	321.5282	65.0600	4.2859	75.02	15.18	18.56	303.19	.068	2.26	.391	
486	339.4294	68.9430	4.5962	73.85	15.00	18.25	300.69	.065	2.31	.385	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
501	294.3475	60.2129	3.9982	73.62	15.06	18.61	315.52	.066	2.35	.399	Flesh
560	382.3173	77.9867	5.2165	73.29	14.95	16.22	320.91	.057	2.50	.432	

Location: 46°30.1'N; Long. 124°14.5'W; Cruise Data:
Date of Collection: May 27, 1969: 69-6; AEC "BARON" #31

495	812.2858	175.9866	25.9185	31.34	6.79	23.22	425.21	.055	4.64	N.D.	Entire Fish
510	954.3016	208.8090	29.6183	32.22	7.05	21.21	432.33	.049	4.70		
493	379.9001	77.9781	5.1234	74.15	15.22	17.51	310.19	.066	2.15	.388	Flesh
504	385.8070	78.7563	5.2122	74.02	15.11	16.82	312.25	.055	2.21	.395	
520	429.4821	86.1872	5.8156	73.85	14.82	16.51	317.72	.055	2.30	.409	
525	412.1289	84.1778	5.6156	73.39	14.99	16.75	320.14	.050	2.37	.422	

Location: Lat. 46°13.1'N; Long. 124°14.8'W; to Cruise Data:
Lat. 46°12.1'W; Long. 124°15.3'W 69-9; AEC "COBB" #32
Date of Collection: August 13, 1969:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
431	674.9667	140.8103	20.9943	32.15	6.71	26.25	400.86	.065	4.50	Not Determined	Entire Fish
440	690.4125	152.7505	21.8215	31.64	7.00	26.31	406.92	.065	4.35		
427	285.9322	60.7205	3.8165	74.92	15.91	21.22	293.62	.076	1.91		Flesh
434	294.4840	62.5021	3.9359	74.82	15.88	21.34	290.59	.074	2.01		
451	307.7443	64.9467	4.1236	74.63	15.75	21.25	302.63	.073	2.09		
462	321.8574	67.5391	4.3156	74.58	15.65	20.75	297.12	.070	2.12		
463	324.0770	68.5806	4.3378	74.71	15.81	21.04	294.61	.070	2.22		
475	304.5208	62.4531	4.1196	73.92	15.16	20.82	303.17	.070	2.30		
482	302.0406	62.1163	4.0866	73.91	15.20	19.56	304.58	.068	2.13		
483	312.3277	63.7930	4.2275	73.88	15.09	20.51	315.16	.070	2.45		
496	358.5930	73.7176	4.8755	73.55	15.12	18.84	312.94	.069	2.53		
501	361.7909	73.7336	4.9123	73.65	15.01	19.23	313.56	.068	2.50		
509	386.7322	79.6706	5.2346	73.88	15.22	18.72	317.25	.066	2.46		
517	452.3968	91.8510	6.1234	73.45	15.00	18.02	318.21	.065	2.42		
536	527.1783	107.9928	7.2236	72.98	14.95	17.51	317.63	.067	2.62		

Location: Lat. 46°38.0'N; Long. 124°rw.0'W; Cruise Data:
Date of Collection: May 30, 1970: 70-06; AEC "COBB" #2

458	682.9468	149.5233	20.5955	33.16	7.26	17.51	400.61	.044	4.40	Not Determined	Entire Fish
461	673.6863	148.1125	20.5142	32.84	7.22	17.15	406.22	.042	4.44		
478	861.0761	190.8360	27.2234	31.63	7.01	16.18	415.39	.039	4.50		
492	935.7052	206.6807	29.6955	31.51	6.96	16.67	417.42	.040	4.59		
503	956.7729	209.3595	29.9085	31.99	7.00	15.48	421.51	.037	4.60		
515	1018.8591	214.3493	30.1102	32.75	6.89	15.02	412.19	.036	4.65		
466	301.4207	61.3168	4.0024	75.31	15.32	15.51	305.13	.058	2.36	.378	Flesh
488	377.7552	76.4304	5.1124	73.89	14.95	15.02	310.22	.055	2.22	.395	
506	389.9189	79.4904	5.3421	72.99	14.88	14.01	316.19	.049	2.12	.412	

