AN ABSTRACT OF THE THESIS OF

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Title: Evaluation of Shrimp and Crab Processing Waste as a Feed Supplement for Mink (Mustela vison)

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Abstract approved:
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Three products derived from shrimp processing waste (Pandalus jordani) and a protein concentrate extracted from king crab waste (Paralithodes camschatica) were evaluated as feed supplements for standard dark and sapphire pelter mink (Mustela vison) replacing approximately 10 and/or 20 percent of the protein in a standard wet diet (33 percent protein) on an equal-protein basis. Partial mean analyses of waste products were as follows: untreated shrimp waste (25.5 percent corrected crude protein (CCP), 14.4 percent calcium, 19.3 percent chitin); shrimp meal (26.6 percent CCP, 13.8 percent calcium, 17.6 percent chitin); sieved shrimp meal (34.0 percent CCP, 10.3 percent calcium, 10.6 percent chitin); and crab protein concentrate (67.1 percent CCP, 0.1 percent calcium, trace chitin). Mink of both sexes and strains fed crustacean waste diets generally showed

lower final weights and weight gains and increased feed consumption as compared to control groups fed a standard ration. These effects were most pronounced in males and, with the exception of the 20 percent protein replacement level (PRL) shrimp meal group, appeared to result primarily from the lower fat concentrations of the test diets. Significantly lower weight gains of males ($P<.01$ darks, $P<.05$ sapphires) on the 20 percent PRL shrimp meal diet appeared to be related to an excessive amount of dietary calcium (Ca/P = 3.48), resulting from shrimp waste supplementation, interfering with nutrient utilization. Pelt sizes and pelt weights varied directly with final body weights. General condition and fur color and quality were not appreciably affected. It is concluded crustacean waste products could be used satisfactorily as protein supplements for mink providing the protein and energy concentration of the diet is maintained at a sufficient level and dietary calcium does not become excessive. The Ca/P ratio of the diet ($Ca/P \leq 2$) is suggested as a guideline for determining the maximum level of crustacean waste supplementation. From an economic standpoint, wet-ground shrimp waste is probably the only shellfish waste product potentially valuable as a mink feed in the Pacific Northwest at the present time.

EVALUATION OF SHRIMP AND CRAB PROCESSING WASTE AS A FEED SUPPLEMENT FOR MINK (*MUSTELA VISON*)

by

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I. INTRODUCTION

Since its beginnings in the 1920's, the mink ranching industry of Oregon has shown considerable ingenuity in seeking low cost, quality feedstuffs to satisfy the high nutritional requirements of mink. Horsemeat was originally the basis of many ranch diets later to be supplanted by fish and, to a lesser extent, poultry by-products after red meats became too expensive following the outbreak of World War II (Kletzer 1941, Davis 1955). Over the years, Oregon has become established as a major producer of mink not only due to its favorable climate but also because of the feed resources provided by its poultry and coastal fishing industries.

Initially mink rations were simple and attempts were made to approximate diets similar to those a wild mink might consume. Conversely in later years, some ranchers formulated diets which were excessively complex; often containing special "secret" ingredients which were believed to promote extra growth and superior fur. Since the 1950's, however, considerable refinement has occurred in the formulation of mink rations. Through experimental research many of the old beliefs have either been substantiated or disproved and today mink feeding is based largely on scientific principles.

Mink are unique in comparison to most other domestic animals in that they are often fed fresh ingredients in a wet ration and their nutritional requirements are not only reflected in body growth, reproduction and general condition but also in fur characteristics.

Moreover, mink attain full growth and produce marketable fur in less than seven months after birth. They are thus interesting subjects for nutrition research and have been studied extensively. Oregon mink investigations have revealed or clarified such factors as a thiaminase enzyme contained in certain raw fish which causes a thiamin-deficient paralysis (Stout et al. 1963); the binding of biotin by the albumen protein avidin which results in grey underfur (Stout and Adair 1969); and the interfering effect formaldehyde, or a related compound, found in raw Pacific hake has on iron absorbtion causing light ("cotton") underfur and anemia (Stout et al. 1960, Costley 1970).

The vagaries of an unpredictable fur market coupled with dependence on by-product feed sources, which are drawing increased demand from pet and livestock interests, place mink ranchers in a precarious position. In the last decade the number of mink ranches in Oregon has decreased from 159 to 40 while average number of mink produced per ranch has increased by over 1,000 (Table 1). To the highly productive and efficient mink ranchers operating today even small increases in feed costs can have serious effects on profit margins. Alternate, inexpensive feed sources are highly desirable.

Another of Oregon's industries faces a different problem. Shellfish processors annually produce tremendous quantities of by-product waste for which there is little demand. In the past this material was simply discharged into the bays and estuaries proximate to the processing plants. However, recent effluent limitations established by the Federal government and administered through solid waste discharge permits issued by Oregon's Department of Environmental Quality

TABLE 1. MINK PRODUCTION IN OREGON 1963-1976.[1]

Year	No. Ranches	No. Mink Pelts	Mean No. Mink Pelts Per Ranch
1963	173	376,000	2173
1964	168	371,000	2208
1965	159	389,520	2450
1966	159	395,301	2486
1967	162	357,372	2206
1968	NA[2]	NA	NA
1969	NA	NA	NA
1970	91	197,000	2165
1971	62	155,000	2500
1972	60	144,000	2400
1973	55	160,000	2909
1974	50	158,000	3160
1975	47	168,000	3574

[1] Sources: 1963-67. Proceedings 21st - 25th Annual Meetings of The National Board of Fur Farm Organizations, Inc.
1970-75. Mink Production. USDA Statistical Reporting Service.

[2] NA = Not available.

no longer allow this practice due to existing and potential pollution problems. Shellfish processors have been forced to seek new means of solid waste disposal. Presently, the majority of waste is being hauled away for landfill at the processor's expense.

Crustacean wastes generally contain 25 - 50 percent protein, thus the potential value of this material as a protein supplement in animal feeds should not be overlooked. Certainly, value as a feedstuff would be far more desirable than use as landfill. The mink, being well adapted to fish diets, is a suitable subject for evaluating shellfish waste as a feed ingredient. Mink ranchers are located along the coast in the vicinity of processing plants and have facilities available (i.e., freezers and mixers) which may be useful in storing and feeding waste material. Moreover, since mink consume a wet ration which often contains fresh ingredients, the feeding of fresh waste without treatment, and hence without additional processing costs, is an area of special interest.

The present study completed under the auspices of the Oregon Sea Grant program and the Mink Farmers Research Foundation had as its objective the evaluation of shrimp and crab processing wastes in mink diets and of variously-treated waste products which could have enhanced nutritional value.

RATIONALE

Although research was directed primarily toward feeding Oregon shellfish wastes to mink, this thesis also contains information on crustacean species which are not processed in Oregon and on the feed value of crustacean waste for other domestic animals. Consideration of these areas was threefold.

1. Disposal and utilization of waste from shellfish processing plants presents a problem not only along the Pacific coast but along the Atlantic and Gulf coasts as well. Since crustacean wastes have basically similar compositions, information on a specific by-product may be applicable to a wide range of waste by-products.

2. Feeding experiments with one domestic species can yield information which is pertinent to others.

3. Shellfish wastes may be better suited for other purposes than as a mink feed. Evaluating a feed source for a particular species can be of little practical value unless existing and potential demands from other interests are considered. Mink ranchers lay in the wake of the larger, more influential human, pet, livestock and poultry food industries. Mink feeds must be of high quality to satisfy the carnivores' nutritional needs, yet they cannot be too attractive to other feed industries which can offer higher prices. Shellfish wastes are unique with regard to other feed products in that there are also several non-nutritional uses as well.

II. SHRIMP AND CRAB LANDINGS AND WASTE PRODUCTION

The tremendous quantities of shrimp landed annually in the United States (370 million pounds in 1974) make this fishery one of the most economically valuable in the nation (Soderquist 1970, Anonymous 1972, Anonymous 1975a). A considerable part of these landings (over 35 percent) occur along the Pacific coast (Table 2). Oregon, second only to Alaska in annual shrimp harvest in the west, landed approximately 10,000 tons of shrimp (primarily Pandalus jordani) in 1974 (Anonymous 1975b). Further expansion in Oregon's shrimp industry may yet occur as harvest off the Oregon coast may be below the maximum sustainable yield (Kreag and Smith 1973).

It has been estimated that approximately 75 to 85 percent, by weight, of pink shrimp (Pandalus sp.) is wasted when mechanically picked (Jenson 1965, Kreag and Smith 1973). Using 0.80 as an average coefficient of wastage, calculated 1974 shrimp waste production in Oregon approached 16 million pounds, which, assuming a dry matter content of 20 percent, converts to approximately 3.2 million pounds of dry waste.

Shrimp harvest season in Oregon (1975) extends from April 1 through October 15. Oregon processors cannot process shrimp taken from California waters between October 16 and April 16. Washington's shrimp season is open year-round and catches off the Washington coast can be landed in Oregon at any time. Catch is fairly uniform throughout the season, although greatest landings usually occur during the

TABLE 2. ANNUAL LANDINGS OF SHRIMP BY STATE, PROVINCE AND ENTIRE PACIFIC COAST in 1,000's of pounds; primarily Pandalus sp. (Anonymous 1975b).

Year	Alaska	British Columbia	Washington	Oregon	California	Total
1966	28,193	1,682	283	4,751	1,190	36,099
1967	41,813	1,696	1,029	10,374	1,413	56,325
1968	42,023	1,566	1,164	10,976	2,275	58,004
1969	47,851	2,119	1,425	10,505	2,948	64,848
1970	74,206	1,538	926	13,735	4,048	94,502
1971	94,891	735	678	9,291	3,081	108,676
1972	81,262	794	1,582	20,861	2,490	106,989
1973	119,964	1,729	5,271	24,500	1,240	152,704
1974	108,748	2,644	9,325	19,968	2,264	142,949

summer months (Kreag and Smith 1973). Oregon's 20 shrimp processors are widely distributed along the coast at most major fishing ports.

Considerably less waste is produced by Oregon's crab industry. Dungeness crab (Cancer magister) is the primary species harvested. Less than 1,800 tons of Dungeness crab were landed during Oregon's 1973-74 season (Table 3). Average loss in processing has been estimated as 75 percent or more of the live weight (Jenson 1965, Kreag and Smith 1973). Not all Dungeness crabs are fully processed, however. Many are marketed whole (approximately 30 percent) or with only backs and entrails removed (Soderquist 1970, Kreag and Smith 1973, Willis 1975).

Since 1972, Dungeness crab harvests have waned considerably. This decrease has been attributed to a natural change in population density which is highly variable (Kreag and Smith 1973). Good harvest success thus far in the 1975-76 season indicates crabs have increased in number over recent years.

Commercial crab season in Oregon (1975) runs from November 15 to September 15. Only male crabs measuring 6.25 inches or more across the back are legal. Greatest landings occur between December and March (Kreag and Smith 1973).

King crabs (Paralithodes camschatica), taken primarily off Alaska, and blue crabs (Callinectes sapidus), harvested along the East coast, are landed in far greater quantities than Dungeness crabs. Of the 329 million pounds of crabs landed nationally during 1974, 30, 43 and 5 percent were king, blue and Dungeness crabs, respectively (Anonymous 1975a). Wastage from king and blue crabs,

TABLE 3. ANNUAL LANDINGS OF DUNGENESS CRAB BY STATE, PROVINCE AND ENTIRE PACIFIC COAST in 1,000's of pounds (Anonymous 1975b).

Year or Season	Alaska	British Columbia	Washington	Oregon	California	Total
1965-66	5,029	4,538	11,649	10,187	10,419	41,822
1966-67	11,597	5,295	9,291	9,428	10,705	46,316
1967-68	13,321	4,373	11,736	10,215	13,158	52,803
1968-69	11,304	3,705	19,250	11,965	13,685	59,909
1969-70	9,697	2,548	18,675	13,849	15,564	60,333
1970-71	3,749	1,963	13,211	14,735	8,501	42,159
1971-72	5,297	1,975	10,095	6,780	2,875	27,022
1972-73	6,300	2,580	5,583	3,143	1,500	19,106
1973-74	3,791	2,500	4,490	3,462	880	15,123

although highly variable depending on the type of processing, has been estimated as 80 to 86 percent of the live weight, respectively (Jenson 1965, Stansby 1963).

III. SHRIMP AND CRAB PROCESSING IN OREGON

Waste production in a typical Oregon shrimp processing operation is diagrammed in Figure 1. Unlike some Gulf coast shrimp operations, Oregon shrimp are not beheaded prior to processing (Soderquist et al. 1970, Cheung 1976).

All processors in Oregon use mechanical peelers. Laitram precook model A (PCA) peelers are used in all operations except one which uses Laitram model A peelers (Cheung 1976). PCA peelers have a cooking section using heated water preceeding the peelers. Shrimp are peeled raw by model A peelers.

After peeling, shrimp are conveyed to washer-cleaners and separators where remaining shells, antennae and eyes are removed. Some processors also use an air blower to further remove unwanted material. Undesirable shrimp meat and residual wastes are sorted out by inspectors before packing the final product.

Most Dungeness crab processing in Oregon is done manually. Large, unpredictable fluctuations in harvests from year to year make processors refrain from investing in expensive equipment. Waste production in a typical Oregon crab processing operation is depicted in Figure 2. After crabs which are undesirable or are to be marketed whole are separated out, the carapace, viscera and gills are removed from those selected to be picked. Butchered crabs are cooked in water or steam at approximately 212^{o}F for 10 to 14 minutes (Willis 1975). A water bath or spray is used to cool down cooked sections and make

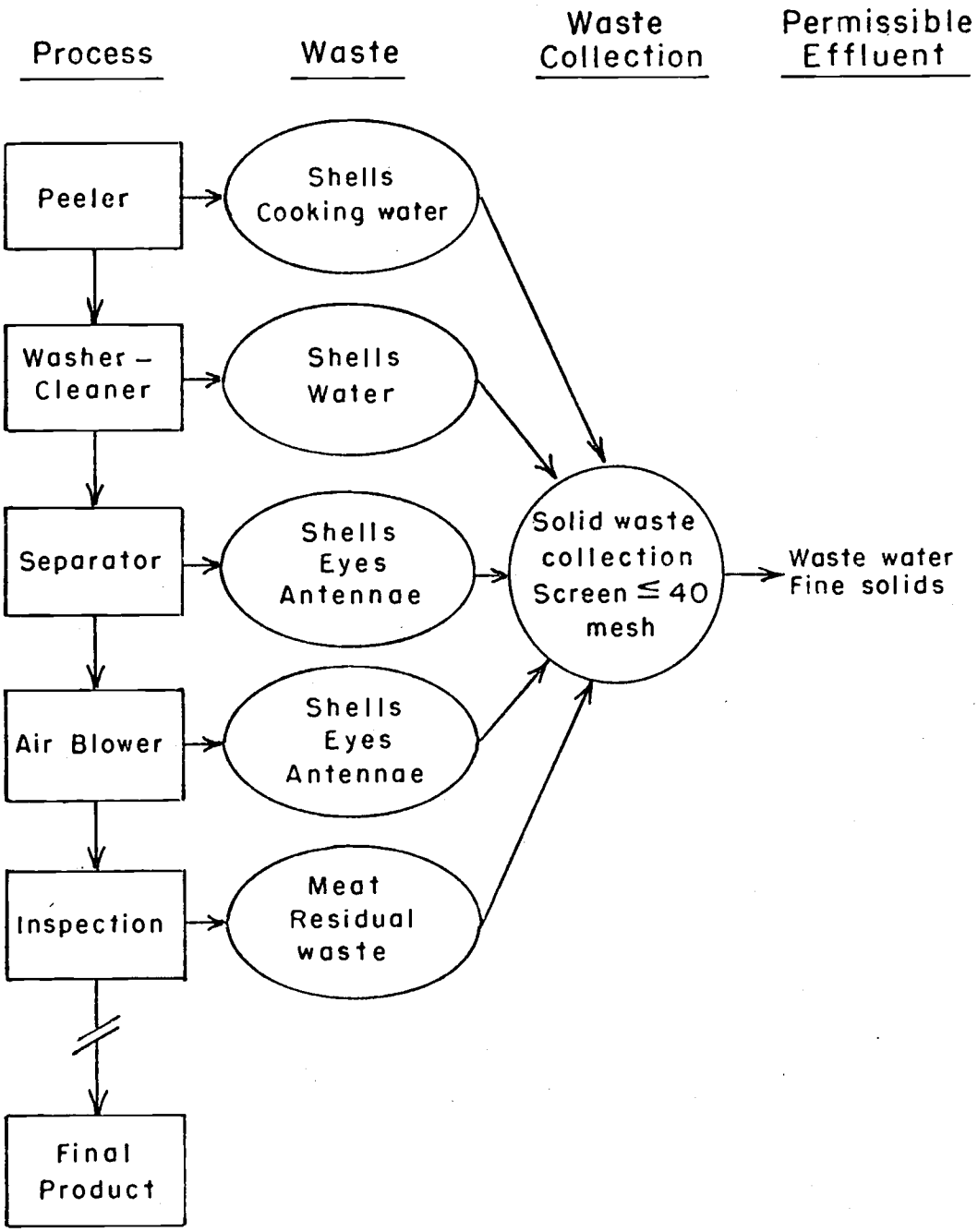

Figure 1. Waste production in an Oregon shrimp processing plant.

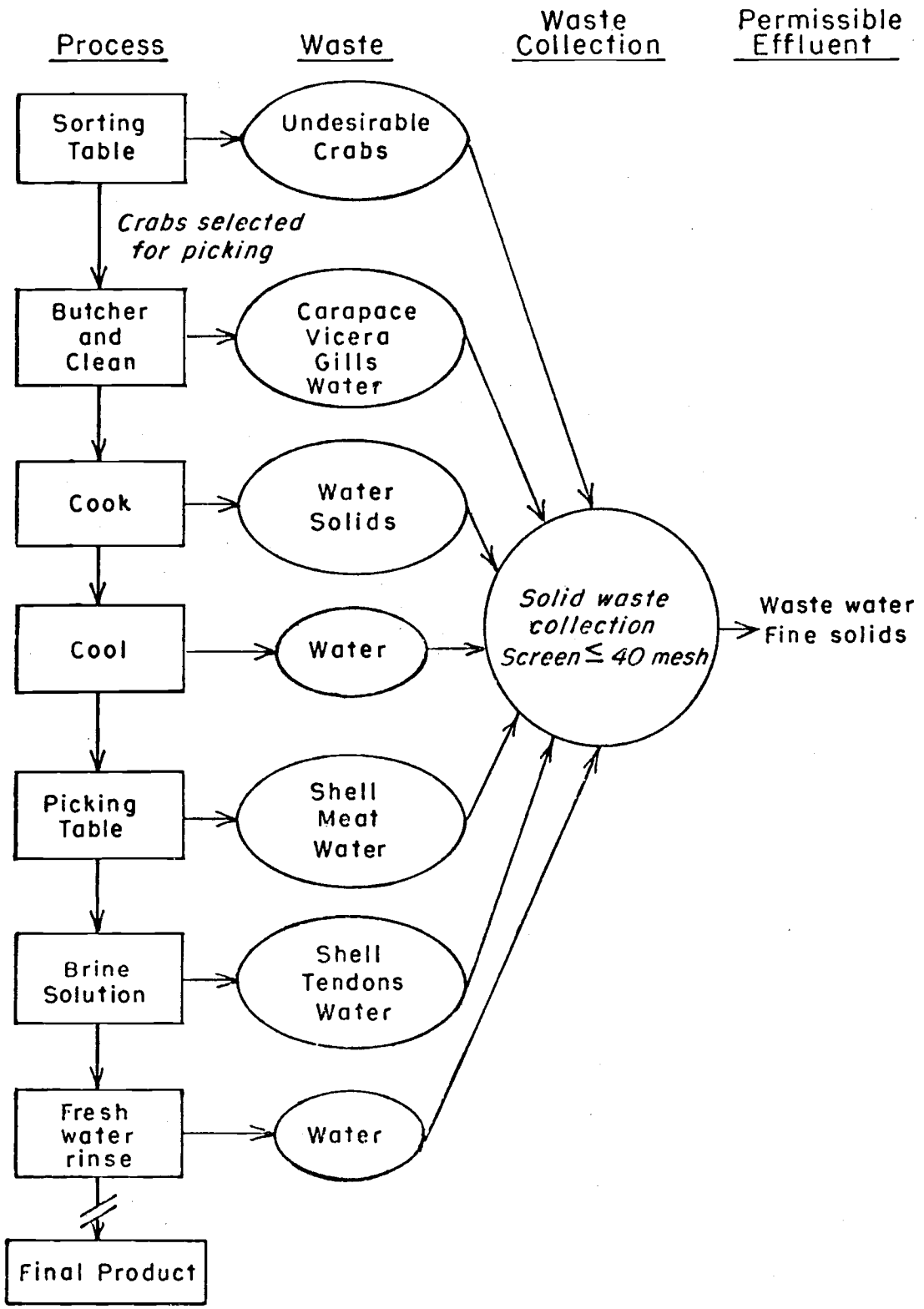

Figure 2. Waste production in an Oregon Dungeness crab processing plant.

the meat more easily extracted. Following extraction by manual picking the meat is placed in a salt brine solution where the less buoyant shells and tendons sink to the bottom. Meat is rinsed off with fresh water and drained before packing.

Federal effluent restrictions require collection and proper disposal of solid seafood processing wastes which cannot pass through a 40 mesh screen. July 1, 1977 is the deadline by which this limitation must be achieved. Pollution control in Oregon is administered through the Department of Environmental Quality and discharge permits issued by this department must satisfy Federal law. Many processors in Oregon have already installed screening devices and are disposing of waste materials in landfill.

Wastewater which passes through screening devices, especially that used in blanching, contains an appreciable amount of soluble organic matter. In Gulf coast shrimp operations up to 50 percent reduction in weight occurs during blanching (Meyer and Sonu 1974) and solids content of the effluent may be as great as one percent (Meyers and Rutledge 1973). Toma (1971) found reclaimed effluent solubles to be 55 - 60 percent protein. Effluent from mechanical peelers on the West coast has been reported to average 29,000 mg/liter total solids and 185 mg/liter total nitrogen (Soderquist and Williamson 1975).

IV. GENERAL COMPOSITION AND ANALYSIS OF CRUSTACEAN WASTES

Shrimp and crab processing wastes consist primarily of protein, minerals and chitin. Protein is found in the wastewater, meat, viscera and exoskeletal matrix. The mineral fraction is largely calcium carbonate which is responsible for scleratization of the cuticle. The fibrous, storage carbohydrate chitin is found in close association with protein and calcium carbonate comprizing the shell.