Location: Lat. 46°34.12'N; Long. 124°13.0'W; to Cruise Data:
Lat. 46°33.2'N; Long. 124°13.1 W; 70-06; AEC "COBB",
Date of Collection: May 30, 1970: Phase #1; Haul #3:

456	258.4087	55.5190	7.5536	34.21	7.35	17.21	420.11	.041	4.50	N.D.	Entire Fish
462	320.9537	70.9627	9.5380	33.65	7.44	16.82	417.18	.040	4.52		

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
466	262.0304	55.3158	7.7800	33.88	7.11	17.01	418.25	.041	4.50	Not Determined	Entire Fish
469	335.8201	66.8580	9.5648	35.11	6.99	16.31	421.29	.039	4.41		
470	292.4799	61.3500	8.9562	32.88	6.85	16.75	426.35	.039	4.63		
474	316.9703	66.6766	9.3254	33.99	7.15	16.25	420.52	.039	4.59		
510	299.1220	63.2219	8.7565	34.16	7.22	15.02	432.41	.035	4.61		
514	335.9504	74.9624	10.2268	32.85	7.33	14.58	425.52	.034	4.70		
425	586.3177	123.2267	17.2345	34.02	7.15	18.51	401.61	.046	4.10		
446	706.8721	153.8424	21.1322	33.45	7.28	17.72	389.64	.045	4.19		
459	724.5647	162.3342	21.9965	32.94	7.38	16.71	395.91	.042	4.44		
477	898.0251	198.2866	27.3122	32.88	7.26	16.02	402.59	.040	4.59		
492	986.5937	217.8452	29.7615	33.15	7.32	15.54	410.88	.038	4.50		
512	1024.3540	229.5083	30.1192	34.01	7.62	15.22	407.79	.037	4.54		
541	1097.1458	244.5290	32.3451	33.92	7.56	14.48	435.68	.033	4.74		

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
428	298.9044	61.2946	3.9216	76.22	15.63	17.51	292.13	.066	2.16	Not Determined	Flesh
432	313.5239	64.5742	4.1264	75.98	15.65	16.48	294.15	.067	2.10		
456	382.7042	78.6568	5.1109	74.88	15.39	16.22	304.11	.058	2.29		
471	310.8962	65.7205	4.2264	75.69	15.55	15.31	313.71	.055	2.30		
481	376.7458	76.3397	5.0026	75.31	15.26	15.48	312.92	.053	2.34		
489	376.3111	75.6527	5.0068	75.16	15.11	14.62	317.63	.050	2.29		
492	450.1275	89.7974	6.0025	74.99	14.96	14.73	308.51	.050	2.50		
503	381.7174	76.1796	5.1196	74.56	14.88	14.62	319.22	.051	2.48		
525	371.0401	74.4978	4.9965	74.26	14.91	14.22	317.42	.049	2.54		
545	445.5760	89.9790	5.9986	74.28	15.00	13.96	326.12	.046	2.50		

Location: 46°55.0'N; Long. 124°28.0'W; Cruise Data:
Date of Collection: June 25, 1970: 70-6; "COMMANDO" #6

478	876.4363	183.1780	25.6193	34.21	7.15	15.32	407.24	.038	4.35	Not Det.	Entire Fish
492	964.0255	207.5724	29.6532	31.43	7.00	14.12	422.26	.033	4.44		
511	1044.0283	224.9392	31.0261	33.65	7.25	14.06	424.22	.033	4.51		
469	317.1191	64.0824	4.2217	75.12	15.18	15.12	312.18	.055	2.30	.375	Flesh
480	322.9419	65.4871	4.3627	74.02	15.01	14.88	309.56	.054	2.44	.388	
495	377.9677	76.4935	5.1132	73.92	14.96	13.65	315.42	.047	2.37	.395	

Location: 46°00.2'N; Long. 124°15.2'W; Cruise Data:
Date of Collection: July 6-7, 1970: Y7007A

490	969.5490	215.3228	29.8231	32.51	7.22	16.18	410.15	.039	4.46	Not. Det.	Flesh
510	1044.0116	218.5212	30.5624	34.16	7.15	16.01	417.16	.038	4.64		
525	1086.5777	224.0366	31.1162	34.92	7.20	15.10	418.29	.036	4.78		

Location: Columbia River Mouth, near Chinook Point: Cruise Data:
Lat. 46°17.0'N; Long. 124°10.0'W: Y7106
Date of Collection: June 16, 1971:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
535	454.7987	93.5437	6.2114	73.22	15.06	7.72	320.21	.022	2.36	.412	Flesh
615	520.3159	100.6396	7.1325	72.95	14.11	6.71	322.54	.020	2.66	.452	

Location: Lat. 47°18.9'N; Long. 124°37.7'W, to
Lat. 47°18.7'N; Long. 124°40.2'W;
Date of Collection: August 5, 1969:

Cruise Data:
69-9; AEC "COBB" #23

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
410	267.4475	54.6394	3.5274	75.82	15.49	20.11	295.16	.068	1.96	.349	Flesh
430	327.0066	69.2166	4.2965	76.11	16.11	18.82	289.34	.065	2.03	.354	
436	262.1945	53.5213	3.5142	74.61	15.23	17.97	297.22	.060	2.20	.364	
439	275.5461	60.4820	3.8159	72.21	15.85	18.02	302.14	.060	2.26	.366	
440	279.0352	59.8206	3.8224	73.00	15.65	17.51	294.61	.059	2.21	.374	
443	269.4636	59.6756	3.6928	72.97	16.16	17.61	295.11	.060	2.22	.371	
447	294.5213	59.6807	3.9212	75.11	15.22	17.19	288.42	.060	2.25	.382	
545	358.0865	72.5099	4.7988	74.62	15.11	15.02	320.64	.047	2.47	.411	

Location: Lat. 48°27.8'N; Long. 124°41.9'W; to
Lat. 48°27.5'N; Long. 124°40.4'W:
Date of Collection: July 19, 1969:

Cruise Data:
69.9; AEC "COBB" #19

472	740.0403	152.7967	24.1217	30.68	6.33	13.88	411.22	.034	4.22	Not Det.	Entire Fish
495	906.1593	199.9005	28.1154	32.23	7.11	13.16	418.61	.031	4.51		
511	960.6485	209.8243	29.8895	32.14	7.02	12.75	411.54	.031	4.76		
427	311.4334	61.5913	4.1392	75.24	14.88	13.65	283.41	.048	2.22	.354	Flesh
439	294.9221	60.5533	4.0022	73.69	15.13	12.78	287.51	.044	2.00	.365	
441	289.7419	60.1601	4.0214	72.05	14.96	12.54	288.36	.043	2.12	.366	
442	312.8269	62.3080	4.1511	75.36	15.01	13.22	286.13	.046	2.27	.372	
447	277.0977	56.0903	3.6853	75.19	15.22	12.15	282.64	.043	1.97	.363	
449	347.1834	68.7980	4.5622	76.10	15.08	12.56	294.16	.043	2.17	.371	
452	289.3132	58.6224	3.9988	72.35	14.66	11.53	287.24	.040	2.03	.382	
452	273.0657	54.7733	3.8143	71.59	14.36	12.22	300.62	.041	2.38	.391	
452	285.8138	56.8423	4.0058	71.35	14.19	12.56	281.39	.045	2.37	.394	
459	305.6771	60.2901	4.3126	70.88	13.98	12.03	287.32	.042	2.19	.400	
478	355.5446	68.5532	5.0112	70.95	13.68	11.33	300.26	.036	2.27	.392	
478	363.4563	70.3232	5.1256	70.91	13.72	11.88	293.61	.040	2.13	.395	

Location: 48°00.0'N; Long. 124°49.5'W:
Date of Collection: August 19, 1972:

Cruise Data:
Y7208 (OSU - Yaquina)

469	374.8370	77.7401	5.2315	71.65	14.86	2.93	310.23	.009	Not Det.	.411	Flesh
472	367.7035	74.1292	5.1622	71.23	14.36	1.89	316.16	.006		.432	

Location: Puget Sound - Pt. Wells (Washington State)
Date of Collection: May 13, 1969:

Cruise Data:
Bureau of Commercial Fisheries

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
316	274.6762	63.9987	8.3895	32.74	7.63	Below the Detection Limits; Errors 20-30%	443.67	Could Not Be Calculated as Zn 65 values were below the detection limits	2.00	Not Determined	Entire Fish
320	275.1245	64.2567	8.4111	32.71	7.64		424.74		2.25		
368	391.2346	84.2385	12.0169	32.56	7.01		425.12		2.70		
391	496.7128	105.1862	14.9838	33.15	7.02		518.98		3.02		
424	651.4164	136.6934	21.2257	30.69	6.44		505.49		3.11		
456	657.0108	133.5452	19.8433	33.11	6.73		500.96		3.09		
304	98.3522	21.1312	1.3537	72.65	15.61		363.18		0.11	.265	Flesh
312	57.4649	11.9101	0.7754	74.11	15.36		374.27		0.26	.282	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
340	132.9498	27.7437	1.8657	71.26	14.87	Below the Detection Limits: Errors 20-30%	396.26	Could Not Be Calculated as Zn^{65} values were below the detection limits	0.55	.294	Flesh
356	154.0524	30.0380	2.0012	76.98	15.01		421.33		0.65	.315	
366	100.8724	20.3890	1.1411	71.49	14.45		416.19		1.01	.318	
379	192.0705	50.2828	2.6695	71.95	15.09		429.66		0.82	.322	
391	182.5727	38.1649	2.3988	76.11	15.91		426.54		1.12	.339	
412	206.1459	41.7440	2.9253	70.47	14.27		442.13		1.39	.351	
434	237.3487	48.2075	3.1263	75.92	15.42		455.61		1.15	.362	
466	290.9865	63.1733	4.1398	70.29	15.26		447.52		1.50	.381	

APPENDIX: TABLE 2: Total Mercury in Water Samples

a: Fresh water samples: Samples collected from the Columbia River Fig. (6) indicates sample location, and is identified as a dot (·).

Date of Collection (1)	Location (2)	Total Mercury (ug/liter) (3)	Date of Collection (1)	Location (2)	Total Mercury (ug/liter) (3)
5.12.71	Prescott	.039*	5.16.71	McNary	.033*
5.26.71	Harrington Point	.042*	5.26.71	Clatskanie	.029*
5.26.71	Prescott	.022*	6.05.71	Prescott	.018
6.05.71	Prescott	.019	6.05.71	Clatskanie	.022
6.05.71	Clatskanie	.024	6.05.71	Harrington Point	.033
6.01.71	Umatilla	.019	6.01.71	McNary	.022
6.05.71	St. Helens	.021	6.05.71	St. Helens	.024
6.09.71	Harrington Point	.039	6.09.71	Clarskanie	.025
6.09.71	Prescott	.020	6.24.71	Prescott	.019
6.24.71	Cltaskanie	.020	6.25.71	Harrington Point	.036
7.01.71	McNary	.020	7.01.71	McNary	.021
7.01.71	Umatilla	.020	7.07.71	Harrington Point	.040
7.08.71	Clatskanie	.021	7.08.71	Prescott	.021
7.22.71	Prescott	.022	7.22.71	Clatskanie	.018
7.21.71	Harrington Point	.037	7.19.71	Umatilla	.021
8.02.71	Umatilla	.022	8.0.71	Umatilla	.022
8.02.71	McNary	.019	8.02.71	McNary	.018
8.04.71	Harrington Point	.041	8.04.71	Prescott	.022
8.04.71	Clatskanie	.021			

*Values with 10 to 20% Error

b: Fresh water samples: Samples collected from river in Oregon. Fig. (6) indicates sample location and is identified as a dot (·).

Date of Collection (1)	Location (2)	Total Mercury (ug/l) (3)	River empties into ocean at (4)
4.29.71	Santiam River (I5)	.021*	-
4.29.71	Willamette River (Spring Hill Bar)	.044*	-
4.29.71	Mackenzie River (Hendrick's Bridge)	.039*	-
4.29.71	Willamette River (Corvallis)	.029*	-
6.05.71	Willamette River (near mouth)	.022	-
6.05.71	Willamette River (1/2 mile from mouth)	.024	-
3.02.73	Public boat landing, Riverton	.037	-
3.02.73	Rogue River, 1 mile above Highway 101, north bank	.037	Gold Beach, Lat. 42°26'N