General composition of crude waste meals runs 25 - 50 percent corrected protein, 10 - 30 percent chitin, 20 - 40 percent ash and 2 - 10 percent fat (Table 4). Crude protein values as determined by conventional Kjeldahl analysis must be corrected for nitrogen contributed by chitin. Chitin, a polymer of N-acetyl-D-glucosamine units, contains approximately 6.8 percent nitrogen. Other nitrogen containing compounds such as nitrates, pyridine-rings, urea, uric acid, and ammonia salts have not been found in significant quantities (Kirk et al. 1968). The ash portion is generally 30 - 60 percent calcium and 3 - 10 percent phosphorus. Crude fiber and acid detergent fiber fractions are primarily chitin. Lovell et al. (1965) and others have reported fiber determination to be a good index of chitin content. This can be seen to be generally true from Table 4.

Crude shrimp wastes typically have higher protein/ash ratios than crab wastes, thus making them better suited, on a weight basis, as animal feed. Composition of waste meals, however, can vary widely depending on several factors (see Section VI, C).

TABLE 4. COMPOSITION OF CRUDE CRUSTACEAN WASTES. Part A. Proximate analysis and chitin.

Type	Reference	Source	Component (Percent) CP	Corrected CP	Chitin	EE	Ash	Crude Fiber
Shrimp	Crawford 1975	OR	40.31	31.25	21.02	3.38	29.20	--
			45.19	36.19	21.17	3.73	27.08	--
	Steel 1971	OR	42.67	38.37	10.04	4.33	24.84	--
	Kirk et al. 1967	FL	49.51	37.60	29.73	1.09	27.65	25.46
	Meyers et al. 1973	LA	40.34	30.81	22.27	1.41	41.30	23.14
			56.86	52.59	9.90	3.19	29.59	11.44
			44.70	39.50	12.10	--	--	--
			57.64	55.27	11.47	9.19	23.35	12.29
			46.88	23.75	56.46	0.42	33.02	28.33
			47.80	44.55	7.59	8.63	28.09	13.00
			36.96	34.03	6.84	10.99	35.08	17.80
	Leekley 1968	AK	55.50	--	--	12.40	16.20	6.27
	Fronda et al. 1933	Philippines	65.08	--	--	3.05	23.09	4.92
	Jarquin et al. 1972	Guatemala	42.55	--	--	2.73	33.22	--
			54.22	--	--	1.60	39.16	--
	Titus et al. 1930	MS	59.9	--	--	3.14	19.81	--
	Brown 1959	AK	56.52	52.97	8.29	14.06	23.53	--
	Chawan & Gerry 1974	Unknown	46.00	--	--	--	--	--
	Khandker 1962	FL	50.34	46.56	8.83	4.49	21.94	--
Crayfish	Lovell et al. 1968	LA	38.24	32.20	14.10	4.90	29.00	14.20
	Rutledge 1971	LA	35.48	29.80	13.26	4.67	46.66	--
Crab	NRC 1971	Unknown	33.44	--	--	--	--	11.83
King crab	Kifer & Bauersfeld 1969	AK	--	41.66	--	7.76	27.91	--
	Anonymous 1966	AK	46.53	41.52	11.70	4.99	32.45	--
Dungeness crab	Farragut & Thompson 1966	Unknown	32.60	--	--	1.86	35.12	--
Blue crab	Kifer & Bauersfeld 1969	Unknown	--	30.75	--	2.20	32.43	--
	Lubitz et al. 1943	SC	34.90	--	--	0.85	44.40	13.77
	Patton et al. 1975a	VA	29.40	--	--	2.20	34.60	10.40
	Rutledge 1971	LA	30.91	25.13	13.51	2.09	58.64	--
	Byerly et al. 1933	Unknown	38.04	--	--	2.50	28.84	--

TABLE 4. (cont.) COMPOSITION OF CRUDE CRUSTACEAN WASTES (DRY MATTER BASIS). Part B. Amino acid analysis.

Type	Reference	Source	Amino acid (Percent)[1]																
			Met	Cys	Trp	His	Arg	Lys	Thr	Val	Ile	Tyr	Phe	Ser	Glu	Leu	Pro	Gly	Ala	Asp
Shrimp	Crawford 1975	OR	0.44	0.35	0.46	0.57	1.38	1.27	0.85	1.15	0.90	0.86	--	0.97	2.78	1.28	1.03	1.19	1.19	2.01
			0.60	0.46	0.46	0.86	2.11	1.85	1.49	1.95	1.41	1.40	--	1.73	4.61	1.95	1.92	2.18	2.27	3.28
	Meyers et al. 1973*	LA	2.48	1.59	1.26	1.90	6.31	6.17	4.28	4.42	3.26	3.64	4.56	4.53	15.46	7.57	3.44	4.29	5.29	10.74
	Meyers & Sonu 1974	LA	0.63	--	--	0.22	3.10	1.39	0.62	0.92	0.67	0.18	0.53	0.63	3.02	1.33	1.21	2.54	1.26	1.80
	Jarquin et al. 1972	Guatemala	0.86	--	--	--	--	2.25	--	--	--	--	--	--	--	--	--	--	--	--
			1.78	--	--	--	--	3.89	--	--	--	--	--	--	--	--	--	--	--	--
	Meyers & Rutledge 1973*	LA	1.65	2.35	0.63	2.23	6.70	9.20	4.22	6.77	6.20	3.64	4.60	3.49	13.61	6.72	3.31	6.57	7.56	9.07
	Chuwan & Gerry 1974	Unknown	0.84	--	--	0.75	2.21	2.35	1.58	2.24	1.84	--	1.87	--	--	2.67	--	2.20	--	--
Crab	NRC 1971	Unknown	0.54	--	0.32	0.54	1.83	1.51	1.08	1.61	1.29	1.29	1.29	--	--	1.72	--	0.54	--	--
King-crab	Kifer & Bauernfeld	AK	0.73	0.31	0.52	1.05	2.52	1.78	1.78	2.20	1.68	1.68	1.68	1.78	4.83	2.41	1.99	2.73	1.99	3.99
Blue-crab	Kifer & Bauernfeld	Unknown	0.52	0.21	0.42	0.73	1.88	1.46	1.05	1.36	1.05	1.05	1.15	0.94	3.14	1.46	1.36	1.88	1.46	2.30

[1] Analyses from references marked with * are given on a 100 percent protein basis.

TABLE 4. (cont.) COMPOSITION OF CRUDE CRUSTACEAN WASTES (DRY MATTER BASIS). Part C. Mineral analysis.

			Percent					Ppm					
Type	Reference	Source	Ca	P	Na	Mg	K	Fe	Cu	Zn	Mn	Cr	B
Shrimp	Crawford 1975	OR	15.83	2.33	0.28	0.63	1.57	233.9	40.6	64.9	12.2	27.1	33.3
			15.44	2.16	0.23	0.68	1.65	107.9	46.7	59.1	12.4	27.2	30.8
	Steel 1971	OR	12.16	1.43	--	--	3.60	435.5	12.6	79.3	10.0	--	--
	Kirk et al. 1967	FL	11.69	2.95	--	--	--	--	--	--	--	--	--
	Meyers et al. 1973	LA	16.72	2.30	--	--	--	--	--	--	--	--	--
			7.70	1.65	--	--	--	--	--	--	--	--	--
			--	--	--	--	--	--	--	--	--	--	--
			7.50	1.74	--	--	--	--	--	--	--	--	--
			11.56	3.29	--	--	--	--	--	--	--	--	--
			10.02	2.56	--	--	--	--	--	--	--	--	--
			12.77	3.99	--	--	--	--	--	--	--	--	--
	Leekley 1968	AK	5.75	1.38	0.58	0.34	0.69	240.0	67.5	164.5	8.9	8.6	7.3
	Chuwen & Gerry 1974	Unknown	9.50	2.40	--	--	--	--	--	--	--	--	--
Crayfish	Lovell et al. 1968	LA	18.10	1.20	--	0.27	0.14	8.8	--	--	157.0	--	--
	Rutledge 1971	LA	19.09	1.27	--	--	--	--	--	--	--	--	--
Crab	NRC 1971	Unknown	16.47	1.71	0.91	0.93	0.48	--	--	--	--	--	--
King crab	Kifer & Bauernfeld 1969	AK	7.24	--	1.26	3.67	0.84	393.5	116.5	263.4	12.6	15.7	21.1
Blue crab	Kifer & Bauernfeld 1969	Unknown	18.83	--	1.88	1.36	1.26	162.1	33.5	106.7	--	43.9	26.2
	Lubitz et al. 1943	SC	17.50	1.75	--	--	0.43	--	--	--	192.0	--	--
	Patton et al. 1975	VA	22.00	--	1.10	1.43	0.55	--	60.0	--	--	--	--
	Rutledge 1971	LA	17.80	1.78	--	--	--	--	--	--	--	--	--

TABLE 4. COMPOSITION OF CRUDE CRUSTACEAN WASTES. Part A. Proximate analysis and chitin.

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Shrimp	Crawford 1975	OR	40.31	31.25	21.02	3.38	29.20	--
			45.19	36.19	21.17	3.73	27.08	--
	Steel 1971	OR	42.67	38.37	10.04	4.33	24.84	--
	Kirk et al. 1967	FL	49.51	37.60	29.73	1.09	27.65	25.46
	Meyers et al. 1973	LA	40.34	30.81	22.27	1.41	41.30	23.14
			56.86	52.59	9.90	3.19	29.59	11.44
			44.70	39.50	12.10	--	--	--
			57.64	55.27	11.47	9.19	23.35	12.29
			46.88	23.75	56.46	0.42	33.02	28.33
			47.80	44.55	7.59	8.63	28.09	13.00
			36.96	34.03	6.84	10.99	35.08	17.80
	Leekley 1968	AK	55.50	--	--	12.40	16.20	6.27
	Fronda et al. 1933	Philippines	65.08	--	--	3.05	23.09	4.92
	Jarquin et al. 1972	Guatemala	42.55	--	--	2.73	33.22	--
			54.22	--	--	1.60	39.16	--
	Titus et al. 1930	MS	59.9	--	--	3.14	19.81	--
	Brown 1959	AK	56.52	52.97	8.29	14.06	23.53	--
	Chawan & Gerry 1974	Unknown	46.00	--	--	--	--	--
	Khandker 1962	FL	50.34	46.56	8.83	4.49	21.94	--
Crayfish	Lovell et al. 1968	LA	38.24	32.20	14.10	4.90	29.00	14.20
	Rutledge 1971	LA	35.48	29.80	13.26	4.67	46.66	--
Crab	NRC 1971	Unknown	33.44	--	--	--	--	11.83
King crab	Kifer & Bauersfeld 1969	AK	--	41.66	--	7.76	27.91	--
	Anonymous 1966	AK	46.53	41.52	11.70	4.99	32.45	--
Dungeness crab	Farragut & Thompson 1966	Unknown	32.60	--	--	1.86	35.12	--
Blue crab	Kifer & Bauersfeld 1969	Unknown	--	30.75	--	2.20	32.43	--
	Lubitz et al. 1943	SC	34.90	--	--	0.85	44.40	13.77
	Patton et al. 1975a	VA	29.40	--	--	2.20	34.60	10.40
	Rutledge 1971	LA	30.91	25.13	13.51	2.09	58.64	--
	Byerly et al. 1933	Unknown	38.04	--	--	2.50	28.84	--

TABLE 4. (cont.) COMPOSITION OF CRUDE CRUSTACEAN WASTES (DRY MATTER BASIS). Part B. Amino acid analysis.

Type	Reference	Source	Amino acid (Percent)[1]																
			Met	Cys	Trp	His	Arg	Lys	Thr	Val	Ile	Tyr	Phe	Ser	Glu	Leu	Pro	Gly	Ala	Asp
Shrimp	Crawford 1975	OR	0.44	0.35	0.46	0.57	1.38	1.27	0.85	1.15	0.90	0.86	--	0.97	2.78	1.28	1.03	1.19	1.19	2.01
			0.60	0.46	0.46	0.86	2.11	1.85	1.49	1.95	1.41	1.40	--	1.73	4.61	1.95	1.92	2.18	2.27	3.28
	Meyers et al. 1973*	LA	2.48	1.59	1.26	1.90	6.31	6.17	4.28	4.42	3.26	3.64	4.56	4.53	15.46	7.57	3.44	4.29	5.29	10.74
	Meyers & Sonu 1974	LA	0.63	--	--	0.22	3.10	1.39	0.62	0.92	0.67	0.18	0.53	0.63	3.02	1.33	1.21	2.54	1.26	1.80
	Jarquin et al. 1972	Guatemala	0.86	--	--	--	--	2.25	--	--	--	--	--	--	--	--	--	--	--	--
			1.78	--	--	--	--	3.89	--	--	--	--	--	--	--	--	--	--	--	--
	Meyers & Rutledge 1973*	LA	1.65	2.35	0.63	2.23	6.70	9.20	4.22	6.77	6.20	3.64	4.60	3.49	13.61	6.72	3.31	6.57	7.56	9.07
	Chawan & Gerry 1974	Unknown	0.84	--	--	0.75	2.21	2.35	1.58	2.24	1.84	--	1.87	--	--	2.67	--	2.20	--	--
Crab	NRC 1971	Unknown	0.54	--	0.32	0.54	1.83	1.51	1.08	1.61	1.29	1.29	1.29	--	--	1.72	--	0.54	--	--
King-crab	Kifer & Bauerafeld	AK	0.73	0.31	0.52	1.05	2.52	1.78	1.78	2.20	1.68	1.68	1.68	1.78	4.83	2.41	1.99	2.73	1.99	3.99
Blue-crab	Kifer & Bauerafeld	Unknown	0.52	0.21	0.42	0.73	1.88	1.46	1.05	1.36	1.05	1.05	1.15	0.94	3.14	1.46	1.36	1.88	1.46	2.30

[1] Analyses from references marked with * are given on a 100 percent protein basis.

TABLE 4. (cont.) COMPOSITION OF CRUDE CRUSTACEAN WASTES (DRY MATTER BASIS). Part C. Mineral analysis.

			Percent					Ppm					
Type	Reference	Source	Ca	P	Na	Mg	K	Fe	Cu	Zn	Mn	Cr	B
Shrimp	Crawford 1975	OR	15.83	2.33	0.28	0.63	1.57	233.9	40.6	64.9	17.2	27.1	31.3
			15.44	2.16	0.23	0.68	1.65	107.9	46.7	59.1	12.4	27.2	30.8
	Steel 1971	OR	12.16	1.43	--	--	5.60	435.5	12.6	79.3	10.0	--	--
	Kirk et al. 1967	FL	11.69	2.95	--	--	--	--	--	--	--	--	--
	Meyers et al. 1973	LA	16.22	2.30	--	--	--	--	--	--	--	--	--
			7.70	1.63	--	--	--	--	--	--	--	--	--
			--	--	--	--	--	--	--	--	--	--	--
			7.50	1.74	--	--	--	--	--	--	--	--	--
			11.56	3.29	--	--	--	--	--	--	--	--	--
			10.02	2.56	--	--	--	--	--	--	--	--	--
			12.77	3.99	--	--	--	--	--	--	--	--	--
	Leekley 1968	AK	5.75	1.38	0.58	0.34	0.69	240.0	67.5	164.5	8.9	8.6	7.3
	Chowan & Gerry 1974	Unknown	9.50	2.40	--	--	--	--	--	--	--	--	--
Crayfish	Lovell et al. 1968	LA	10.10	1.20	--	0.27	0.14	8.8	--	--	157.0	--	--
	Rutledge 1971	LA	19.09	1.27	--	--	--	--	--	--	--	--	--
Crab	NRC 1971	Unknown	16.47	1.71	0.91	0.93	0.48	--	--	--	--	--	--
King crab	Kifer & Bauernfeld 1969	AK	7.24	--	1.26	3.67	0.84	393.5	116.5	263.4	12.6	15.7	21.1
Blue crab	Kifer & Bauernfeld 1969	Unknown	18.83	--	1.88	1.36	1.26	162.1	33.5	106.7	--	43.9	26.2
	Lublin et al. 1943	SC	17.50	1.75	--	--	0.43	--	--	--	192.0	--	--
	Patton et al. 1975	VA	22.00	--	1.10	1.45	0.55	--	60.0	--	--	--	--
	Rutledge 1971	LA	17.80	1.78	--	--	--	--	--	--	--	--	--

Shrimp and some crab species contain a red carotenoid pigment, astaxanthin, which can be transferred to the tissues of certain animals when included in the diet. In waste products the pigment is easily destroyed by oxidation if not properly handled (Rousseau 1960).

V. UTILIZATION OF CRUSTACEAN WASTE: PAST, PRESENT AND POTENTIAL

One of the first applications for crustacean waste was as fertilizer (Stevenson 1902). The nitrogen containing components, protein and chitin, and the high mineral content make waste material potentially valuable as a soil amendment. Limited use of crustacean meals still occurs in some commercial fertilizers. In Oregon, fresh waste is occasionally used as a soil amendment by farmers in the vicinity of processing plants (Kreag and Smith 1973, Costa 1976). Acidic coastal soils can be benefited by the prodigious calcium carbonate content of waste materials (Kreag and Smith 1973, Costa 1976). A detailed investigation on the value of shellfish waste fertilizers for different coastal soils and plants is currently being conducted by Oregon State University researchers (Costa 1976).

Use of shellfish waste as a feed supplement in animal diets dates back more than half a century. Although presently used to some extent in poultry and livestock rations, primarily in the eastern United States, demand is low. Feed value of by-product wastes and economic considerations are discussed in Sections VI and XI.

A more recent use of crustacean waste is as a pigment source for commercially raised salmonids. Astaxanthin has been found to impart a pink color to the flesh which is attractive to some consumers (Steel 1971, Saito and Regier 1971). Relatively small quantities of shrimp waste are used for this purpose by Northwest fish culturists.

A new market for crustacean waste meals in the southeastern United States is the expanding shrimp and prawn cultivation industry

(Joseph and Meyers 1975). Diets containing up to 30 percent shrimp meal have been found to yield significant increases in growth of farm shrimp over conventional diets (Meyers and Rutledge 1973).

A large number of applications have been suggested for chitin and its deacytelated derivative, chitosan. These include, among others, use in films, papers, adhesives and water-base paint emulsions; as a food thickener, a gel stabilizer, and as a water treatment coagulent (McNeely 1959, Anonymous 1973). A small pilot plant operating in conjunction with Sea Grant is presently isolating chitin from king crab shells in Seattle, Washington (Peniston et al. 1969, Anonymous 1973). Although potential uses for chitin and chitosan are numerous, demand has been low due to limited supply. Cost of isolation, the widely scattered distribution of shellfish processors, and differences between shrimp and crab species which can affect isolation efficiency would keep such a potential market from utilizing large quantities of waste materials for some time.

An indirect use of crustacean waste in animal feeding has recently been suggested (Bough et al. 1975). Chitosan, due to its cationic polyelectrolytic properties, may have potential use as a flocculent for food processing effluent. Organic solids coagulated by chitosan could possibly be recovered for use in animal feeds. Bough et al. reported such products recovered from poultry processing effluent contained as much as 67.9 percent protein and 54.2 percent fat.

Other uses for crustacean wastes include novelties such as ashtrays made from crab backs (Anonymous 1956) and flavor additives

derived from certain nucleotides and amino acids found in shrimp blanching water (Meyers and Sonu 1974).

Even in view of the several potential uses for shellfish wastes relatively small quantities are actually utilized. During 1974, commercial production of crab meal and scrap and shrimp meal and scrap in the United States was 8,245 tons and 508 tons respectively (Anonymous 1976). Only 3 of 35 shrimp processing plants along the Gulf coast produced shrimp meal from bulk waste in 1974 and none were actively engaged in reclamation of soluble matter (Toma and Meyers 1975). No commercial production of crustacean meals presently occurs in Oregon.

VI. EFFICACY AS AN ANIMAL FEED SUPPLEMENT

Investigations on the use of shrimp and crab processing wastes in animal feeds began as early as the 1920's with considerable work following in the 1930's. These incipient studies involving poultry, cattle and swine generally reported, as corroborated by more recent research, that crustacean waste may have potential value as a feed supplement if offered at low levels in combination with traditional feedstuffs.

The appreciable protein content of shellfish waste was the primary impetus behind most initial feed studies. Early investigators, however, did not make a distinction between chitin nitrogen and protein nitrogen and thus were misled by exaggerated crude protein levels as determined by Kjeldahl analysis.

A. Previous Feeding Trials

POULTRY

Much of the research, especially prior to World War II, on the feed value of crustacean waste has concerned poultry. Early workers often reported favorable results when shrimp or crab meals were included in chick and layer diets and encouraged greater utilization of waste material as an inexpensive protein and mineral source.

Manning (1929a, 1929b) found general appearance, plumage and egg production of chickens fed 20 percent blue crab waste to be similar to or better than groups fed meat meal or a corn-wheat diet. Fronda (1929) reported supplementation of a corn-rice bran-based diet with 5 and 10 percent freshwater shrimp meal resulted in

increased egg production, reduced mortality and gave results similar to fish meal supplementation. Differentiating between sun-dried shrimp meal and steam-dried shrimp meal, Upp (1935) and Polk and Barnett (1943) found the high salt content of the former limited its feed value. Steam-dried shrimp meal, however, was considered a satisfactory protein source for chickens especially when used as an adjunct to other protein supplements.

In a study comparing North Atlantic white fish meal, menhaden meal, meat meal and shrimp meal fed as 10 percent of a basal diet (corn, wheat, dried buttermilk and bone meal), shrimp meal was found to give the least efficient feed/gain results (Titus et al. 1930). At 16 weeks (end of experiment) weights of chicks fed shrimp meal were slightly above those fed menhaden meal and slightly below weights in the other groups. Through 10 weeks of age the shrimp waste group had the poorest rate of gain; during the last six weeks, however, weight gain exceeded that in the other groups. To explain this change in growth rate the authors suggested accelerated early growth possibly offset rapid late growth in the fish and meat meal groups. It seems more realistic, however, to assume compensatory growth may have occurred in chicks receiving shrimp meal because nutrient requirements, not being met during maximum growth periods, were reduced during late growth and/or adjustment and maturation of the alimental system allowed more efficient utilization of the shrimp meal diet.

Byerly, Titus and Ellis (1933) examined egg production of laying hens fed 20 percent blue crab meal and compared results with those from hens receiving equal amounts of either meat meal, North Atlantic

fish meal, dried yeast and corn meal, soybean meal, cottonseed meal (CSM), or a combination of meat meal, fish meal and dried buttermilk. The crab meal diet was readily consumed and resulted in good egg production which was slightly exceeded only by that in the meat meal and fish meal groups. Feed/egg was somewhat higher in the crab meal group but hatchability was better than in eggs produced by hens receiving fish meal.