(1)	(2)	(3)	(4)
3.02.73	Elk River; 1/2 mile downstream from Highway 101, north bank	.038 .039	South of Cape Blanco: Lat. 42°46'N
3.02.73	Sixes River; 200 yards from Highway 101, north bank	.049 .056	Cape Blanco: 42°50'N - Lat.
3.02.73	Coos River; 1 1/2 mile upstream from east side, south bank	.0227 .0232	Coos Bay: 43°20'N - Lat.
3.02.73	Umpqua River; at Umpqua wayside 10 miles upstream from Reedsport	.161 .151	Winchester Bay: Lat. 43°40'N
3.02.73	Smith River; south side of Smith River road, 3 miles up from Highway 101	.110 .143	Winchester Bay: Lat. 43°42'N
3.02.73	Siuslaw River; 1 mile upstream from confluence with north fork (Siuslaw River)	.104 .104	Hecata Beach: 44°00'N - Lat.
3.02.73	Siuslaw River: north fork, 1/4 mile upstream from above	.116	Same as above
3.02.73	Ten mile creek; at Highway 101 Bridge	.116	South of Yachats: Lat. 44°17'N
3.02.73	Yachats River; at Highway 101 Bridge	.083	Yachats: Lat. 44°19'N
3.02.73	Alsea River; 7 miles east of Waldport at Highway 34 Bridge	.091	Waldport; 44°25'N-Lat.
3.02.73	Marys River	.095	--

APPENDIX: TABLE 2: (continued)

Date of Collection	Time of Collection (hours)	Tidal Data*	Total Mercury (ug/l)
c: Estuarine water samples; Samples collected from the Columbia River at Chinook Point			
6.09.71	1400	Close to high water (1 hr)	.043
6.25.71	1500	Close to high water (1 hr)	.046
7.07.71	1230	Close to high water (1 hr)	.044
7.21.71	1300	Close to high water (1 hr)	.040
8.05.71	1200	Close to high water (1 hr)	.037
8.19.71	1200	Close to high water (1 hr)	.033
9.17.71	1200	Almost at high water	.030
10.08.71	1500	Close to high water (1 hr)	.029
11.04.71	1300	Close to high water (1 hr)	.024
12.29.71	1000	Close to high water (1 hr)	.028
2.11.72	1000	Almost at high water	.031
3.17.72	1400	Close to high water (1 hr)	.033
4.27.72	1230	Close to high water (1 hr)	.036
5.25.72	1130	Close to high water (1 hr)	.039
6.27.72	1400	Close to high water (1 hr)	.042
7.27.72	1400	Close to high water (1 hr)	.045
8.28.72	1500	Close to high water (1 hr)	.041

*U. S. Dept. of Commerce, Environmental Science Services Administration. Coast and Geodetic Survey; Tide Tables, High and Low Water Prediction. West Coast of North and South America, 1971 (pp. 86-88), 1972 (pp. 86-88), for Astoria, Tongue Point

APPENDIX: TABLE 2: (continued)

Station No.	Date	Time (hrs)	Location Lat. °N	Long. °W	Depth (meters)	Total Mercury (ug/l)	Fig. ( ) Reference Code
d: Sea water samples							
i: Oregon State University Cruise: Y7208A							
3	8.16.72	2004	45°56'	124°39'	0	.030	i
		2040			100	.025	
4	8.16.72	2335	45°56'	124°29'	0	.0925	h
		2330			75	.085	
6	8.17.72	0715	45°56'	124°02'	0	.050	g
		0720			25	.040	
10	8.17.72	1240	46°13'	124°12'	0	.040	j
		1310			30	.040	
14	8.17.72	1754	46°38'	124°41	0	.050	l
		1800			80	.055	
16	8.18.72	0115	46°38'	124°22'	0	.065	k
		0130			40	.050	
ii: Oregon State University Cruise: Y7301E							
1	1.19.73	1400	44°21'	124°10'	0	.050	f
		1410			10	.045	
2	1.20.73	0112	43°23'	124°21'	0	.065	e
		0124			11	.055	
3	1.20.73	1130	42°23'	124°28'	0	.035	c
		1145			80	.040	
4	1.20.73	2200	41°32'	124°16'	0	.040	b
		2215			30	.035	
5	1.21.73	0506	40°08'	125°20'	0	.040	a
		0520			150	.050	
34	1.23.73	0735	42°26'	124°35'	0	.080	d

APPENDIX: TABLE 3: Summary of data pertaining to Zn, Cd, and Hg, taken from literature.

Property (1)	Zinc (2)	Ref. (2a)	Cadmium (3)	Ref. (3a)	Mercury (4)	Ref. (4a)
Concentration in the Earth's crust g/ton (ug/g)	120	8	0.5	8	0.5	8
Amount mined kg/yr	$3x10^9$	4	10^7	4	10^7	4
Amount added to the ocean kg/yr	$3.7x10^8$	4	$3x10^9$	4	$3x10^6$	4
Amount lost from the ocean kg/yr	$7.8x10^7$	4	$3\ 1x10^5$	4	10^6	4
Percent retention in seawater (%)	.01	15, 16	.05	15, 16	.03	15, 16
Residence time in seawater (yrs x 1000)	180	15, 16	500	15, 16	42	15, 16
Physical form	ionic	15	ionic	15	soluble, ionic	15
Chemical form	Zn^{++}, $ZnOH^+$	1,	$CdCl^+$, $CdCl_2$, Cd^{++}, $CdSO_4$	1,15,22	Hg^{++}, $HgCl_3^-$, $HgCl_4^{--}$, $HgCl_2$, CH_3HgCl, $(CH_3)_2Hg$	1, 15, 19
Oceanic concentration ug/l (total)	range: .6-25 average:	2, 7, 11, 25, 26	.06-.18 .11	23	.08-.27 (.36)	17, 18
Nearshore concentration	range:3-50 average: 22	5,	.011	29		32
River, ug/l: total	10-20	21	.24	21	.08	21

APPENDIX: TABLE 3: (continued)

(1)	(2)	(2a)	(3)	(3a)	(4)	(4a)
Columbia River: ug/1 (total)	20	21	.2	21	.01-.03	32
Concentration in plants (marine)	150,000 ug/l	20	400 ug/l	29	.03 ug/g (dry wt.) Algae	14
Concentration in organisms (marine)	1,500,000 ug/l	28	150-300 ug/l	28	.3 ug/g (wet)	28
Concentration in fish ug/g (dry wt.)	80	4	3	4	.3(?)	4
Concentration factor: organism/sea water	1,000-65,000 (plankton) 100,000 (oyster)	4	910 (plankton)	4	10^3-10^4 (fish)	20
Concentration in mammals ug/g (dry wt.)	180	26	.06	12	.02	13
Toxicity	Organism: Macrocystis pyrifera (giant kelp)	24	Organism: Crassostrea virginica (oyster)	29	Organism: Macrocystis pyrifera (giant kelp)	24
	Conc: as SO_4 (mg/l) / Effect: / Duration: of test (days)		Conc: as $Cd(NO_3)_2$ (mg/l) / Effect: / Duration: of test (days)		Conc: as Cl^- (mg/l) / Effect: / Duration of test (days)	
	1.31 / None / 4		.2 / TL_m / 8		.05 / 50% decrease in photosynthesis / 4	

APPENDIX: TABLE 3: (continued)

(1)	(2)		(2a)	(3)		(3a)	(4)		(4a)
	Conc: as SO_4 (mg/l)	Effect:	Duration: of test (days)	Conc: as $Cd(NO_3)_2$ mg/l)	Effect:	Duration: of test (days)	Conc: as Cl^- (mg/l)	Effect:	Duration of test (days)
	10	50% inactivation	4	.1	TL_m	15	.1	15% decrease in photosynthesis	4
Organism: Nitzschia sp.: (diatom)			7	Organism: Mya arenaria (soft shell clams)		28	Organism: Acartia clausii (copepod)		9
	Conc: as $ZnSO_4$ (mg/l)	Effect:	Duration of test	Conc: (ug/g)	Effect:	Duration of test (days)	Conc: (mg/l)	Effect:	Duration: of test (hours)
	.25	reduction in division rate	--	.1	apparently non-toxic	56	.05 as Cl^-	50% mortality	2.5
							.05 as I^-	50% mortality	2.3