Schaperclaus (1933) reported negative results with crab meal in poultry diets and concluded the high mineral content made crab meal undesirable as a feed supplement (From Parkhurst et al. 1944). Fronda et al. (1933) included 10 percent freshwater shrimp meal in a corn-palay-rice bran diet for growing chicks. Meat scraps, tankage and fish meal were used as 10 percent supplements in comparison. Chicks on the shrimp meal diet displayed the best growth as well as the most vigor and feathered and matured earlier than chicks in the other groups. The shrimp meal diet was also reported to be the most palatable. A similar experiment with laying hens (Francisco et al. 1934) found egg production and hatchability to be highest on the 10 percent shrimp meal ration. To determine the optimum amount of shrimp meal for growing chicks Fronda and Kabigting (1935) included shrimp meal in a rice bran-corn meal-base diet at five percent increments between 5 and 40 percent. The 25 percent level was considered to give the best results although all diets including 20 to 40 percent shrimp meal produced similar weight gains. Feed consumption did not differ appreciably between groups.

Mangold and Damkohler (1938) offered a diet containing 25 percent crab meal to six week old pullets for 24 weeks (From Parkhurst et al. 1944). Another group fed a diet containing 10 percent fish meal showed better growth at 30 weeks of age but the difference was not significant. The authors implicated lower protein availability in the crab meal diet. In another chick growth study, Parkhurst et al. (1944a) replaced the 2.5 percent red fish meal component of a standard diet with blue crab meal with and without adjustment of a calcium supplement. In another diet one half of the meat scrap (three percent) as well as all of the fish meal was replaced by blue crab meal. The standard diet resulted in significantly better growth, however all diets produced above average weight gains. There were no significant weight differences between the three rations containing crab meal. Chicks receiving crab had greater pigmentation; meat flavor was not affected. In a second experiment, the dried skim milk component of the same standard diet was replaced by 5.5 percent crab meal. Significantly better growth occurred on the crab meal diet. No significant differences were detected in mortality, feed efficiency, feathering or pigmentation.

To investigate the value of blue crab waste as a feed supplement for laying hens Parkhurst et al. (1944b) replaced red fish meal (2.5 percent) in an all mash diet with crab meal (4.0 percent) on an equal-protein basis. Calcium levels were equalized between rations. Egg production, feed efficiency, fertility, hatchability, egg weight, yolk color, albumen quality and shell texture were found to be similar between groups.

Kifer and Bauersfeld (1969) compared blue crab meal, king crab meal, and menhaden meal as protein supplements to a corn-soybean meal-base diet for growing chicks. A corn-soybean meal diet with and without methionine supplementation and a commercial ration served as controls. Fish and crab meals were added to the base diet at 2, 4, 6, 8 and 10 percent on an equal-protein, isocaloric basis. Calcium and phosphorus levels were equalized between all diets. The king crab, blue crab, and menhaden meal diets, as well as the methionine supplemented control diet, produced significantly better rates of gain than did the control ration without added methionine. Shellfish and fish meal groups grew similarly at equal levels of supplementation and had rates of gain comparable to the group receiving the commercial ration. No significant differences were detected between rates of gain across different levels of the marine meals. Feed utilization of the fish and crab meals equalled or exceeded that of the control diet without added methionine, but generally were not superior when methionine was included in the control diet. Utilization of the 4 - 10 percent king crab diets was significantly poorer than the menhaden diets at equal levels. The blue crab meal rations did not differ significantly from the fish diets at any level tested.

Jarquin et al. (1972) evaluated two Guatemalan shrimp meals, one made from heads only and one made from bodies plus tails, as supplements for growing chicks. When compared to fish meals on an equal-protein basis, the shrimp meals resulted in somewhat slower rates of growth. Addition of lysine, but not methionine, to the

head meal improved growth response. Both supplemental lysine and methionine gave increased weight gains in the body-and-tail meal groups. Addition of H_3PO_4 was also found to increase growth of chicks on the shrimp meal diets.

Experiments on feeding crustacean meals to ducks and turkeys have also been reported. Fronda et al. (1938) included 20, 30 and 40 percent freshwater shrimp meal in a corn meal-rice bran based diet for laying ducks. Egg production in the shrimp meal group increased as the amount of shrimp meal in the diet increased. Production on a 30 percent fish meal diet was slightly less than in the 40 percent shrimp meal group. Feed/egg was highest and lowest in the 20 and 40 percent shrimp meal groups respectively. Potter and Shelton (1973) added three and six percent crab meal to a corn-soybean meal based ration for newly hatched turkey poults for four weeks. Comparison with a corn-soybean meal control diet showed both weight gain and feed consumption of chicks receiving crab meal increased by approximately five to six percent, being highest on the six percent crab meal diet. Addition of five percent crab meal between four and eight weeks of age increased weight gain and feed consumption by approximately 1.3 percent. Feed efficiency was not significantly altered during either period. Five percent supplementation with herring fish meal was found to give significantly greater feed efficiency than an equal amount of crab meal.

Unidentified growth factor (UGF) activity has also been reported in crustacean meals. Combs et al. (1954) reported liver, fish meal, fish solubles, whale solubles, meat scraps and crab meal contained

a similar or common UGF. Sullivan et al. (1960) evaluated UGF activity in a variety of fishery by-products under different processing and storage conditions. Shrimp meal and Dungeness crab waste were both found positive for UGF activity. Drying temperatures and ordinary storage conditions were not found to be influential.

Crustacean waste has also received consideration from poultry researchers as a pigment source. Nelson and Baptist (1968) found astaxanthin, extracted from lobster shells, turned egg yolks pink when used alone as the major pigment source in the diet. When used in combination with lutein, however, a small amount of astaxanthin turned yolks a desirable, deep yellow color. Astaxanthin was found to be 30 to 50 times as effective as lutein on a weight basis when fed in combination with lutein. Chawan and Gerry (1974) evaluated shrimp waste as a pigment source for broilers. Four percent shrimp meal added to a conventional yellow corn-soybean diet caused excessively high skin pigmentation. When wheat was substituted for yellow corn, however, shrimp meal added at 2, 4 and 6 percent produced significantly less pigmentation than the conventional diet. By adjusting the levels of yellow corn and shrimp meal in the ration, different levels of skin pigmentation were obtained. The authors concluded shrimp meal can have value as a pigment source for broilers when used as a complement to certain levels of plant xanthophylls.

BROILER CHICK GROWTH STUDY

Since no reports on feeding pink shrimp meals (Pandalus sp.) to poultry could be found, a study as described below was undertaken

to evaluate the inclusion of Pandalus jordani processing waste in the diets of broiler chicks. Different treatments of the shrimp waste were also investigated in an attempt to improve nutritive value.

Materials

Four shrimp meals were tested: untreated, hydrolyzed, sieved and protein concentrate. Source of materials is discussed in Section VII. Each meal was prepared from wet-packed waste by freeze-drying to less than five percent moisture and grinding in a Wiley mill. All meals could pass through an 18 mesh screen. Partial analysis of experimental materials is given in Table 5.

Untreated meal. Fresh shrimp waste was freeze-dried and ground without additional treatment.

Hydrolyzed meal. A commercially prepared proteolytic enzyme was added to shrimp waste and the material heated at 60°C for one hour in a steam-jacketed cooker. After one hour the temperature was raised to 82°C for ten minutes to denature the enzyme.

Sieved meal. Dried waste was first ground in a Wiley mill with a ten mesh screen. Larger shell fragments were then separated out by passing the coarse-ground material over an 18 mesh sieve (see Sections VI, D and VII).

Protein concentrate. Protein was extracted from fresh waste by heating the material at 60°C for four hours in a solution of dilute (approximately two percent) NaOH. The resulting protein solution was strained, neutralized with HCl, centrifuged (2,000 rmp: 15 minutes) to remove particulate matter and then freeze-dried (see Section VI, D).

TABLE 5. PARTIAL COMPOSITION OF THE SHRIMP MEALS TESTED (Dry Matter Basis).

Component	Untreated	Hydrolyzed	Sieved	Protein Conc.
Crude Protein (CP) %	35.34	35.17	41.87	55.39
Chitin, %	17.59	13.00	17.40	--
Corrected CP, %	27.81	29.61	34.42	--
Ash, %	26.69	24.57	27.00	--

Method

Day-old, Hubbard, feather-sexed broiler chicks were allotted to six groups, each containing five males and five females. Composition and protein content of rations fed each group are summarized in Table 6. Control groups (I) and (I') received identical rations. Each shrimp meal, except the protein concentrate, replaced four percent of the cerelose-soymeal control diet. Due to a lack of material the protein concentrate was fed as only 1.35 percent of the ration.

Chicks were raised on wire floors in heated brooders and provided feed and water ad libitum. Group weights and feed consumption data were recorded at weekly intervals and at the termination of the experiment on the 25th day.

Results

Mean weights of chicks taken at weekly intervals up to 25 days are given in Table 7. All groups receiving shrimp meals had higher mean weights than the control throughout the trial. The group receiving the hydrolyzed meal showed the greatest mean weight gain followed in decreasing order by the sieved and untreated meals and the protein concentrate.

With the notable exception of group 3, the mean final weights of male and female chicks tended to be higher and lower, respectively, in the shrimp meal groups than in the control. The mean final weight of females in group 3 receiving the hydrolyzed meal was over 20 percent greater than that of the males.

Differential growth responses (DGR) between male and female chicks have been reported previously. Titus et al. (1930) found

TABLE 6. COMPOSITION OF DIETS.

Ingredient	1 Control (I) & (I')	2 Untreated	3 Hydrolyzed	4 Sieved	5 Protein Conc.
Soybean Meal (%)	49.00	46.42	46.42	43.08	46.42
Cerelose (%)	43.69	43.28	43.28	45.61	45.47
Shrimp Meal (%)	--	4.00	4.00	4.00	1.35
Salts N (GBI[1]) (%)	6.00	5.00	5.00	6.00	6.00
Salts N Mod. Se + Mo (%)	0.10	0.10	0.10	0.10	0.10
Vitamin Mix (%)[2]	0.91	0.91	0.91	0.91	0.91
BHT (%)	0.01	0.01	0.01	0.01	0.01
DL-methionine (%)	0.20	0.20	0.20	0.20	0.20
Total Protein (%)	22.44	22.37	22.44	21.41	22.01
Shrimp Protein (%)	--	1.11	1.18	1.68	0.75

[1] GBI = General Biochemicals, Inc., Chagrin Falls, Ohio.

[2] Vitamin Mix: Vitamin A (30,000 IU), 0.03%; vitamin D_3 (1,500 ICU), 0.007%; vitamin E (Myvamix Distillation Products Corp., Rochester, N.Y.), 0.1%; Choline chloride (25%), 0.17%; Gordon's B-complex and vitamin K (Nutritional Biochemicals Corp., Cleveland, Ohio), 0.60%.

TABLE 7. MEAN WEIGHTS (GRAMS) OF BROILER CHICKS.

Group	Number of Chicks	Mean Weights (grams)							Mean Final Weight (grams) Gain
		Initial Weight	7 days	14 days	21 days	25 days Final	Final Weight Males	Final Weight Females	
Control (I)	10[1]	40	126.0	275.0	456.2	575.6	570.0	581.2	535.6
Control (I')	10	40	132.5	--	--	570.5	597.0	544.0	530.5
Untreated	10	40	132.0	291.5	486.0	588.0	624.0	552.0	548.0
Hydrolyzed	10	40	136.0	302.5	513.5	626.5	569.0	684.0	586.5
Sieved	10	40	135.0	294.0	485.0	594.5	637.5	555.0	554.5
Protein Conc.	10	40	140.0	285.0	478.0	581.5	657.0	506.0	541.5

[1] Two chicks died during the second week.

the growth of pullets, instead of cockerels, to be enhanced when shrimp meal was included in the diet. Parkhurst et al. (1944a) also reported female chicks to grow most rapidly on a crab meal diet. A reason for DGR between sexes has not been suggested, however, hormonal influences would appear to be involved.

Feed consumption by chicks on rations containing shrimp meals was slightly greater than that by the control group (Table 8). Feed efficiency was best in the group receiving the hydrolyzed meal; the other shrimp meal groups and the control were approximately equal to one another.

Discussion

Results obtained from feeding crustacean waste meals to poultry have been somewhat variable. Certainly the composition of the base diet and the level of waste meal supplementation have a major influence. Standard diets low in calcium or without an adequate source of animal or high quality plant protein typically give appreciably better results when shrimp or crab meals are included. The genera of crustacea, the mode of processing and the composition of the waste meal, as well as other factors (see Section VI, C), also may affect efficacy.

Type, sex and life stage of the birds may be important considerations, also. Laying hens, having high calcium requirements for egg production, appear especially well suited to shrimp and crab meal diets. Moreover, improved egg hatchability has been reported in many studies. Cornell University researchers studying the effects of excess calcium in poultry diets have shown high Ca levels do not

TABLE 8. FEED CONSUMPTION AND FEED/GAIN OF BROILER CHICKS 25 days old.

Group	Total feed consumed per group (gms.)	Mean feed consumption per chick (gms.)	Mean feed/gain ratio per chick
Control (I)	8,390	--	--
Control (I')	10,090	1,009.0	1.90
Untreated	10,315	1,031.5	1.88
Hydrolyzed	10,600	1,060.0	1.81
Sieved	10,580	1,058.0	1.91
Protein Conc.	10,465	1,046.5	1.93

adversely affect pullets when over 20 weeks of age, whereas younger birds suffer from a high incidence of nephrosis, visceral gout, calcium urate deposits, reduced weight gains and 10 to 20 percent mortality (Scott et al. 1969). In older birds, normal sexual development results in physiological hypercalcemia and the ability to metabolize greater amounts of calcium. The somewhat contradictory DGR between male and female chicks fed shellfish diets deserves further study. Changing growth rates of chicks fed waste meals during different life periods, as reported by Titus et al. (1930) and others, may also be significant. Perhaps crustacean meals could be most efficiently utilized if included only during certain periods.

Crustacean meals have generally been shown to be less efficiently utilized by poultry than other quality protein supplements. This lower efficiency is no doubt due, in part, to indigestible chitin which many early poultry researchers interpreted as protein. In the future protein digestibilities of crustacean meals should be given only for corrected protein values and should be so specified. At high levels of waste meal supplementation excess calcium in the diet could also affect feed utilization efficiency.

Most researchers have concurred that shrimp and crab waste meals can be desirable feed supplements for poultry if offered at low levels in combination with other protein sources and if mineral content of the total ration (properly balanced for Ca and P) does not become excessive. Even so, little of this material is presently being utilized in poultry diets. Blue crab meal is used in limited amounts along the East coast. Very little, if any, use of shrimp

or crab waste for poultry occurs in the Pacific Northwest (Arscott 1976). In recent years high quality protein supplements such as soybean meal and meat meal have been used extensively in poultry rations. For crustacean meals to be competitive, costs would have to be comparable on a protein basis. Economic considerations are discussed in Section XI.

SWINE

Little information is available on feeding crustacean waste to swine. Radcliffe (1920) reported shrimp meal to be equal to fish meal as a protein source for pigs (From Manning 1934). Barnett and Goodell (1923) compared alfalfa hay, alfalfa meal, soybeans, peanut meal, tankage, CSM and tankage, and shrimp meal as self-fed, free choice protein supplements to a corn-based diet for fattening hogs. Weight gain in the shrimp meal group was slightly less than in the tankage and CSM-tankage groups but greater than in the others. Carcasses of the hogs fed shrimp meal were reported firm.

Bray et al. (1932) also compared up to 12.5 percent shrimp meal to tankage in several experiments. Swine receiving shrimp meal showed better weight gains than did those offered comparable amounts of tankage. Shrimp meal used in combination with other protein supplements such as CSM gave better growth than when used alone. Bray (1935) reported hogs fed shrimp meal made almost 12 percent better gains than others receiving tankage. Angel (1935) included freshwater shrimp meal in a corn-rice bran-copra meal-based diet for growing pigs at 5, 10, 15 and 20 percent. Weight gain and feed

efficiency, found to be greatest on the five percent shrimp meal diet, decreased with higher levels of shrimp meal.

Swine fed some fish meals produce fish-flavored pork. Quality and oil content of the fish meal, as well as level in the diet, can be influential (Morrison 1954). Discontinuing supplementation in advance of slaughter has been found to reduce severity of the flavor defect (Brody 1965). Although no cases of undesirably flavored pork were reported in the shrimp meal studies reviewed, it may be a potential problem. Crustacean wastes, however, usually contain considerably less fat than fish meals. Vitamin E content of the diet, to prevent oxidative rancidity, would also be a factor.

Unlike poultry, swine may not require crustacean wastes to be dried and ground. Feeding fresh waste would be more economical if accepted by the animals. Nevertheless, most swine operations do not have freezer facilities, therefore possible utilization of fresh material would be restricted to the immediate vicinity of processing plants.

RUMINANTS

Fiedler (1931) reported sheep fed nine percent shrimp meal in a grain mixture grew as well or better than those fed an equal amount of linseed oil meal. Wool production did not differ between groups.

Lush (1935a, 1935b) examined shrimp meal as a feed supplement for dairy cows. Sun-dried shrimp meal when included as 12 - 19 percent of a grain ration (rice polishing, ground corn, wheat bran, CSM and a mineral supplement) resulted in an average increase of over two percent in yield of four percent fat-corrected milk.

Shrimp meal rations were well accepted when introduced gradually into the diet and no noticeable effect was reported on milk or butter flavor.

More recently Kirk et al. (1968) compared shrimp meal and CSM as protein supplements for grade steers. In a series of trials, up to three pounds of shrimp meal per steer were included in the daily ration. Generally, weight gain, feed efficiency and carcass yields were found to be less in the shrimp meal groups. Lower TDN in the shrimp meal as compared to CSM, probably due to the high mineral content, was suggested as a possible cause. Shrimp meal diets were readily consumed and no adverse health effects were noted.

Patton, Chandler and Gonzales (1975) evaluated blue crab meal as a protein supplement for ruminating Holstein calves. When crab meal was substituted for 10 and 20 percent of the basal diet no significant differences in weight gain or feed efficiency occurred. In the first four week trial with twelve week old calves, no significant difference in nitrogen absorption or nitrogen retention was found between control and test diets. In a second trial involving 24 week old animals on test for six weeks, nitrogen retention was significantly less on a 20 percent crab meal diet. The authors implicated increased urine output resulting from high mineral content in the crab meal ration.

The role of rumen microorganisms in the utilization of shellfish products is discussed in Section VI, B.

MINK

Preliminary feeding trials to investigate the use of king crab and shrimp wastes in the diets of pelter mink were carried out at the Alaska Experimental Station during 1966, 1967, and 1968 (Leekley 1966, 1968). King crab meal included as 3, 6 and 10 percent of the diet replacing equal amounts of fur seal meal (on a wet basis) resulted in 3.1, 7.8 and 8.0 percent lower mean final weights and 0.4, -2.4, and 1.3 percent greater feed consumption. Average pelt value was highest in the three percent crab meal group but in the other groups receiving crab meal, it was somewhat below that of the control.

Shrimp waste was evaluated as a replacement for 45, 45 and 30 percent halibut waste, salmon heads, and halibut waste and salmon heads (wet basis), respectively. Mink fed shrimp meal rations showed 11.9, 1.0 and 3.5 percent lower mean final weights and 26, 20.6, and 19.0 percent greater feed consumption than respective control groups.

Fat and mineral levels were not adjusted in either trial; therefore crustacean waste diets were considerably lower in fat and higher in mineral content.

B. Nutritive Value

PROTEIN

Several researchers have completed growth and nitrogen balance studies with crustacean waste proteins using rats. Lubitz *et al.* (1943) reported that blue crab meal protein (corrected for chitin) had a biological value of 76 when compared to casein protein at 100. Sure and Easterling (1952) found crab meal protein to have a

biological value of 85.9 which compared favorably with several fish meals also tested. Using dried whole egg as reference protein set at 100, net protein utilization of the crab meal was found to be a relatively low 63.7. Low true digestibility of crab meal protein was implicated as the cause for reduced utilization. Crude protein values were not corrected for chitin, however, and mineral content of the crab meal diet was appreciably higher than in the other diets tested. Both factors could have influenced digestibility ratings. Lovell et al. (1968) found uncorrected crayfish meal protein to be only 82.5 percent as digestible as methionine-supplemented soy protein (MSP) for growing rats. With crude protein corrected for chitin, digestibility of crayfish meal protein and MSP was essentially the same. Toma (1971) ran PER studies using protein recovered from the effluent of a Louisiana shrimp cannery. Shrimp waste protein promoted rat growth 80 percent as efficiently as casein and when substituted for half the protein in a soybean-based diet, improved protein quality by 74 percent. Johnson and Peniston (1971) reported Alaskan shrimp waste protein to be equal in nutritional value to casein when supplemented with sulfur-containing amino acids.

Essential amino acid profiles of crustacean waste proteins have been found to compare favorably with those of casein, soybean and menhaden meal proteins (Kifer and Bauersfeld 1969, Johnson and Peniston 1971, Meyers and Rutledge 1973, Meyers et al. 1973). From these results shellfish waste proteins appear to be generally of good quality and very similar to fin-fish proteins.

CHITIN

In insects and crustaceans, chitin serves as a carbohydrate and nitrogen reserve and is closely associated with proteins (Muzzarelli 1973). N-acetyl-D-glucosamine units of the chitin polymer are joined in beta 1, 4 linkage. This bond, the same as that in cellulose, is resistant to hydrolysis by enzymes produced by domestic animals; hence the chitin molecule is essentially indigestible. Chitinolytic activity has been reported in some undomesticated species such as the omnivorous prosimian Perodicticus potto, however (Beerten-Joly et al. 1974). Chitin also does not appear to serve as a source of nitrogen for domestic monogastrics (Lubitz et al. 1943). With regard to mink, in view of their natural diet and rapid rate of food passage (two to four hours), it is highly doubtful that chitin has any nitrogen or energy value whatsoever.

Certain microorganisms, both soil and alimental, can degrade chitin. Recent studies with ruminants suggest chitin may be utilized to some extent for energy and nitrogen via the rumen microflora. Patton and Chandler (1975) studied in vivo digestibility of cockroaches, grasshoppers, shrimp meal, crab meal and purified chitin in fistulated steers. Average rumen solubilities were reported as 66.5, 32.0, 17.4, 35.7 and 21.5 percent, respectively. Average adjusted rumen solubilities (over that in water) were 5, 3.2, 8.3, 15.0, and 12.9 percent, respectively. Solubility differences indicate true chitin digestion occurs in the rumen. Church (1975) examined in vitro rumen cellulose digestion and ammonia production with D-glucosamine and N-acetyl-D-glucosamine as nitrogen sources

as compared to urea. D-glucosamine gave little improvement in cellulose digestion over a negative control with no added nitrogen. Addition of N-acetyl-D-glucosamine resulted in somewhat greater cellulose digestion. When half of the nitrogen was supplied by the chitin derivatives and half by urea, further improvement in percentage of cellulose digestion was noted but it still did not approach that with urea alone. Ammonia N was found to increase only when the chitin derivatives were added without urea. The results suggest deamination of D-glucosamine and N-acetyl-D-glucosamine by microorganisms can occur in the rumen and that chitin may serve as a source of nitrogen for ruminants.

Chitin digestion and deamination may be enhanced if rumen bacteria are given a period to adapt. Increased utilization over time has been found with other nonprotein nitrogen sources such as urea and biuret (Meiske and Goodrich 1972). Patton et al. (1975) reported greater digestibility of chitin in ruminating calves after previous exposure.

The adverse effects of chitin may be a primary consideration in domestic monogastrics. Lubitz et al. (1943) fed rats glucosamine HCl and reported an inhibitory effect on growth. Perhaps more important is the effect of chitin on protein availability. Chitin may serve as a physical barrier to proteolytic enzymes thus preventing access to closely associated proteins. Chemical reactions may also be involved. Hackman (1960) suggested some protein may be covalently bound to chitin since aspartyl and histidyl residues remained associated with chitin after extensive treatment with alkali.

Attwood and Zola (1967), however, were not able to corroborate these findings. It is possible some of the protein in crustacean wastes may be rendered unavailable due to a browning or Maillard type reaction occurring between amino acids having free amino groups and the free anomeric carbon on the terminal N-acetyl-D-glucosamine residue of chitin. Such a reaction is especially favored in heat treatment and has been well documented in the processing of certain feedstuffs (Rolfe 1970). Browned proteins resulting from amino group-reducing sugar interactions can be considerably lower in overall digestibility.

MACRO-MINERALS

Approximately half the ash content of shellfish waste meals is calcium, primarily in the form of calcium carbonate. Calcium carbonate, as limestone, is frequently used as a calcium supplement in animal diets and has been found very satisfactory (Morrison 1954). Higashi (1962), however, expressed doubt that calcium contained in crustacean shells can efficiently be utilized for nutritive purposes. Nevertheless, feeding trial studies indicate calcium in shellfish wastes can satisfy nutritional needs; the primary concern of crustacean waste supplemented diets being an excess rather than a deficiency of calcium (see Section X).

Phosphorus is generally much less common and usually does not exceed three percent of the total dry waste. It is found in a variety of organic and inorganic compounds contained in crustacean wastes including phospholipids, nucleotides and PO_4, and is probably fairly available biologically.

Sodium, chlorine, potassium and magnesium content is comparable to that of many fish by-products. Sodium and chlorine content, however, may be variable depending on the type of processing. Waste from sun-dried shrimp operations is often substantially higher in these elements than crude wastes due to the addition of NaCl to retard spoilage.

MICRO-MINERALS

Crustacean wastes contain high amounts of micro-minerals. Based on NRC recommendations (1968), iron content of waste materials (approximately 110 - 400 ppm) would probably be more than adequate to prevent the cotton-fur syndrome from occurring in mink, assuming there are no interfering factors (see Section IX). Other micro-minerals in crustacean wastes are present in comparable or higher quantities than in most fish products.

VITAMINS

Very little information is available on the vitamin content of shellfish wastes. Lubitz et al. (1943) found blue crab meal contained 2.9 ppm of riboflavin, less than one I.U. of vitamin A per gram and no measurable amounts of thiamin or vitamin D. NRC (1971) reported crab meal in general to contain 2,000 mg/kg choline, 44 mg/kg niacin, 6.6 mg/kg pantothenic acid and 5.9 mg/kg riboflavin. From these analyses the vitamin content of crustacean wastes are comparable to many fish products, although generally lower. With regard to mink, based on NRC (1968) recommendations, crab meal appears to be more than adequate in niacin and riboflavin and marginal in

pantothenic acid. Thiamin and fat soluble vitamins would have to be supplied by other sources in the diet.

LIPIDS

Fat is a minor component of shellfish wastes. Only recently have analyses been made on the fatty acid composition of crustacean waste lipids (Table 9). Like other marine products, crustacean waste lipids show high proportions of polyunsaturated fatty acids. Essential fatty acids, linoleic (18:2ω6), linolenic (18:3ω3) and arachidonic (20:4ω6), are all present. Linoleic acid content is generally lower than that found in the lipids of terrestrial animals.

Oxidative rancidity of unsaturated fat can cause steatitis or yellow fat disease in mink. This problem is easily rectified with Vitamin E fortification of the diet, however.

In view of the low fat content of shellfish wastes, supplementation of fat as an energy source would be essential if waste materials were to make up a high percentage of mink diets.

C. Factors Influencing Composition and Nutritive Value

A wide range of factors can affect the chemical composition and nutritive value of crustacean waste. Different species of shrimp and crab show wide diversity in biochemical structure, which in turn is reflected in their waste products. For example, arginine and lysine, reported to be deficient in the exoskeleton of the Dungeness crab (Allen 1971), have been found to be present in high proportions in the exoskeleton of the blue crab (Degen et al. 1967). Gross morphological composition of waste can have a considerable

TABLE 9. FATTY ACID COMPOSITION OF CRUSTACEAN WASTE (weight percent of total fatty acid comp.).

Fatty Acids	Pandalus borealis waste[1]	Vacuum-dried Pandalid meal (9.2% lipid)[2]	Panaeus setiferus waste[2]	Sun-dried Penaeid meal (3.5% lipid)[2]	Cancer magister exo-skeleton[3]
12:0	0.6	0.2	trace	0.3	0.0
14:0	2.0	2.4	1.8	2.5	0.4
16:0	13.9	10.1	12.6	20.8	14.5
18:0	3.0	2.0	6.7	8.7	8.5
20:0	trace	0.1	--	0.7	0.9
22:0	--	--	--	1.4	--
16:1	6.7	9.0	6.3	10.9	6.8
18:1	23.5	17.9	11.9	21.4	17.5
20:1	2.4	13.4	4.1	3.3	5.0
22:1	2.7	18.4	2.0	1.5	4.0
18:2ω6	0.8	1.4	2.5	2.9	--
20:2ω6	1.4	0.3	1.9	1.5	1.3
18:3ω3	0.9	0.8	1.0	1.3	--
20:3ω6	trace	--	--	--	0.5
18:4ω3	trace	1.1	0.2	0.2	--
20:4ω6	0.5	0.9	4.0	1.7	0.6
22:4ω6	trace	--	--	--	0.9
20:5ω3	18.4	7.6	16.9	2.1	22.6
22:5ω3	2.4	--	--	--	1.6
22:6ω3	13.4	9.0	15.7	2.2	12.5

[1] Krzeczkowski 1970.

[2] Joseph and Meyers 1975.

[3] Allen 1971.

effect on nutritive value. Waste products low in exoskeletal matter are generally better suited for animal feed purposes. Meyers et al. (1973) reported shrimp meal made from head waste had almost twice as much protein as that made from shells. Visceral waste from Dungeness crabs has been found to be appreciably higher in protein and fat content than exoskeletal waste (Allen 1971). Alverson (1968) reported leg and claw waste of the Tanner crab (Chinoecetes bairdi) contained half as much protein as body butchering waste. Gross waste composition is determined largely by processing methods and product type. Wastes produced between canned, frozen, and sun-dried shrimp operations can be highly variable. Further differences in waste composition occur between and within hand-peeled shrimp operations and machine-peeled operations (Alverson 1968, Meyers et al. 1973). Crawford (1975) found total amino acid content of wastes from two mechanized shrimp processing plants in Oregon differed by more than 11 percent.

Other factors influencing nutritive value of raw waste material include method of handling, season of harvest and geographic location of harvest. In a Florida study, protein content of shrimp head waste decreased approximately 10 percent when 24 hours elapsed between de-icing and deheading (Khandker 1962). Seasonal variations in the proximate composition of the Dungeness crab and its waste by-products have been well documented by Farragut (1966).

Dehydrating waste to produce meal can also have a significant effect on nutritive value. Several drying methods have been used: steam, heated air, vacuum-drying, drum-drying, and sun-drying.

Temperature and duration are critically important in any drying procedure. Heat damaged proteins are inefficiently utilized by animals. Heating also favors browning reactions between proteins and reducing carbohydrates which lessen digestibility. Little quantitative information is available on the effect drying has on shellfish proteins. Studies dealing with fish meal production have generally shown that temperatures slightly above the boiling point of water have little effect on protein quality until moisture content of the material drops to a low level (Ousterhout and Snyder 1962). Further heating causes protein damage. As long as the temperature is maintained close to the boiling point, quality reduction proceeds slowly. If temperature increases, however, rapid loss in protein quality follows. Vitamins, lipids, and pigments can also be affected by drying (Higashi 1962, Lovern 1962, Rousseau 1960). Generally, drying by any of the aforementioned methods probably has minor effect on nutritive value if time and temperature are properly controlled.

Grinding dried waste into a fine meal may serve to improve nutrient availability for monogastric animals. By reducing particle size, surface to volume ratio is increased which consequently increases contact with digestive enzymes. Mink, having a short digestive tract and rapid rate of food passage, may be especially benefited. Fine grinding cereal grains has been found to improve their utilization by mink (Adair et al. 1966). Grinding can also prevent animals from sorting out and rejecting larger exoskeletal fragments.

If shellfish by-products are to be used for animal feed, quality control would be essential. Corrected crude protein values and drying time and temperature would require close monitoring.

D. Improving Nutritive Value

Improving the nutritive value of crustacean waste involves increasing protein level and decreasing relative chitin and calcium levels. Physical, chemical and enzymatic methods have been suggested. Physical methods are based on gross structural differences between protein, calcium carbonate and chitin which permit size classification. Rutledge (1970) reported grinding dried crayfish waste (Procambarus clarka) and blue crab waste in a Wiley mill through a one-fourth inch screen and then sieving through a No. 12 U.S. standard mesh screen, substantially increased protein content and reduced calcium and chitin levels of both meals (Table 10). In principle, particles high in protein are considered more susceptible to the shock wave and impact created in milling than hard, fibrous particles high in calcium and chitin, and therefore are more likely to be reduced in size.

Along with residual soft tissue, certain portions of the exoskeleton may be favored for recovery. The crustacean cuticle is considered to have four major layers: epicuticle, exocuticle, endocuticle and membranous layer. Welinder (1975) found 100g of demineralized crab (Cancer pagurus) cuticle contained 33.1g protein and 66.9g chitin. The epi-exocuticle, endocuticle, and membranous layer contained 10.1g and 6.7g, 20.5g and 55.5g, and 1.7g and 4.7g protein and chitin, respectively. Assuming a similar relationship

TABLE 10. PROXIMATE ANALYSES OF BLUE CRAB AND FRESHWATER CRAYFISH WASTES BEFORE AND AFTER SIEVING (Rutledge 1971).

	Crude meal		Sieved meal	
Component (%)	Blue crab	Crayfish	Blue crab	Crayfish
Moisture	4.5	5.7	8.2	6.4
Corrected CP	24.0	28.1	58.4	58.5
Fat	2.0	4.4	2.7	6.0
Chitin	12.9	12.5	2.6	2.1
Ash	56.0	44.0	20.5	16.8
Calcium	17.0	18.0	7.5	5.7
Phosphorus	1.7	1.2	1.4	0.9

between protein and chitin holds for other crustacean species, the epi-exocuticle complex would probably be more susceptible to size reduction than the other layers which have lower protein to chitin ratios.

Another physical method involves wet-waste processing. Use of a fish flesh separator consisting of a perforated drum through which soft tissue exudes when placed under pressure has been suggested as a means of reclaiming residual protein tissue from shrimp waste (Miyauchi and Steinberg 1970). If followed by alcohol extraction, a protein concentrate containing over 80 percent protein can be obtained. This procedure would have only limited application because of the small amount of waste which can be reclaimed and because no use is made of protein contained in the exoskeletal matrix.

Chemical methods can yield almost total recovery of protein contained in shellfish wastes. Protein is presently being extracted from king crab waste by a Seattle, Washington firm as a by-product of their chitin isolation process (Peniston et al. 1969, Johnson and Peniston 1971, Anonymous 1973). The procedure consists of alkali treatment of waste with one to two percent NaOH at about 60 C for four hours, neutralization with HCl, isoelectric precipitation, filtration, and spray or drum-drying. The final product can contain up to 90 percent protein, only six to eight percent ash and be free of fluorides. Feeding trials with rats and amino acid analyses (Table 11) have shown the protein to be of high quality without adverse side effects (Johnson and Peniston 1971). Alkaline treatment,

TABLE 11. AMINO ACID COMPOSITION OF NaOH EXTRACTED CRUSTACEAN WASTE PROTEINS COMPARED WITH CASEIN (100% protein basis, %) (Johnson and Peniston 1971).

Amino Acid	Dungeness Crab Protein	Alaskan Shrimp Protein	Casein
Lysine	6.35	8.34	6.02
Histidine	2.60	2.97	2.31
Arginine	6.47	8.06	2.41
Aspartic Acid	12.10	8.63	4.45
Threonine	4.20	3.91	3.81
Serine	3.18	4.69	5.88
Glutamic Acid	14.50	17.80	21.90
Proline	5.10	4.54	15.71
Glycine	4.94	7.52	1.16
Alanine	5.41	7.14	1.47
Cystine	0.28	ND[1]	ND
Valine	6.47	5.62	7.91
Methionine	2.32	2.60	2.75
Isoleucine	5.53	5.17	3.91
Leucine	7.78	8.14	11.07
Tyrosine	4.70	3.61	2.72
Phenylalanine	4.80	5.05	5.46
Tryptophan	1.18	0.73	1.00

[1] ND = Not determined.

however, appears to be destructive to cystine, therefore supplementation with sulfur-containing amino acids may be necessary if NaOH extracted proteins are to serve as the major protein base in the diet. Although this method can be applied to all crustacean wastes, different equipment may be necessary for different species due to diversities in exoskeletal structure.

Kamasastri and Prabhu (1963) reported on a similar alkali extraction technique. When applied to prawn shell waste, a product (five to six percent of the raw material) containing 86 - 87 percent protein, 2.8 - 3.0 percent ash, 0.38 - 0.51 percent calcium and 0.29 - 0.39 percent phosphorus was obtained. Digestibility of the protein concentrate was 97 - 98 percent.

Enzymatic methods have been successfully used to reclaim protein from fish by-products (Liston 1972), although cost of enzymes and the bitter taste of enzyme hydrolysates tend to detract from the usefulness of this technique (Shenouda and Pigott 1975). Onoue and Riddle (1973) reported on the application of a plastein reaction to facilitate recombination of soluble peptides resulting from enzyme hydrolysis. The resulting product is tasteless and contains a higher proportion of essential amino acids than the shorter hydrolysates. Only 35 percent of the total original protein is recovered, however, and production costs would probably price plastein protein out of the animal feed market. Enzymatic methods have also been proposed for processing krill (Euphausia spp.), a small crustacean found in Antarctic waters, into a mash composed of 42 percent protein and 7 percent ash (Meyers and Rutledge 1971).

Similar enzymatic techniques may find application in the conversion of crustacean wastes into more valuable products, but high cost and low protein recovery must first be overcome.

VII. EXPERIMENTAL MATERIALS AND METHODS

Three shrimp waste products (Pandalus jordani) and a protein concentrate extracted from king crab waste were selected for investigation. Materials were chosen on the basis of availability, protein/ash content and potential cost. Shrimp waste, by far the most abundant crustacean by-product in the Northwest and having the highest protein/ash content, was considered to have the greatest efficacy as a feed source and therefore received more attention than crab waste.

A. Source of Materials

Shrimp waste was obtained from Astoria Seafoods Co., Inc., Astoria, Oregon. Equipment used in processing included Laitram PCA peelers, washer-cleaners and separators. Waste material was both dry and wet-packed. Dry-packing involved bagging the shells as they came from the peelers. Wet-packing involved solid waste from all sources which had been screened and collected by a 50 mesh Hydrasieve.[1] Water was added to the screened material to produce a slurry which could be pumped into bags. Wet-packing by this method prevented rapid oxidation of astaxanthin. Bags of shrimp waste were quick frozen and stored at -18°C until treated or fed.

King crab protein concentrate was obtained from Food, Chemical and Research Lab., Inc., Seattle, Washington.

B. Experimental Materials

Waste products tested included untreated shrimp waste (USW), shrimp meal (SM), sieved shrimp meal (SSM), and a crab protein

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[1] C-E Bauer Process Equipment, Springfield, Ohio.

concentrate (CPC) extracted from king crab waste (Figure 3). SM and SSM were produced from wet and dry-packed wastes dried at 45 - 65°C for approximately six hours in a steam jacketed dryer[1]. Three batches of dried waste differing in moisture content were used in the experiment (Table 12).

Untreated shrimp waste. This product consisted of wet-packed waste as it was received from the processor. Shell fragments ranged up to 2.5 cm in length and moisture content was as high as 88 percent. USW would have the advantage of least direct cost.

Shrimp meal. SM was produced by grinding dried waste in a large Wiley mill through an 18 mesh screen. Particle size consistency was comparable to that of the SSM. Fine grinding may enhance utilization of nutrients by mink and would prevent sorting. Although drying and grinding add to the direct cost of the waste, expenses may be defrayed by lower handling, transportation and storage charges due to reduced volume.

Sieved shrimp meal. In seeking methods for improving the feed value of shrimp waste a physical classification procedure was considered a practical alternative because of simplicity and low cost. As discussed in Section VI, D components of crustacean waste can be separated to some extent on the basis of their structural characteristics.

SSM was produced by grinding dried waste in a hammermill with 5 mm openings and then sieving through a 20 mesh screen. A rotating drum sieve constructed for this purpose was found to be an easy and

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[1] Dryer operated by Oregon Aqua-Foods, Newport, Oregon.

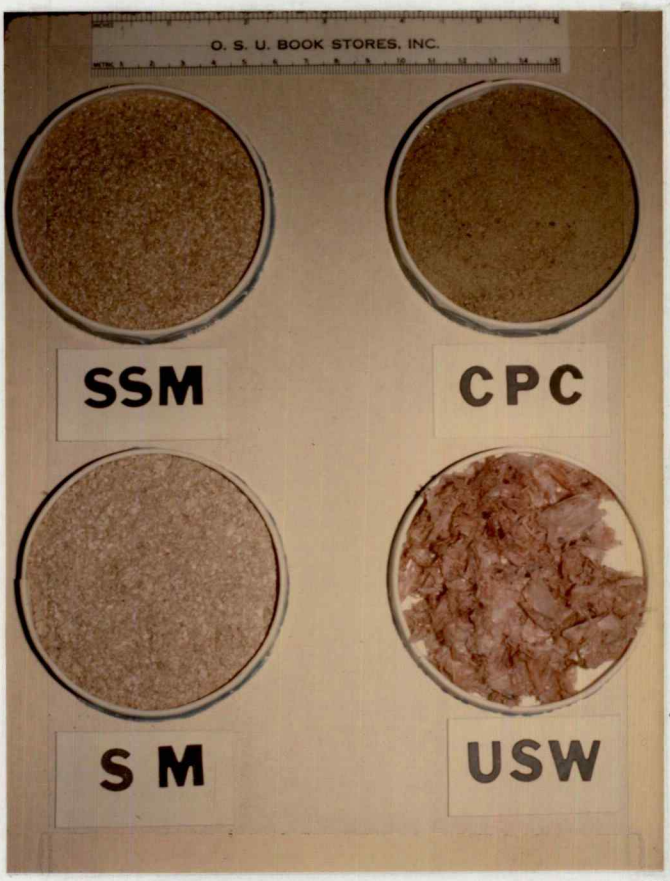

Figure 3. Experimental materials: Sieved shrimp meal (SSM), crab protein concentrate (CPC), untreated shrimp waste (USW), shrimp meal (SM).

TABLE 12. DRY MATTER CONTENT AND AVERAGE SCREEN PASSAGE OF THE THREE BATCHES OF DRIED SHRIMP USED.

Batch	Percent	
	Dry Matter	Average Screen Passage
1	98.1	54.8
2	82.9	42.4
3	89.0	44.7

efficient means of separation (Figures 4 and 5). Waste material was sieved until passage through the screen was essentially complete. Sieved shrimp yield averaged 47.3 percent of the total waste. Screen passage increased directly (R = 0.93) with the dry matter content of the waste (Figure 6). A larger screen size (16 mesh) was also tried but screen passage was considered too high to be effective.

Crab protein concentrate. Protein was extracted from king crab picking-line waste with dilute (one to two percent) NaOH, neutralized with HCl and drum-dried as outlined by Peniston et al. (1969). CPC is a by-product of the chitin isolation process developed by Food, Chemical and Research Lab., Inc., Seattle, Washington. The primary purpose for testing CPC was to evaluate the utilization of shellfish protein uninhibited by high chitin and mineral fractions.

Ten batches of CPC were used in the experiment. Two batches were very dark and appeared scorched.

C. Analytical Methods

All samples were freeze dried and ground in an analytical mill to prevent volatization of fat. Crude protein was determined by the Kjeldahl method. Chitin nitrogen was determined following the technique of Brown (1965) which consisted of fat extraction with acetone, demineralization with formic acid and protein extraction with NaOH. The remaining residue was subjected to Kjeldahl analysis to determine apparent crude protein nitrogen contributed by chitin. Percentage of chitin was calculated by the following:

$$(\text{Apparent CP\%} \div 6.25)\ 14.6 = \text{Chitin \%}$$

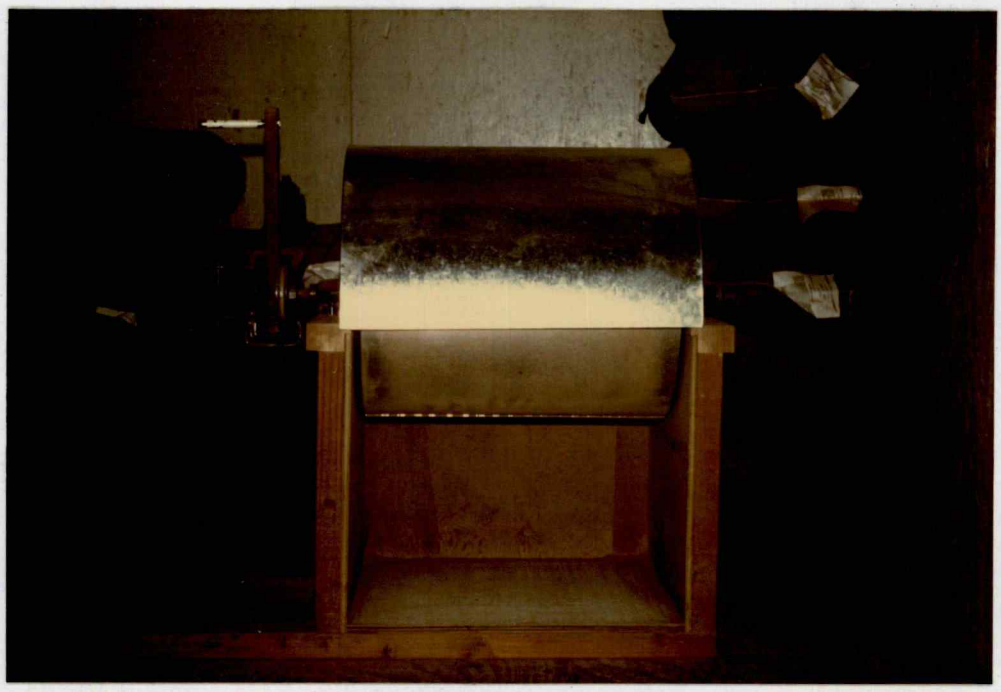

Figure 4. Drum sieve with dust hood in place.