APPENDIX: TABLE 3: (continued)

(1)	(2)	(2a)	(3)	(3a)	(4)	(4a)
	Organism: Fundulus heteroclitus (killfish)	10				
	Conc: as $ZnSO_4$ (ug/g) / Effect: / Duration of test (weeks)					
	200 / non-toxic / 1-2					
	Essential and toxic	4	Essential (?), moderately toxic	4	Essential (??) very toxic	4
Water Quality	1/100 of the 96 hour TL_m value is safe concentration for continuous exposure	27	The concentration must not exceed 1/30 of the 96 hour TL_m concentration at any time or place and the maximum 24 hour average concentration should not exceed 1/500 of the 96 hour TL_m concentration	12		
Biological half-life (man)	154 days	27	very long (time ?)	12	70-74 days	13
Amount in diet of man (mg/day)	10-15 as Zn^{++}	27	.6 as Cd^{++}	12	.005-.02 as Hg^{++}	13

APPENDIX: TABLE 3: (continued)

(1)	(2)	(2a)	(3)	(3a)	(4)	(4a)
Federal Drug Administration Limit	5 mg/l	29	.01 mg/l	29	.5 Pg/g	13

References:

1. Baric, A., and M. Branica. 1967. J. Polarog. Soc., 13:4-8.
2. Bertrand, G. 1938. Compt. rend., 207:1137-1141.
3. Black, W. A. P., and R. L. Mitchell. 1952. J. Mar. Biol. Assoc. U. K., 30:575-584.
4. Bowen, H. J. M. 1966.
5. Brooks, R. R. 1965. Geochim. Cosmoch. Acta 29:1369-1370.
6. Buffo, L. K. 1967.
7. Chipman, W. A., T. R. Rice, and T. J. Price. 1958. U. S. Fish and Wildl. Serv., Fish. Bull 50(120):279-292.
8. Clark, G. L. ed. 1966.
9. Corner, E. D. S., and B. W. Sparrow. 1956. J. Mar. Biol. Assoc. U. K., 35:531-548.
10. Doudoroff, P., and M. Katz. 1953. Sewage Industr. Wastes, 25:802-839.
11. Fonselius, S. H., and F. Koroleff. 1963. Pull. Inst. Oceanogr., Monaco 61:No. 1281. 15 p.
12. Friberg, L. 1971.
13. Friberg, L. 1972.
14. Glooschenko, W. A. 1969. J. Phycol. 5(3):224-226.
15. Goldberg, E. D. 1963.
16. Goldberg, E. D. 1965.
17. Hamaguchi, H., R. Kuroda, and H. Hoshara. 1961. Nippon Kagaku Zasshi 82:347-349.
18. Hoshara, K. 1961. Nippon Kagaku Zasshi 82:1107-1108.
19. Hosohara, K., H. Kozuma, K Kawasaki, and T. Tsurota. 1961. Nippon Kagaku Zasshi 82:1479-1480.
20. Klein, D. H., and E. D. Goldberg. 1970. Evn. Sci. Tech. 4(9):765-768
21. Kopp, J. F., and R. C. Kroner. 1969.
22. Kranskopf, K. B. 1956. Geochim. Cosmoch. Acta 9: 1-32.
23. Lowman, F. G., D. K. Phelps, R. McClin, V. Roman deVega I. Olivar de Padovani and R. J. Garcia. 1966.
24. McKee, J. E., and H. W. Wolf, eds. 1963.
25. Noddack, I., and W. Noddack. 1950. Arkiv. Zool. 32A (4):1-35.

APPENDIX: TABLE 3: (continued)

26. Noddack, I., and W. Noddack. 1940. Arkiv. Zool. 32A (4):1-35.
27. Prasad, A. S. ed. 1966.
28. Pringle, B. H., D. E. Hissong, E. L. Katz, and S. T. Mulawka. 1968. J. Sanit. Engng. Div. Am. Soc. Civ. Engrs. 94:SA3, 455-475. Pap. No. Pap. No. 4970.
29. USDI. 1968b. Water Quality Criteria.
30. Water Pollution Control Research Series. 1971.
31. Westoo, G. 1967. Acta Chem. Scand. 21(7):1790-1800.

END

DATE FILMED

11/08/91