Figure 5. Drum sieve with hood removed and door opened showing screen and mixing paddles.

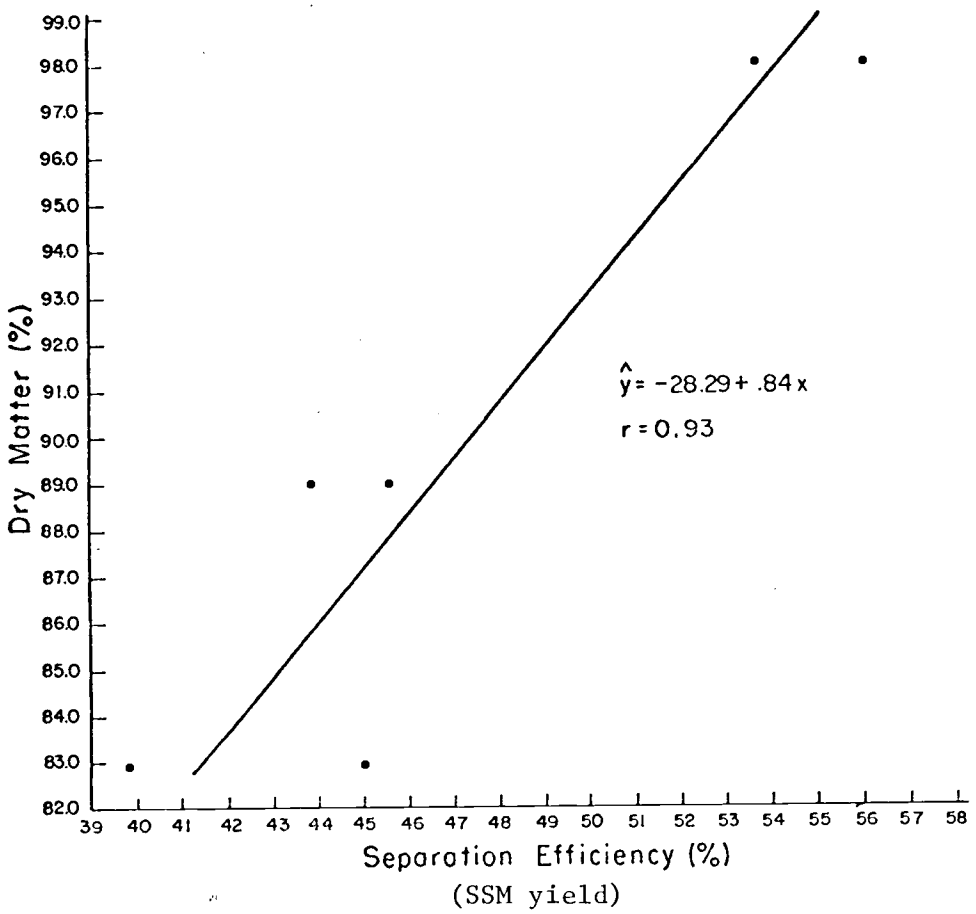

Figure 6. Sieved shrimp meal (SSM) yield versus dry matter content.

where 6.25 and 14.6 are based on 16 percent and 6.8 percent nitrogen in protein and chitin, respectively. Corrected crude protein was calculated by subtracting apparent crude protein from total crude protein. Dry matter content was determined gravimetrically by freeze drying. Fat was determined by four hour, anhydrous, diethyl ether extraction using a Goldfisch apparatus. Mineral samples were ashed in a muffle furnace at 550°C for eight hours. Calcium was determined using a Perkin-Elmer atomic absorption spectrophotometer. Phosphorus was determined colorimetrically using a Zeiss spectrophotometer. Amino acid analyses were run on a Beckman Model 120B amino acid analyzer. Glucosamine was separated from tyrosine and phenylalanine on a Durnam Microbore DC-4A resin.

D. Analytical Results and Discussion

Proximate analyses and chitin levels of experimental materials and fish carcass are shown in Table 13. Sieving resulted in a 28 percent increase in corrected protein and a 40 percent decrease in chitin over SM. Contrary to results reported by Rutledge (1970), sieving had only a minor effect on calcium level.

Acid detergent fiber (ADF) and chitin levels were closely related; differences between these determinations may have been due to silica and/or solubilization of chitin during demineralization with formic acid.

The protein content of CPC averaged 67 percent but varied considerably between batches (59.8 to 74.5 percent). This variability was probably due to equipment and procedure modifications by Food, Chemical and Research Lab., Inc.

TABLE 13. MEAN PROXIMATE ANALYSES AND CHITIN LEVELS OF EXPERIMENTAL MATERIALS AND FISH CARCASS.[1]

	Material (Percent, dry matter basis)				
Component	USW	SM	SSM	CPC	Fish Carcass
Dry matter	11.23	Var[2]	Var	90.14	27.10(2)
Crude protein	33.80	34.12	38.54	67.09	46.45(2)
Corrected protein	25.54	26.59	33.99	--	--
Chitin	19.30	17.59	10.63	trace	--
Ether extract	3.59(2)	4.31(2)	4.98(2)	0.45(2)	20.42(2)
Ash	28.53	29.39	27.83	6.84	14.81(2)
Acid detergent fiber	21.43	21.42	12.59	1.14	0.49(2)
Calcium	14.42(2)	13.75	10.31	0.10(2)	1.26(1)
Phosphorus	2.10(2)	2.08(2)	1.98(2)	0.66(2)	2.18(1)

[1] Analyses made on three or more duplicate samples unless specified in parentheses.

[2] Varied (see Table 12).

Amino acid compositions of SM, SSM, and CPC were very similar on a 100 percent protein basis (Table 14). Essential amino acid contents compared favorably with casein (see Table 11) with only leucine being notably lower in the shellfish proteins.

Glucosamine values as shown in Table 14 are not representative of true chitin content due to destruction during hydrolysis.

SM amino acid protein (sum of amino acid residues) showed close agreement with corrected protein. CPC amino acid protein (81.37 percent) was somewhat higher than Kjeldahl protein (74.5 percent) determined on the same sample. Peniston et al. (1969) reported isolated shellfish protein may be better characterized as containing 15 instead of 16 percent nitrogen. Using this value Kjeldahl protein equaled 79.5 percent. SSM amino acid protein was considerably higher than corrected protein. This may have been the result of sampling error.

Analyses on Pandalus jordani waste by Crawford (1975) showed corrected protein (determined by the same techniques as used in this study) gave an appreciably higher value than amino acid protein (see Table 4). Welinder (1974) suggested formic acid may solubilize chitin to some extent. Lovell et al. (1968) found HCl demineralization yielded a higher percentage of chitin nitrogen than formic acid. It is possible the formic acid demineralization step in Brown's procedure (1959) may result in a loss of some chitin before nitrogen analysis. Analyses in the present study did not suggest any loss of chitin with formic acid.

TABLE 14. AMINO ACID AND GLUCOSAMINE ANALYSES OF SHRIMP MEAL (SM), SIEVED SHRIMP MEAL (SSM) AND CRAB PROTEIN CONCENTRATE (CPC) (dry matter basis).

	Percent (Total)			Percent (100% Protein Basis)		
Amino acid	SM	SSM	CPC	SM	SSM	CPC
Lysine	1.89	3.17	4.02	5.68	5.50	4,93
Histidine	0.76	1.42	2.55	2.29	2.47	3.13
Arginine	1.95	3.79	6.14	5.87	6.58	7.54
Aspartic acid	3.12	5.74	5.91	9.37	10.00	7.31
Threonine	1.05	2.57	3.84	3.17	4.46	4.71
Serine	1.39	2.63	3.54	4.18	4.59	4.35
Glutamic acid	3.86	6.88	14.31	11.59	11.95	17.57
Proline	1.42	2.87	4.53	4.26	4.99	5.57
Glycine	1.45	2.79	4.30	4.35	4.85	5.29
Alanine	1.70	2.97	5.04	5.12	5.17	6.18
Half cystine	0.25	0.26	trace	0.75	0.46	trace
Valine	1.62	3.05	5.57	4.86	5.29	6.84
Methionine	1.00	1.37	0.93	3.01	2.38	1.15
Isoleucine	1.30	2.56	3.73	3.90	4.45	4.58
Leucine	1.93	3.94	5.85	5.79	6.85	7.18
Tyrosine	2.15*	8.25*	5.33	6.43*	14.35*	6.55
Phenylalanine	6.44*	3.28	5.65	19.35*	5.70	6.94
Cysteic acid	trace	--	0.13	trace	--	0.17
Total	33.28	57.54	81.37	99.97	100.04	99.99
Glucosamine[1]	4.15	4.67	--	12.50	8.11	--
Tyrosine[1]	0.96	2.56	--	2.89	4.45	--
Phenylalanine[1]	1.64	2.95	--	4.91	5.13	--
Corrected total	27.29	51.52	81.37	81.99	89.57	99.99

* Contaminated with glucosamine.

[1] Run on Durnum Microbore DC-4A resin to distinguish glucosamine.

Corrected protein values, however, were calculated as averages from several samples while amino acid analyses were made on a single sample.

VIII. EXPERIMENTAL DESIGN AND METHODS

Three hundred and eighty mink kits were randomly allotted into seven groups such that no littermates of the same sex were in the same group. Groups 3A through 3F each initially consisted of 20 each standard dark males and females and 10 each sapphire males and females. Group 3G initially contained 20 standard dark males. All animals were caged individually in conventional wire pens raised above ground with nest boxes and free access to water.

Composition and analyses of rations fed ad libitum once daily to each group from July 28 (August 1 for 3G) until pelting in early December (Appendix Table I) are summarized in Tables 15 and 16. Each morning feed left from the previous day was redistributed between all animals within each group. Unconsumed feed was picked up and the amount recorded before refeeding.

Untreated shrimp waste was fed as 25 percent of the control diet replacing over 45 percent of the fish carcass. At this level the shrimp accounted for approximately 10 percent of the dietary protein. Experimental materials in groups 3C through 3G replaced approximately isonitrogenous quantities of fish carcass; other feed ingredients were held constant across all groups. In 3C and 3D, SM and SSM, respectively, were included at a level approximating 10 percent of the dietary protein. In groups 3E, 3F and 3G, SSM, SM, and CPC respectively replaced approximately 20 percent of the dietary protein. The amount of dried shrimp, wet weight basis, included in rations 3C through 3F varied directly with moisture content since the percentage of dry matter was not uniform between dried shrimp batches.

TABLE 15. COMPOSITION OF CONTROL AND EXPERIMENTAL RATIONS (as fed).[1]

Ingredient (%)	Group 3A	3B	3C	3D	3E	3F	3G
Chicken offal	25	25	25	25	25	25	25
Tripe	10	10	10	10	10	10	10
Fish carcass	55	30	47	47	39	39	39
Fresh shrimp		25					
Shrimp meal[2]			4.40			8.80	
Sieved shrimp[2]				3.85	7.70		
Crab protein conc.[2]							2.75
Oat groats	8	8	8	8	8	8	8
Wheat bran	2	2	2	2	2	2	2
Water (Difference)[3]	___	___	VAR	VAR	VAR	VAR	VAR
Total	100	100	100	100	100	100	100
Water[4]	10	10	10	10	10	10	10
Total + Water	110	110	110	110	110	110	110

[1] Vitamin E included at 5 IU/pound of feed.
[2] Dry matter basis.
[3] Amount of water added to bring total % up to 100 varied with the moisture content of the experimental materials.
[4] Rations were mixed with 10% water to adjust consistency.

TABLE 16. MEAN PROXIMATE ANALYSES OF CONTROL AND EXPERIMENTAL RATIONS.[1]

Component	Group (Percent, dry matter basis)						
	3A	3B	3C	3D	3E	3F	3G
Dry matter	32.68	28.51	34.46	34.00	34.17	34.59	34.94
Crude protein	33.22	34.23	34.30	34.52	34.25	33.29	35.64
Calculated corrected protein	33.22	33.50	33.43	34.05	33.35	31.64	35.64
Ether extract	28.69	20.70	21.89	22.33	19.50	19.23	26.32
Ash	9.27	11.48	12.08	11.64	11.87	12.45	8.01
Acid detergent fiber	2.15	4.91	4.96	3.85	4.86	6.21	2.17
Calcium	1.08	1.56	1.84	1.28	2.20	4.84	0.87
Phosphorus	1.54	1.31	1.49	1.52	1.40	1.39	1.13
Ca/P	0.70	1.19	1.23	0.84	1.57	3.48	0.77

[1] Analyses made on three or more duplicate samples.

Additional water was added to rations 3C through 3G in order to adjust consistency and raise total ingredients to 100 percent on a wet weight basis.

Data examined included final weights; average daily weight gain; average feed, protein and fat consumption; feed efficiency; pelt color and quality; and pelt length and weight. Pelt color and quality ratings (1 = best to 4 = poor) were assigned to each pelt by professional fur graders. Wet belly (WB) severity ratings were designated as follows: 0 = normal pigmented area, 1 = WB damage less than one inch diameter, 2 = WB damage one to two inches diameter, 3 = WB damage over two inches diameter. Mink were weighed at four week intervals until pelting in December when final weights were taken. Daily feed consumption records were kept for each group and for dark males in groups 3A, 3E and 3F. To simplify statistical analysis of the data, the number of animals in each group was made uniform by random selection. Uneven sample sizes resulted from widespread mortality during the experiment which did not appear related to treatment effects. Results were analyzed by one and two-way analysis of variance and Newman-Keuls test for comparison of treatment means. A t-test was used for comparing SM against SSM. Simple linear regression analysis was used to evaluate the effects of dietary fat on final weights.

IX. RESULTS

A. Growth and Feed Consumption

Average performance of each group is summarized in Tables 17 - 20; Figures 7 - 10 depict mean growth response. Final weights and average weight gain per day differed significantly ($P<.01$) in both dark and sapphire mink (Table 21). In one-way analysis, only sapphire females did not show a significant difference between treatments. Carcass lengths of dark males and females considered together also differed significantly ($P<.05$), but not when taken separately. Possibly owing, in part, to small sample size (due to the selection of breeder mink from experimental groups), carcass length differences in sapphire mink were not found to be significant between groups.

Clearly the control diet (3A) resulted in the highest final weights and greatest weight gains across both sexes and strains. Moreover, groups offered diets low in shrimp waste (3B, 3C, 3D) generally showed better growth than those fed higher amounts (3E and 3F). It is important to note that no attempt was made in this experiment to balance fat levels between treatments. Increased amounts of shrimp in the diet were accompanied by decreased fat and hence energy levels, since the shrimp contained a lower percentage of fat than the fish carcass it replaced. Although dietary fat differed by as much as eight percent of the total ration dry matter between control and experimental diets, caloric densities were considered sufficient for good growth in all groups. Nevertheless, relatively small differences in fat content of the diet have been found to affect final body weight of pelter mink (Stout *et al.* 1965); therefore,

TABLE 17. PERFORMANCE OF STANDARD DARK MALES.[1]

Item	Group 3A	3B	3C	3D	3E	3F	3G
Mink (no.)	20 (17)	20 (17)	19 (17)	20 (17)	18 (17)	19 (17)	18 (17)
Final body weight (g)	2423 (2444)[a]	2229 (2238)[bc]	2334 (2300)[ac]	2337 (2359)[ac]	2202 (2205)[bc]	2007 (2006)[b]	2351 (2336)[ac]
Standard deviation	225	272	255	246	266	270	280
Average weight gain/day (g)	7.70 (7.86)[a]	6.79 (6.77)[a]	7.20 (7.07)[a]	7.53 (7.63)[a]	6.66 (6.68)[a]	4.97 (4.60)[b]	6.64 (6.60)[a]
Standard deviation	1.36	1.52	1.60	1.20	1.54	1.43	1.78
Carcass length (cm)	45.7 (45.7)[a]	44.6 (44.7)[a]	45.5 (45.1)[a]	46.2 (46.2)[a]	45.3 (45.2)[a]	44.8 (44.8)[a]	44.9 (44.8)[a]
Standard deviation	1.19	1.40	1.59	1.33	1.29	1.67	1.89
Pelt length (cm)	76.3 ± 2.45	73.3 ± 4.07	74.9 ± 3.89	75.5 ± 4.09	72.8 ± 4.06	70.1 ± 4.08	74.9 ± 4.42
Dry pelt weight (g)	137.3 ± 13.4	125.9 ± 14.9	130.3 ± 14.6	130.1 ± 12.5	120.6 ± 13.9	111.7 ± 13.4	132.4 ± 20.8
Fur color	2.35 ± 0.85	2.45 ± 0.74	2.53 ± 0.60	2.40 ± 0.58	2.44 ± 0.49	2.58 ± 0.49	2.17 ± 0.60
Fur quality	1.20 ± 0.51	1.35 ± 0.66	1.32 ± 0.65	1.20 ± 0.41	1.28 ± 0.45	1.42 ± 0.58	1.28 ± 0.45
WB incidence (%)	95.0	95.0	84.2	70.0	89.5	63.2	94.4
WB severity[2]	2.26	2.21	2.38	1.67	2.24	1.92	2.23

[1] Mean ± Standard deviation. Values in parentheses are those derived from even sample sizes used in data analysis. Means not followed by same superscript differ significantly ($P<.05$).

[2] Sum of wet belly ratings divided by the number of WB mink in the group.

TABLE 18. PERFORMANCE OF STANDARD DARK FEMALES.

Item	Group					
	3A	3B	3C	3D	3E	3F
Mink (no.)	19 (17)	19 (17)	19 (17)	17 (17)	18 (17)	20 (17)
Final body weight (g)	1344 (1357)[a]	1228 (1245)[ab]	1113 (1113)[bc]	1161 (1161)[bc]	1128 (1141)[bc]	1076 (1070)[c]
Standard deviation	158	138	117	149	136	212
Average weight gain/day (g)	3.43 (3.49)[a]	2.70 (2.86)[ab]	1.97 (2.02)[bc]	2.23 (2.23)[bc]	1.81 (1.87)[c]	1.73 (1.70)[c]
Standard deviation	1.05	0.80	0.76	0.69	0.65	0.96
Carcass length (cm)	38.2 (38.3)[a]	38.1 (38.1)[a]	37.8 (37.8)[a]	38.0 (38.0)[a]	37.9 (38.0)[a]	37.3 (37.1)[a]
Standard deviation	1.21	1.12	1.02	2.57	1.27	1.68
Pelt length (cm)	61.4 ± 2.75	59.3 ± 2.51	57.1 ± 2.44	57.8 ± 3.05	61.4 ± 3.47	56.3 ± 4.07
Dry pelt weight (g)	71.2 ± 6.7	65.0 ± 5.4	64.9 ± 6.1	63.6 ± 6.3	68.5 ± 5.1	61.4 ± 8.7
Fur color	2.53 ± 0.60	2.25 ± 0.62	2.05 ± 0.76	2.41 ± 0.49	2.61 ± 0.68	2.55 ± 0.50
Fur quality	1.68 ± 0.56	1.55 ± 0.50	1.21 ± 0.40	1.41 ± 0.50	1.39 ± 0.45	1.45 ± 0.59
WB incidence (%)	10.5	0	5.3	0	0	0
WB severity	2.20	0	1.0	0	0	0

TABLE 19. PERFORMANCE OF SAPPHIRE MALES.

Item	Group 3A	3B	3C	3D	3E	3F
Mink (no.)	10 (9)	10 (9)	10 (9)	10 (9)	9 (9)	10 (9)
Final body weight (g)	2450 (2460)[a]	2241 (2251)[ab]	2340 (2346)[a]	2311 (2287)[a]	2101 (2101)[ab]	1774 (1733)[b]
Standard deviation	133	421	268	363	380	328
Average weight gain/day (g)	9.95 (10.14)[a]	8.74 (8.76)[a]	9.02 (8.99)[a]	9.13 (8.74)[a]	7.64 (7.63)[ab]	4.57 (4.32)[b]
Standard deviation	3.27	2.50	1.43	2.39	2.57	2.18
Carcass length (cm)[1]	4.72 (47.2)[a]	46.2 (46.3)[a]	4.70 (46.9)[a]	4.68 (46.6)a	46.6 (46.9)[a]	45.5 (45.4)[a]
Standard deviation	0.82	1.46	1.45	1.19	1.32	1.13
Pelt length (cm)	76.9 ± 4.35	73.4 ± 4.50	76.6 ± 1.39	74.4 ± 4.59	70.8 ± 4.18	67.6 ± 4.26
Dry pelt weight (g)	126.1 ± 14.7	114.7 ± 12.5	118.3 ± 12.0	120.7 ± 12.5	106.9 ± 12.3	99.8 ± 13.5
Fur quality[1]	1.67 ± 0.47	1.33 ± 0.47	1.33 ± 0.47	1.40 ± 0.49	1.50 ± 0.71	1.11 ± 0.32

[1] Sample size used in data analysis was 7 due to the selection of breeder mink out of experimental groups.

TABLE 20. PERFORMANCE OF SAPPHIRE FEMALES.

Item	Group					
	3A	3B	3C	3D	3E	3F
Mink (no.)	10 (9)	9 (9)	10 (9)	10 (9)	9 (9)	9 (9)
Final body weight (g)	1294 (1296)[a]	1252 (1252)[a]	1182 (1158)[a]	1236 (1208)[a]	1176 (1176)[a]	1213 (1213)[a]
Standard deviation	145	169	216	200	208	153
Average weight gain/day (g)	4.04 (4.11)[a]	3.46 (3.46)[a]	2.93 (2.86)[a]	3.45 (3.19)[a]	2.86 (2.86)[a]	2.92 (2.92)[a]
Standard deviation	0.91	1.21	1.11	1.30	1.00	1.17
Carcass length (cm)[1]	38.7 (38.8)	39.1 (39.2)	39.3 (39.1)[a]	39.0 (38.9)[a]	38.9 (38.9)[a]	39.6 (39.6)[a]
Standard deviation	0.72	1.11	1.71	1.65	1.40	1.27
Pelt length (cm)	60.8 ± 2.08	60.5 ± 2.92	59.6 ± 4.74	60.2 ± 3.88	58.1 ± 3.81	59.1 ± 2.70
Dry pelt weight (g)	64.0 ± 3.7	61.9 ± 4.3	63.8 ± 6.0	63.6 ± 7.2	61.6 ± 8.3	62.0 ± 4.2
Fur quality	1.13 ± 0.32	1.00 ± 0	1.25 ± 0.66	1.00 ± 0	1.00 ± 0	1.29 ± 0.46

[1] Sample size used in data analysis was 7 due to the selection of breeder mink out of experimental groups.

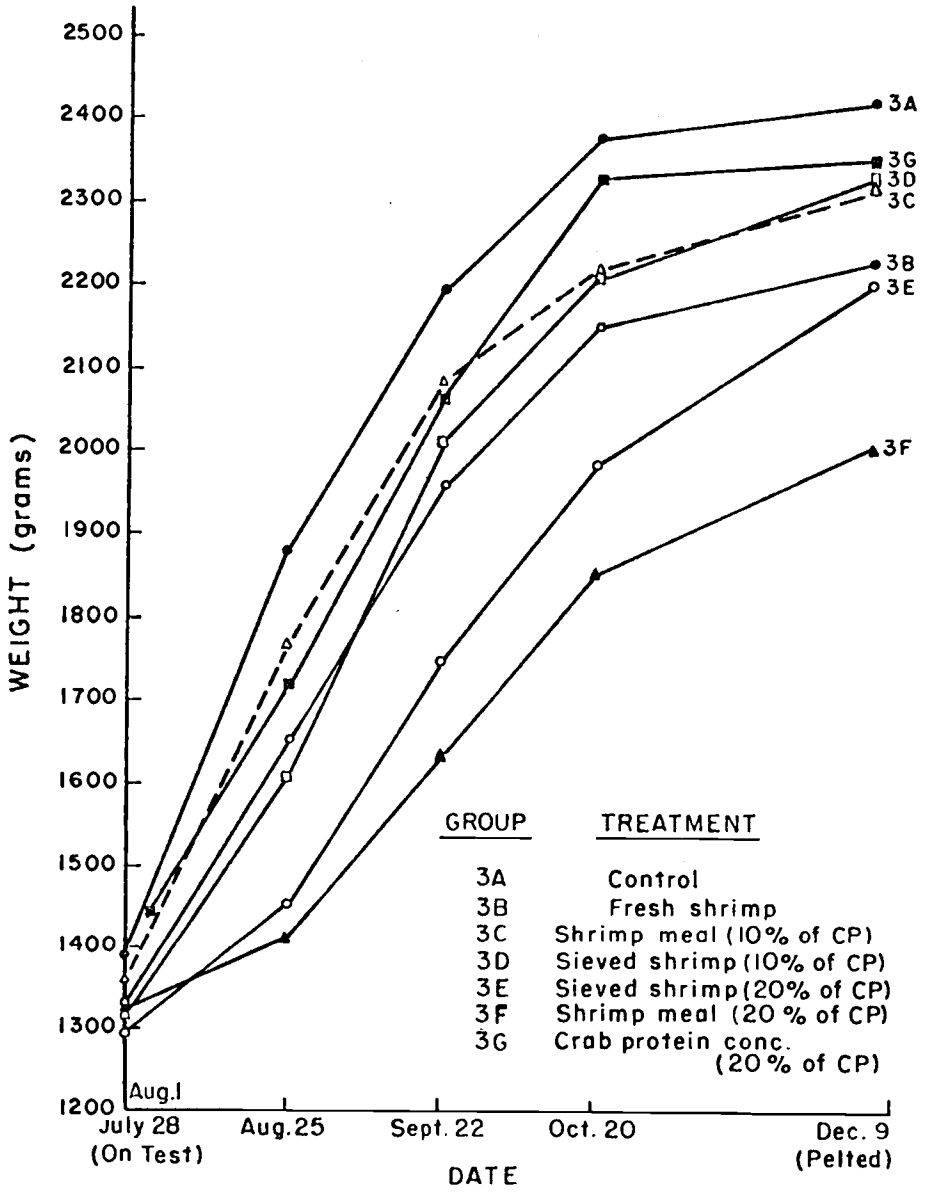

Figure 7. Mean growth response of standard dark males.

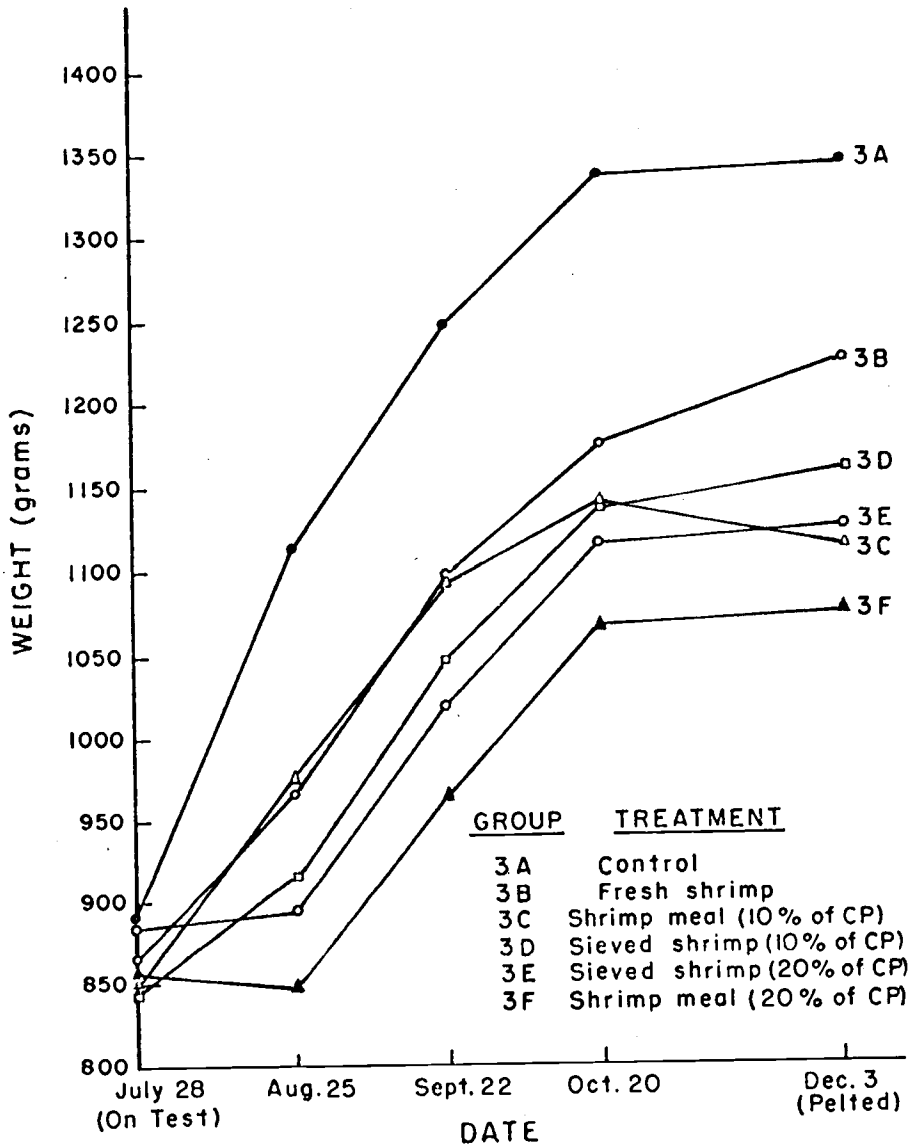

Figure 8. Mean growth response of standard dark females.

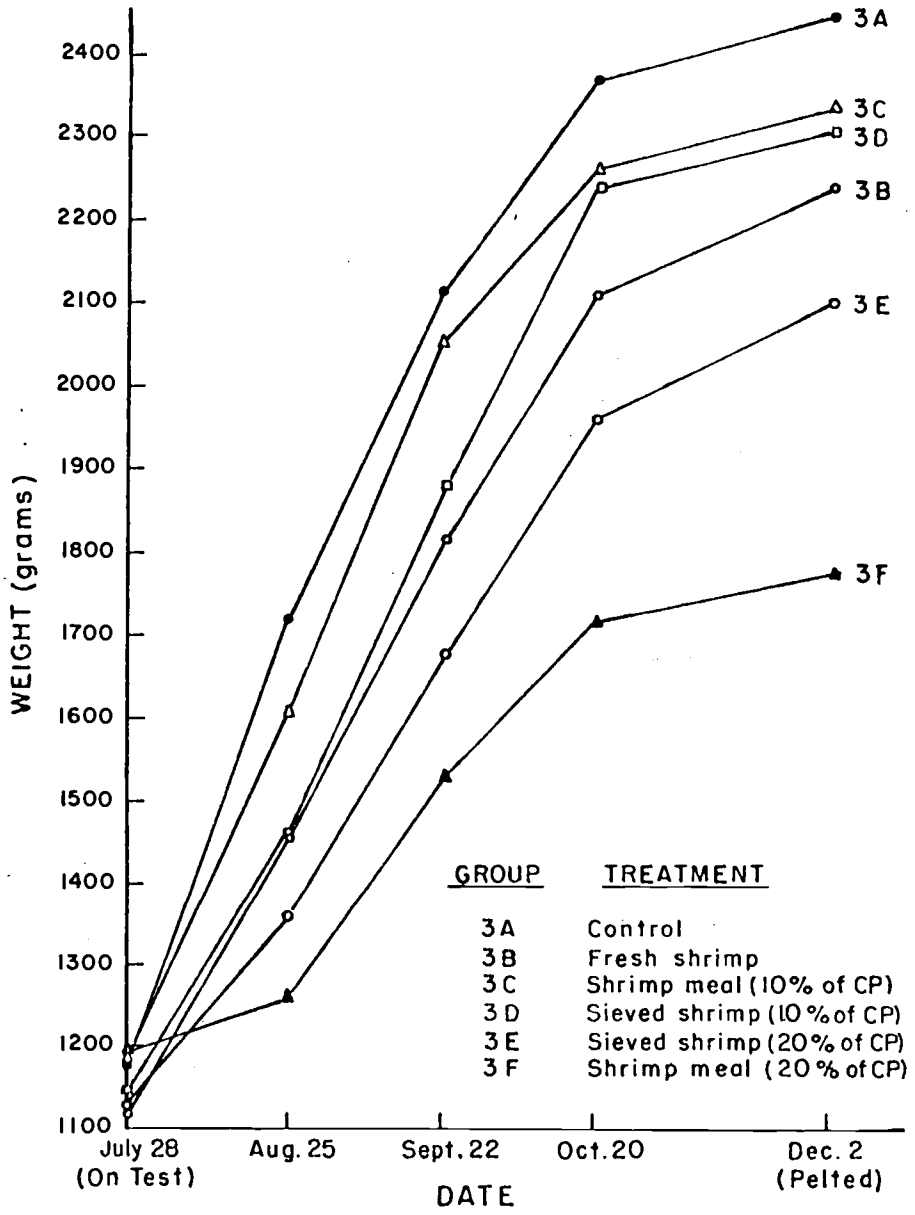

Figure 9. Mean growth response of sapphire males.

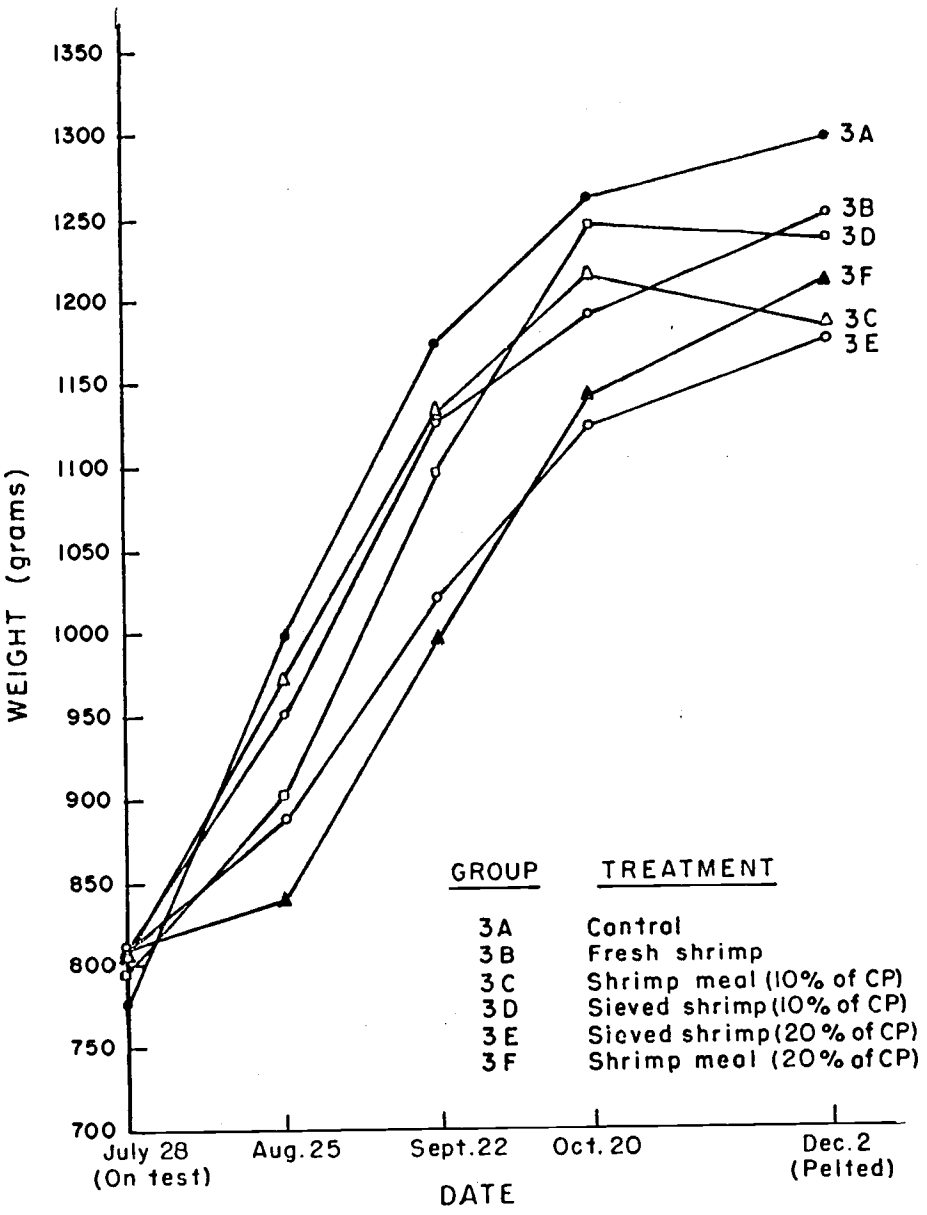

Figure 10. Mean growth response of sapphire females.

TABLE 21. F-VALUES FROM ANALYSIS OF VARIANCE.

	Final Weight	Average Weight Gain Per Day	Carcass Length
Two-Way Classification			
Dark males and females (3A-3F)	10.02*	16.35*	2.68**
Sapphire males and females (3A-3F)	3.41*	5.85*	0.28
One-Way Classification			
Dark males (3A-3G)	4.67*	7.90*	2.14
Dark females (3A-3F)	7.15*	11.82*	1.26
Sapphire males (3A-3F)	3.65*	5.17*	1.60
Sapphire females (3A-3F)	0.61	1.60	0.23

* Significant at ($P<.01$).

** Significant at ($P<.05$).

spurious conclusions may result if body weights are only directly compared across different fat densities without considering variability attributed to dietary fat level (see Section X). Specific comparisons, however, can be made between those treatments having similarly reduced fat levels (3C and 3D; 3E and 3F).

Average daily feed, protein and fat consumption per mink and feed efficiency for each group and for dark males in groups 3A, 3E, 3F and 3G are summarized in Tables 22 and 23. All diets containing experimental materials were readily consumed by the animals, although mink in group 3B sorted out and rejected a considerable quantity of the larger shell fragments contained in the untreated shrimp waste (Figure 11). Overall group feed consumption and dark male feed consumption showed a close inverse relationship to dietary fat level -- an expected result since mink, like other monogastrics, generally eat to satisfy their energy requirements. Average feed consumption decreased during the course of the experiment in 3A but tended to increase in the shrimp waste groups (Appendix Tables IV and V) suggesting adjustment and adaptation to the waste containing diets.

Group 3B. Unlike other materials tested larger shell fragments in the untreated waste were subject to sorting. As a result the relative percentages of other components in the diet (which were higher in fat) were increased; thus, depending on the degree of sorting, the composition of the diet as offered differed from that consumed by the mink.

The amount of shell rejected appeared to vary between individuals. Evidence that mink were not selecting out all the shell was easily

TABLE 22. AVERAGE FEED, PROTEIN AND FAT CONSUMPTION PER MINK PER DAY, GROUPS 3A-3F (grams).

	Group					
	3A	3B	3C	3D	3E	3F
As fed						
Feed intake	253.1	330.2	267.6	257.6	274.6	292.1
Dry basis						
Feed intake	82.7	94.1	92.2	87.6	93.8	101.0
Feed/gain	13.6	17.9	18.2	15.9	21.5	29.1
Protein intake	27.5	31.5	30.8	29.8	31.3	31.9
Fat intake	23.7	19.5	20.2	19.6	18.3	19.4

TABLE 23. AVERAGE FEED, PROTEIN AND FAT CONSUMPTION PER DARK MALE MINK PER DAY, GROUPS 3A, 3E, 3F and 3G (grams).

	Group			
	3A	3E	3F	3G
As fed				
Feed intake	266.7	333.4	325.2	276.2
Dry basis				
Feed intake	87.2	113.9	112.5	96.5
Feed/gain	11.3	17.1	22.6	14.5
Protein intake	29.0	38.0	35.0	34.4
Fat intake	25.0	22.0	21.6	25.4

Figure 11. Sorted shrimp shell beneath group 3B mink pen.

verified by inspection of feces containing profuse exoskeletal fragments. Although the exact amount of shell consumed was not measured, performance data suggests female mink were more efficient than males at separating out shell. Final weights and weight gain of 3B dark females did not differ significantly, unlike all other groups, from those in the control. Similarly, final weights and weight gain of 3B sapphire females were closer to those in the control than were the other groups. Conversely, weight gain and final weights of 3B male mink of both strains were generally below those for 3C and 3D, and in dark males 3B final weights differed significantly ($P<.05$) from those in the control.

Apparent feed consumption by group 3B was the second highest of any of the groups. This was probably due to the combined effects of low dietary fat and animals eating around exoskeletal matter. The relatively low feed/gain ratio was primarily the result of good growth made by females. Growth of males was considerably poorer than that of females relative to their respective sex in the other groups and more in keeping with fat level of the diet as offered (see Section X).

Groups 3C and 3D. Drying and grinding shrimp waste prevented mink from separating out shell particles and therefore allowed clearer evaluation of waste material in the diet. Weight gain per day between groups 3C and 3D did not differ significantly in either sex or strain (Table 24). Final weights and carcass lengths were also very similar in both groups. Weight gains and final weights in 3C and 3D differed significantly ($P<.05$) from the control (3A) only in dark females. Also only in dark females did 3B result in better growth. For an

TABLE 24. SHRIMP MEAL VERSUS SIEVED SHRIMP
t-values for average weight gain per day.

	Dark Males	Dark Females	Sapphire Males
3C versus 3D	-0.83	-0.87	-0.69
3E versus 3F	3.52*	0.49	2.80**

* Significant at ($P<.01$).

** Significant at ($P<.05$).

unknown reason 3C females of both strains showed a marked decrease in weight, -27 and -32 grams average respectively, for darks and sapphires during the final five weeks of the experiment (Appendix Table II).

Lower feed consumption by group 3D than 3C was reflected in better feed efficiency on the SSM diet. Protein and fat intakes did not differ appreciably between the two groups, however, as less waste material was required to replace 10 percent of the dietary protein in 3D than 3C.

Groups 3E and 3F. Unlike results obtained from 3C and 3D, when shrimp waste was offered at a replacement level approximating 20 percent of the dietary protein, the SSM (3E) produced significantly greater weight gains per day than the SM (3F) in dark males ($P<.01$) and sapphire males ($P<.05$). That females did not show a significant difference between treatments may be due to their small size as compared to males.

In comparison with the other groups, 3F final weights and weight gains were significantly lower ($P<.05$) than the control in dark males and females, 3C, 3D, and 3G in males, and 3B in dark females. In contrast, 3E final weights and weight gain of dark females and final weights of dark males differed significantly ($P<.05$) only from the control, with the exception of dark female weight gains which also differed significantly ($P<.05$) from those of 3B dark females.

Reduced growth rate in 3E and 3F was most apparent during the first four weeks of the experiment (Appendix Table III). Many mink, especially in 3F, actually lost weight during this period. Growth rates during the remainder of the trial more closely corresponded to

those in the other groups. Diets relatively low in fat might be expected to have their most pronounced effects on early growth (Sinclair et al. 1962). The extremely retarded growth rate given by 3F during the first month, however, suggests additional factors may be involved (see Section X).

Average daily feed consumption per mink in group 3E was 7.1 percent lower than in 3F. Feed consumption by dark males was very similar in both groups. Feed efficiency was appreciably better in group 3E primarily reflecting the significantly greater weight gains obtained on the SSM diet. Protein and fat intakes were similar between the two groups overall, but were somewhat lower in 3F dark males than 3E dark males.

At a replacement level approximating 20 percent of the dietary protein the reduction in chitin and minerals due to sieving indeed appears to have a beneficial effect on body growth and feed efficiency. This effect being due, in part, to the lesser amount of SSM which must be added to the diet in order to replace the desired amount of protein and also to the lower percentages of ash and chitin in the sieved material.

Group 3G. The CPC was the most refined material tested in terms of low chitin and mineral content. Some batches of CPC appeared scorched and thus protein quality may have been reduced by heat damage. Nevertheless, weight gain and final weights did not differ significantly from the control (3A). Final weights were nearer to the controls than were those in any of the other treatments. Weight gain per day may have been somewhat low because the on-test date was four days

later than that of the other groups and the animals were relatively large at this time.

The CPC diet was readily accepted by the mink even when scorched appearing material was offered. Feed consumption averaged 9.3 grams more per dark male mink per day than in the control, but fat intakes between the two groups were almost identical.

B. Fur and Pelt Characteristics

Fur color and quality of dark males tended to be slightly poorer in the shrimp waste groups with ratings becoming higher[1] as the level of waste supplementation increased. Group 3G received the best color ratings. Dark females generally showed just the reverse with 3A receiving high ratings, although fur color and quality still appeared to decrease when higher levels of shrimp waste were offered. Fur quality of sapphires was generally best on the experimental diets. From these results, shrimp waste appears to have little if any adverse effect on fur characteristics when offered at low levels, but may reduce color and quality of dark mink when larger quantities are fed.

Shrimp waste evaluated in this study was obtained from a processing plant equipped with Laitram PCA peelers, wherein shrimp were cooked for three minutes using live steam prior to generating any waste. It is of interest to speculate how fur color and quality may have been affected if raw, uncooked shrimp waste had been fed. Pink shrimp contain formaldehyde and trimethylamine oxide (Argaiz 1976) -- compounds which have been implicated in causing cotton-fur syndrome

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[1] Note: Higher ratings denote poorer color and quality.

in mink by interfering with the absorbtion of iron (Costely 1970, Ender et al. 1972). When fish, such as Pacific hake (Merluccius productus), containing these compounds are cooked, the interfering effect is no longer evident (Stout et al. 1960). It is therefore possible mink fed uncooked shrimp waste might show significantly inferior fur color and quality whereas experimental groups in this study did not.

Pelt lengths and weights varied directly with final body weights. Although pelt measurements were not subjected to statistical analysis, by inspection analysis on final body weights probably provides an adequate index to pelt length and weight differences between groups. Less relationship was evident between pelt measurements and carcass lengths. Stout et al. (1965), Allen et al. (1963) and others have similarly reported body weight to be a good and better index of pelt length and weight than body length.

C. General Condition

No abnormal conditions occurred in any of the groups. Unusually high mortality during the experiment was widespread throughout the OSU farm for an unknown reason; hence, losses in shrimp and crab groups were probably not a result of experimental treatments. Urinary calculi were not detected in any animals, even though high mineral diets which increase the pH of the urine have been reported to favor this condition in mink (Gorham et al. 1972). Increased or unusual pigmentation in the pelt or flesh also was not noticed, suggesting mink lack the ability to use astaxanthin directly as a pigment source.

Wet belly incidence in dark males was not significantly correlated to final body weight (Figure 12). Previous work at OSU has shown the occurrence of wet belly in genetically susceptible mink to be highly related to final body weight in a linear manner (Stout and Adair 1972). Travis et al. (1961) and Schaible et al. (1962) reported wet belly incidence to also be enhanced when high calcium diets (1.03 and 1.25 percent) were offered. Stout et al. (1963) found a significant positive correlation between wet belly incidence and Ca:P ratio. In the present study group 3F which had the highest Ca:P ratio (3.48:1) had the lowest incidence of wet belly. Interaction between fat and calcium levels may have served to confound relationships as reported in previous studies. Also the large size of male mink obtained in this experiment and possible differences in genetic susceptibility may have been influential.

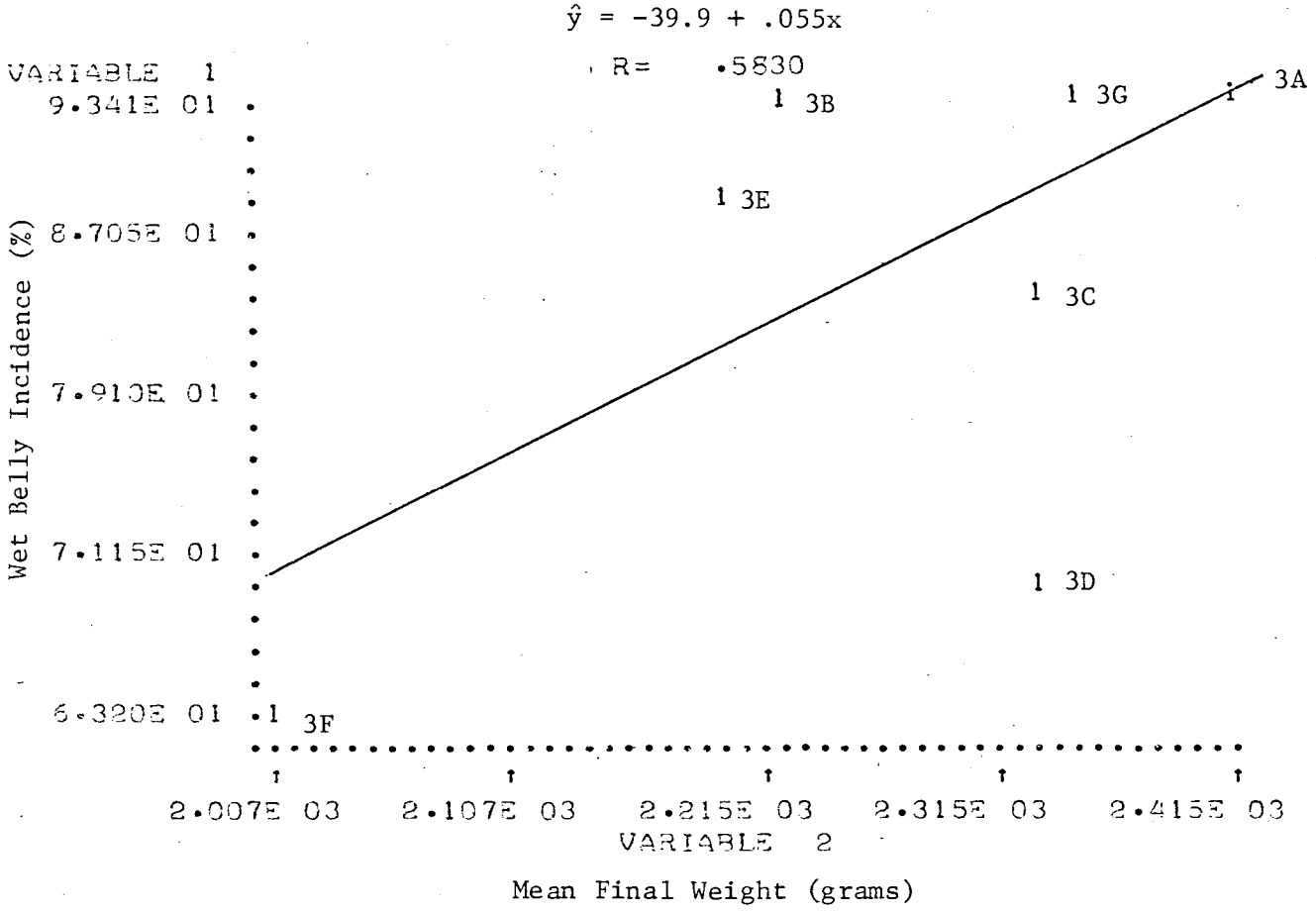

Figure 12. Regression on standard dark male data: Wet belly incidence on mean final weight (axes labeled in scientific notation).

X. DISCUSSION

A. Protein

Above a certain level in the diet, protein exerts little if any influence on final body weights of mink (Stout et al. 1963, Stout et al. 1965, Kumeno et al. 1970). Assuming good protein quality, this level appears dependent primarily on energy density of the diet since high fat rations result in lowered feed consumption, and hence reduced protein intake, and low fat rations result in increased utilization of protein for energy purposes. Based on work by Stout et al. (1963), NRC (1968) recommended, in general, 25 percent protein as the minimum level for maximum body growth and fur production of mink. Bassett et al. (1951a) reported protein deficient diets resulted in poor general condition, reduced growth and impaired fur development (From NRC 1968).

It is doubtful protein level and availability appreciably affected final body weights on experimental diets in the present study. Based on studies with rats (Section VI, B) and amino acid analyses (Section VII, D) the digestibility and essential amino acid content of crustacean proteins at the levels offered were probably sufficient, in combination with other protein sources in the diet, to fulfill protein requirements. Except during the first stage of the experiment, protein intakes on the shrimp and crab diets were higher than on the control diet, due to increased feed consumption. Animals in all groups displayed normal fur development and good general condition.

B. Fat

Dietary fat level has been shown to have a definite influence on final body weight of pelter mink. Sinclair et al. (1962) reported high energy diets to be superior to low energy diets in their ability to promote early growth of both male and female standard dark mink and to result in increased final weights of males. Allen et al. (1963) reported similar results. In both studies final weights of female mink were found to be less influenced by energy level of the diet. Using simple correlation coefficients to evaluate the effects of various dietary components on final weight of standard dark mink, Stout et al. (1965) found fat level to have the greatest influence ($R = 0.35$) over the range of variables tested. These results indicated a one percent increase in dietary fat level could increase final body weight of male mink by 25 grams. Farrell and Wood (1966) found a significant correlation ($R = 0.80$) between body weight of adult female mink exhibiting weight stasis and apparent digestible energy intake.

In order to evaluate the influence of dietary fat level on final weight in the present experiment, results were subjected to regression analysis and compared to previous Oregon State University Experiment Station data (Figures 13 - 19, Table 25).

Previous data. Mean final weights of standard dark male and female mink from 31 male groups (representing 429 animals) and 30 female groups (representing 399 animals) from studies conducted at the OSU Experimental Fur Farm between 1961 and 1974, were regressed on the percentage of dietary fat of their respective rations. All groups from experiments conducted at the station received consideration but

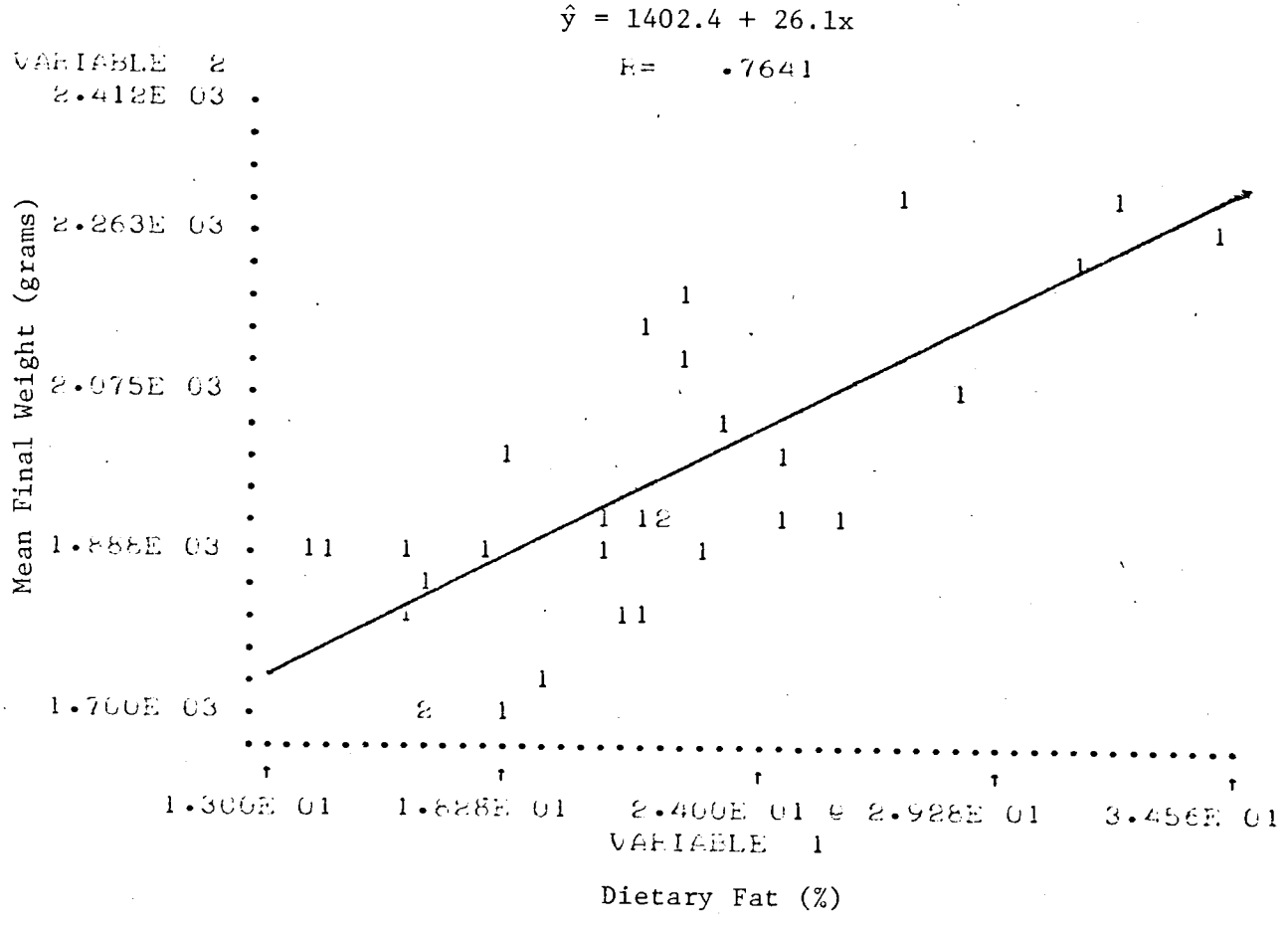

Figure 13. Regression on past standard dark male data: Mean final weight on dietary fat level.

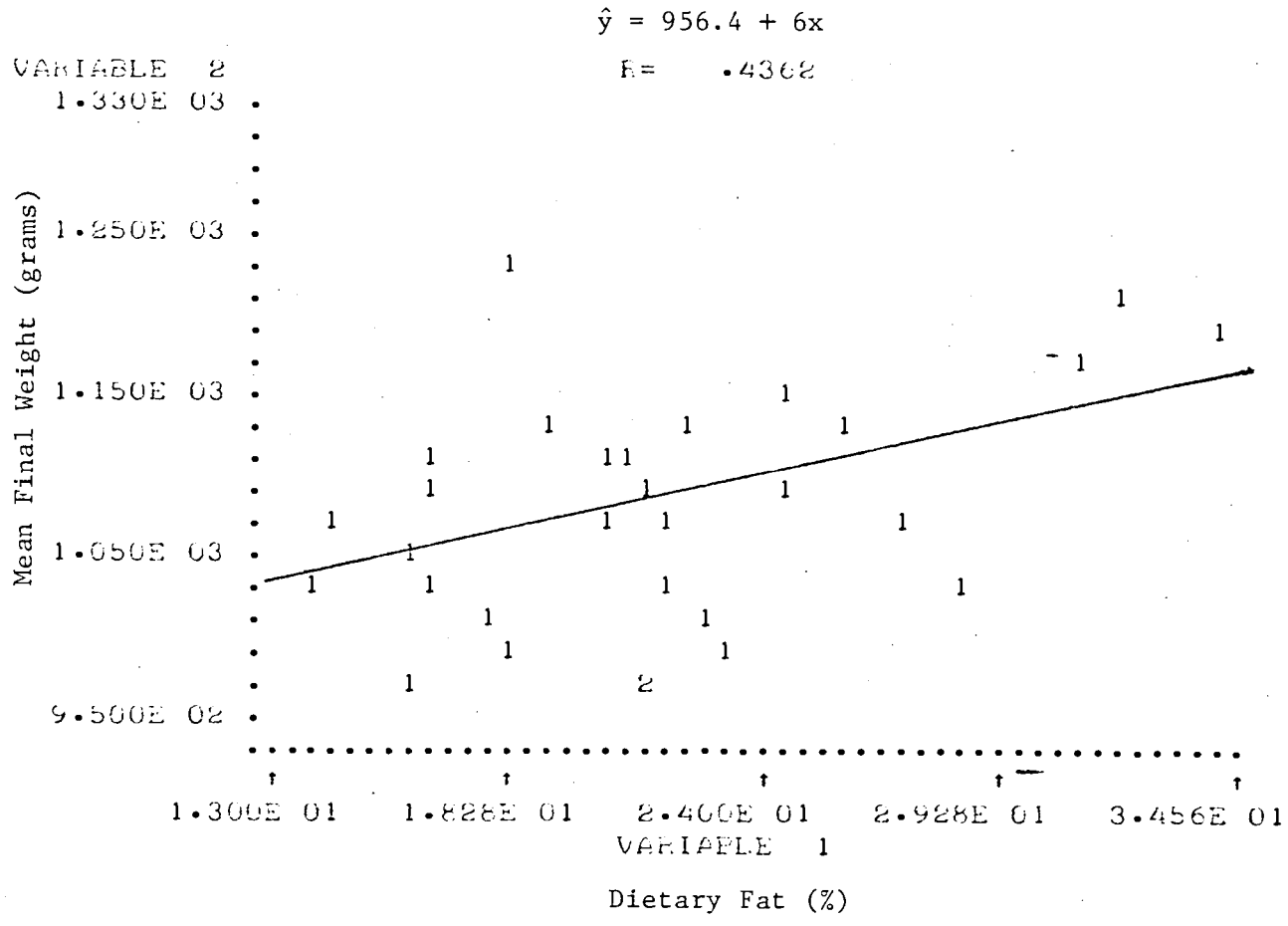

Figure 14. Regression on past standard dark female data: Mean final weight on dietary fat level.

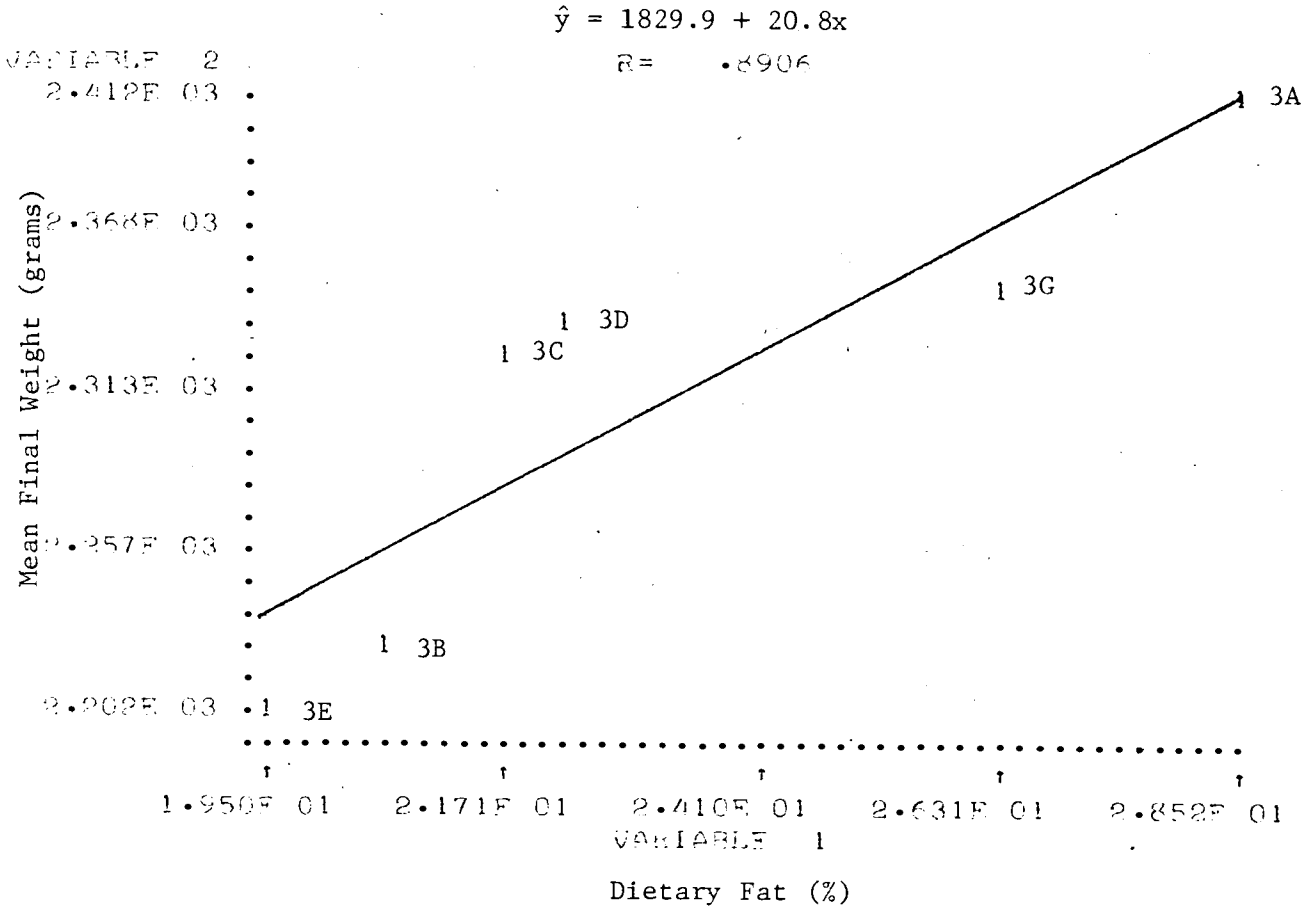

Figure 15. Regression on present standard dark male data: Mean final weight on dietary fat level.

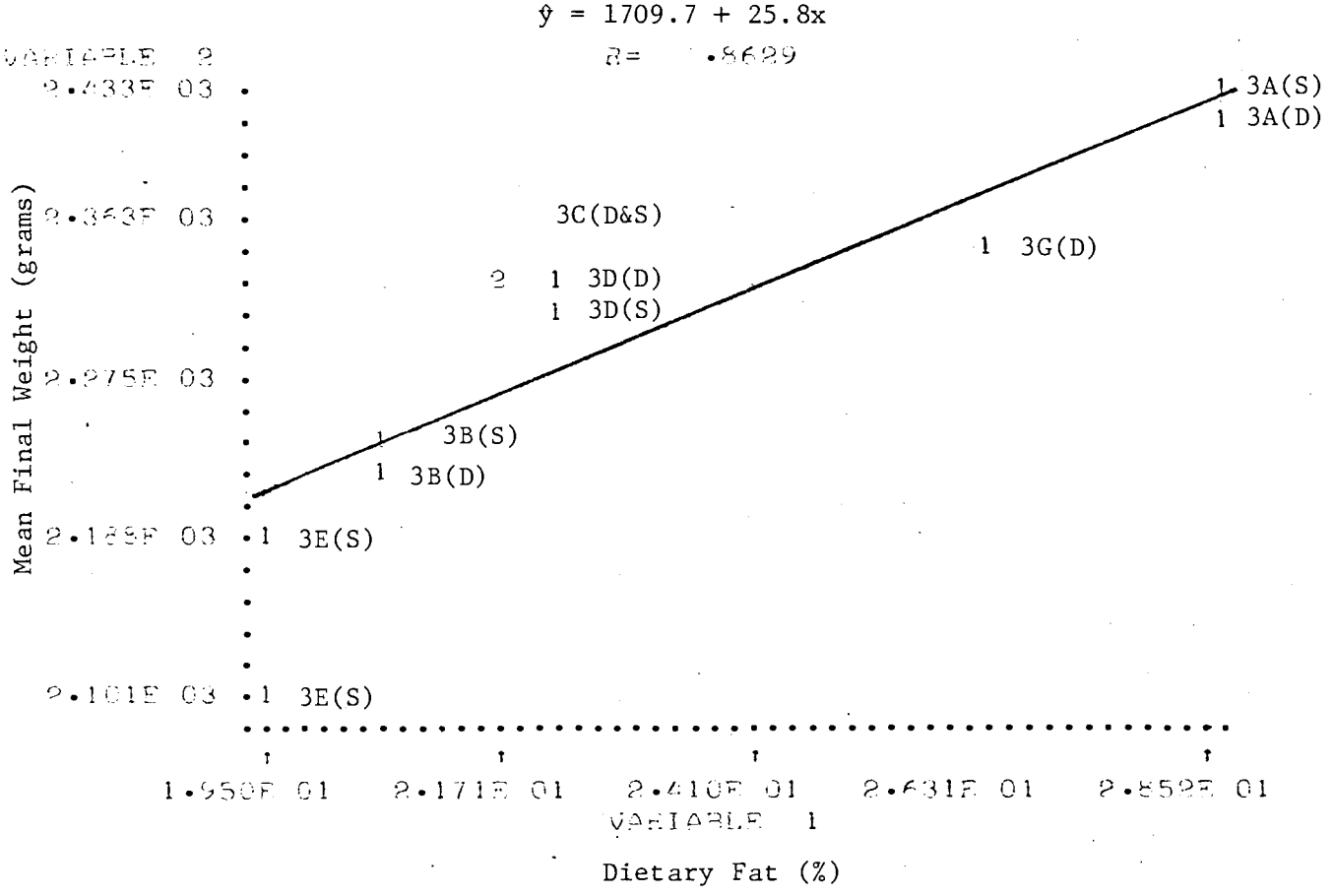

Figure 16. Regression on present standard dark (D) and sapphire (S) male data: Mean final weight on dietary fat level.

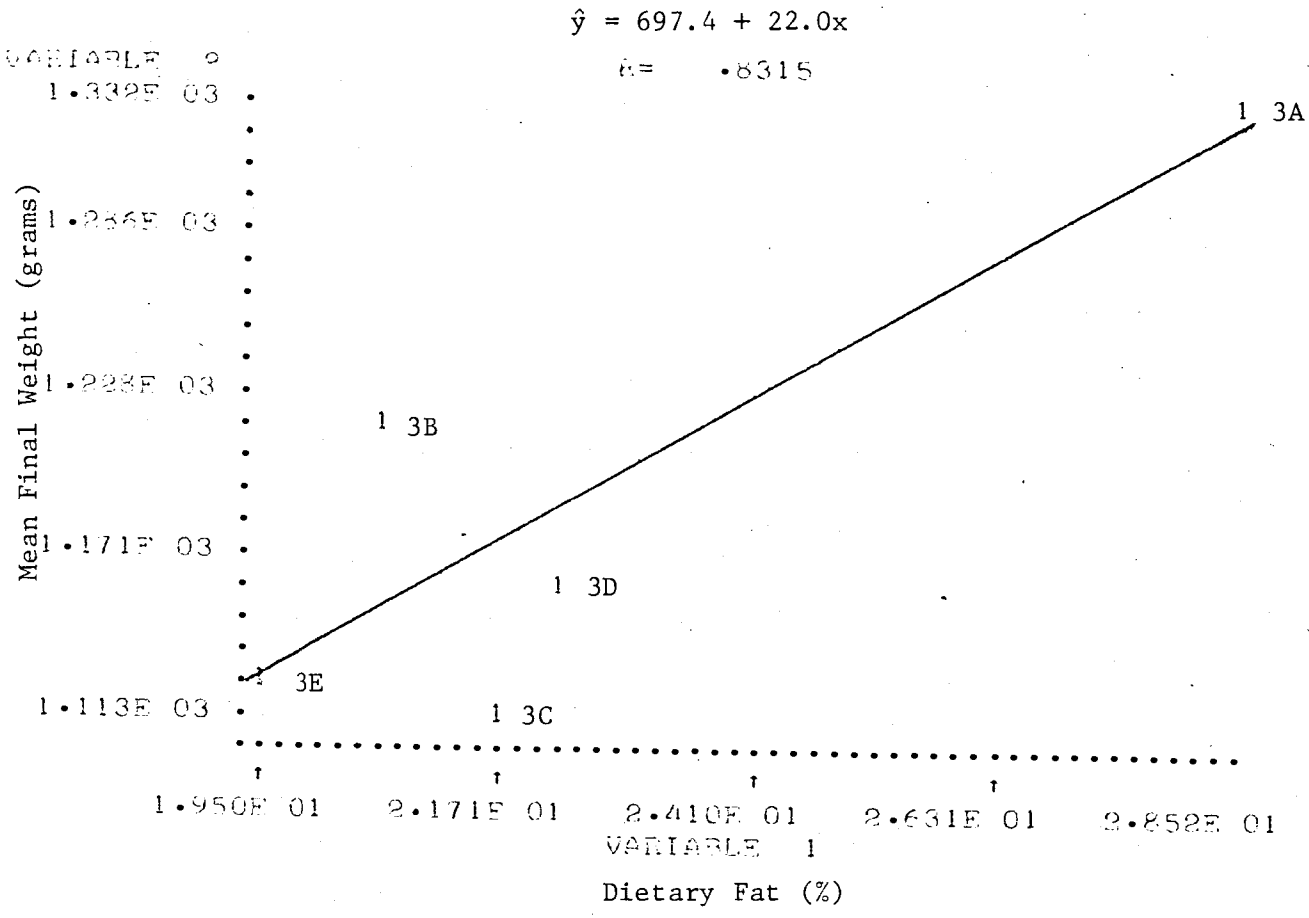

Figure 17. Regression on present standard dark female data: Mean final weight on dietary fat level.

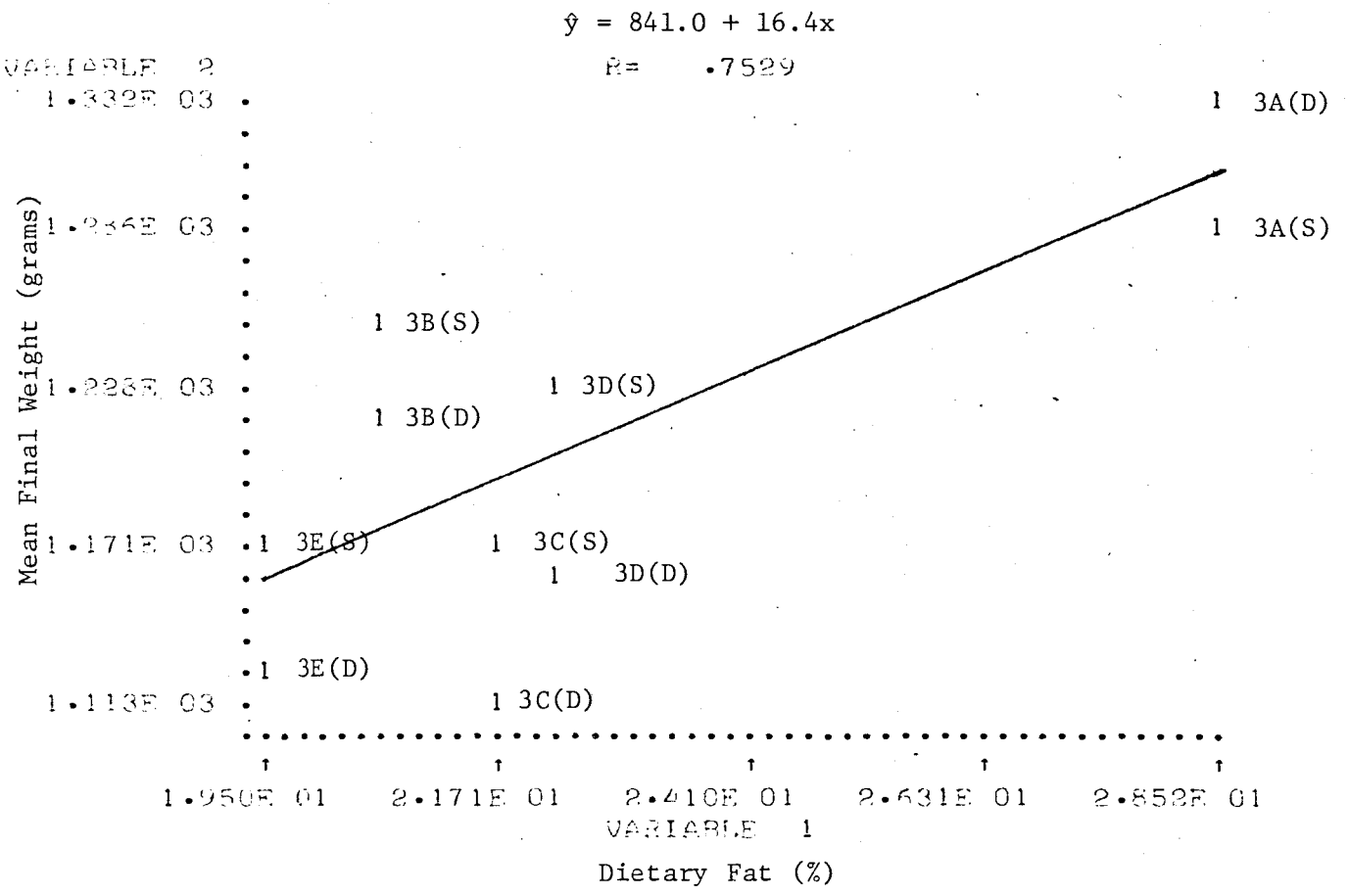

Figure 18. Regression on present standard dark (D) and sapphire (S) female data: Mean final weight on dietary fat level.

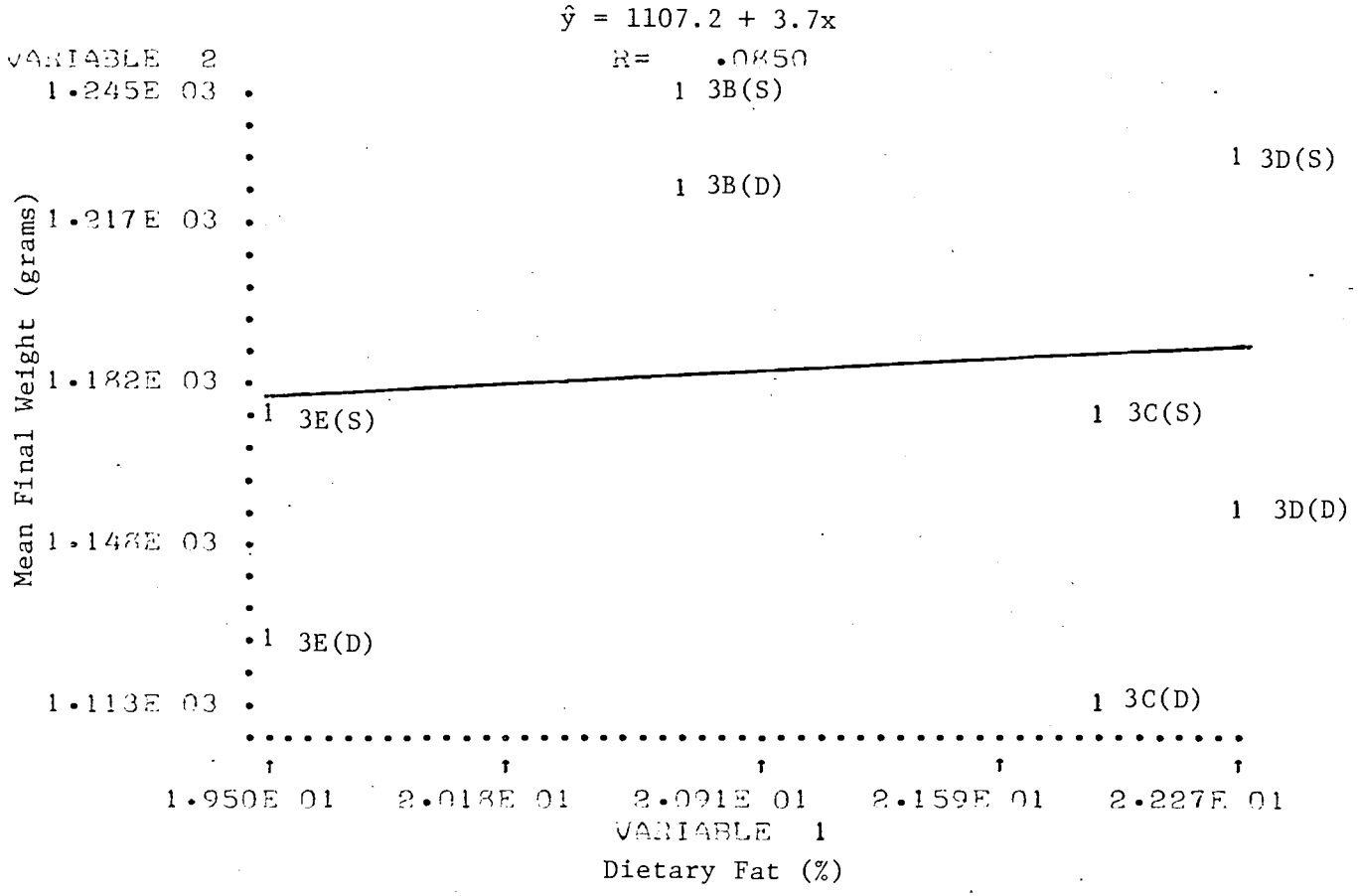

Figure 19. Regression on present standard dark (D) and sapphire (S) data without controls: Mean final weight on dietary fat level.

TABLE 25. REGRESSION ANALYSIS: MEAN FINAL WEIGHT ON DIETARY FAT LEVEL (excludes 3F data).

Data Group[1]	n	R	Regression Model	F-value	Significance Level
Past D Males	31	0.76	$\hat{y}$=1402.4+26.1x	40.69	.001
Present D Males	6	0.89	$\hat{y}$=1829.9+20.8x	15.35	.025
Present D&S Males	11	0.86	$\hat{y}$=1709.7+25.8x	26.23	.001
Present D Males (no control)	5	0.80	$\hat{y}$=1813.7+21.5x	5.30	NS[2]
Present D&S Males (no control)	9	0.76	$\hat{y}$=1593.9+31.3x	9.54	.025
Past D Females	30	0.44	$\hat{y}$= 956.4+ 6.0x	6.58	.050
Present D Females	5	0.83	$\hat{y}$= 697.4+22.0x	6.72	NS
Present D&S Females	10	0.75	$\hat{y}$= 841.0+16.4x	10.47	.025
Present D Females (no control)	4	-0.06	$\hat{y}$=1209 - 2.4x	0.01	NS
Present D&S Females	8	0.89	$\hat{y}$=1107.2+ 3.7x	0.04	NS

[1] D = dark mink; S = sapphire mink.

[2] NS = not significant.

only those meeting the following criteria were included in the regression analysis: (1) total diet contained 30 to 36 percent crude protein (corresponding to the percentage of protein in diets in the present study); (2) feed (wet ration) and water offered ad libitum; (3) no known toxic or growth inhibitory effects or dietary constituents; (4) no known nutrient deficiencies; and (5) no physical or environmental treatments (i.e., toe clipping, light control). The regression on the male data was found to be linear and highly significant ($P<.001$) ($R = 0.76$). The regression on the female data showed less explained variation but was still significant ($P<.05$) ($R = 0.44$). Present data. Mean final weights of male and female mink from each group, excluding 3F, were regressed on dietary fat level in the following manner: (1) darks only, (2) darks and sapphires, (3) darks only excluding the control, and (4) darks and sapphires excluding the control. Dark males yielded a significant regression ($P<.025$) ($R = 0.89$) which was further improved by including sapphire males ($P<.001$) ($R = 0.86$). Eliminating the bias of 3A, the dark male regression was no longer significant; however, when dark and sapphire males were considered together significance was maintained ($P<.025$) ($R = 0.76$). Although a distinct curvilinear relationship was apparent in the present male data, only linear regression analysis was performed in order to remain consistent with the linearity exhibited by the past male data.

Females showed much less relationship between final weight and dietary fat level. Only when dark and sapphire mink were taken together did females yield a significant regression ($P<.025$) ($R = 0.75$).

When the bias of 3A was omitted, the relationship was no longer significant. Influencing the female regressions were the high final weights in group 3B and the low final weights in group 3C in relation to fat level of their diets. The large size of 3B females may have occurred primarily due to sorting which resulted in the consumption of a diet higher in fat than that offered. For an unknown reason, group 3C females showed a marked decline in weight during the final part of the experiment.

Past versus Present data. A t-test was used to compare regression coefficients from past and present (including sapphires) data (Table 26). Slopes of male regressions were very similar (26.1; 25.8) and did not differ significantly. Slopes of female regressions differed significantly ($P<.05$) when 3A was included but not without influence of the control.

These results indicate the variability in final weights between groups 3A - 3E and 3G, especially in males of both strains, was largely due to fat levels of the diets. Females showed less explained variation with respect to fat. Other researchers have also reported fat level of the diet to have considerably less effect on final weights of females than males (Sinclair et al. 1962, Allen et al. 1963). This may be due to the smaller size and thus lesser growth requirements of females. Allen et al. (1963) found no significant difference in energy digestibilities between male and female mink. Sorting of the diet (group 3B) and possible experimental error (group 3C) may also have confused energy-growth relationships.

TABLE 26. COMPARISON OF REGRESSION COEFFICIENTS (t-values): Mean final weight on dietary fat level (excludes 3F data).

Null Hypothesis[1]	t-value	Significance Level
$\beta_1 = \beta_1^a$	0.05	NS[2]
$\beta_1 = \beta_1^b$	0.47	NS
$\beta_1^* = \beta_1^c$	1.87	.05
$\beta_1^* = \beta_1^d$	0.13	NS

[1] β_1 = slope of past male data; β_1^a = slope of present D&S male data; β_1^b = slope of present D&S male data (no controls); β_1^* = slope of past female data; β_1^c = slope of present D&S female data; β_1^d = slope of present D&S female data (no controls).

[2] NS = not significant.

With energy fortification, diets 3B - 3E and 3G would very likely give final weights similar to those obtained by feeding the control diet. Fats such as lard and tallow have been used widely as energy supplements for mink. A potential problem with fat supplementation, however, would be the effect on protein consumption. By adding fat, the percentage of protein in the diet would be lowered; feed consumption would also decrease and hence a protein deficiency could result.

Group 3F was not considered in regression analysis because final weights did not conform with dietary fat level, thus suggesting influence of an additional size limiting factor. Using the regression derived from dark and sapphire male data, mean final weights of 3F males fell outside 99 percent prediction limits for the fat level of the 3F diet (Table 27). Mean final weights of 3F females were within 99 percent prediction limits but, as discussed, regression models for the present female data may not be accurate.

C. Calcium

Little information is available on the effects high calcium diets have on pelter mink. Bassett et al. (1951b) recommended diets for growing mink contain 0.4 to 1.0 percent calcium and 0.4 to 0.8 percent phosphorus with a Ca:P ratio between 0.75:1.0 and 1.7:1.0. Travis et al. (1961) reported growth of male mink to be reduced when the diet contained 1.25 percent calcium and 0.53 percent phosphorus as compared to one percent calcium and one percent phosphorus. Schaible et al. (1962) compared diets containing 0.47 percent calcium (Ca/P=1) and 1.03 percent calcium (Ca/P=1) and found little difference in growth response.

TABLE 27. PREDICTED MEAN FINAL WEIGHTS AND 99 PERCENT PREDICTION LIMITS FOR GROUP 3F: Mean final weight regressed on dietary fat level.

Strain and Sex	Group 3F (grams)			
	Mean Final Weight	Predicted Mean Final Weight	99% Prediction Limits	
			Lower	Upper
D males[1]	2007	2206	2013	2398
S males[1]	1774	2206	2013	2398
D&S males[1]	1927	2206	2013	2398
D females[2]	1076	1156	967	1345
S females[2]	1213	1156	967	1345
D&S females[2]	1119	1156	967	1345
D&S females[3]	1119	1178	931	1425

[1] Regression model = D&S males.

[2] Regression model = D&S females.

[3] Regression model = D&S females (no controls).

Studies with rats have provided more detailed information concerning the effects of high calcium diets. Goto and Sawamura (1973a, 1973b) fed young rats excess calcium ($CaCO_3$ and calcium lactate supplements) and normal phosphorus (EN) diets (Ca/P=4) and excess calcium and excess phosphorus (EE) diets (Ca/P=1). Young rats on EN diets exhibited lower weight gains than control groups receiving normal levels of calcium and phosphorus. Animals on EE diets experienced slight or negative weight gains and high mortality due to reduced feed intakes and possibly kidney problems. EN groups showed decreases in percentage of nitrogen absorption and retention. EE groups displayed a percentage of nitrogen absorption more similar to the controls, but appreciably lower retention due to increased urine outputs. Both EN and EE groups showed less efficient utilization of calcium and phosphorus.

Rats fed high calcium diets also exhibit reduced absorption of fats. Yacowitz et al. (1967), using calcium carbonate, reported a significant increase in fecal excretion of both saturated and unsaturated fats in mature rats fed excess calcium. Goto and Sawamura (1973b), using calcium lactate, found a similar decrease in fat absorption in young rats which resulted in high excretion of combined fatty acids.

The reason for reduced efficiency of nutrient utilization on high calcium diets is not known. Possibly an increase in the intestinal pH due to the alkalinity of the diet affects nutrient solubilities thereby reducing absorption (Gotto and Sawamura 1973a). Furthermore,

fats hydrolyzed to free fatty acids may combine with calcium forming insoluble calcium soaps and be excreted in the feces (Gotto and Sawamura 1973b).

In view of the high calcium level in group 3F's diet, it appears likely that the significantly lower weight gain experienced on the SM as compared to the SSM was primarily due to excessive dietary calcium interfering with feed utilization. Reduced fat absorption may have been the major reason for smaller size. Bassett et al. (1951b) noted phosphorus deficiency symptoms (i.e., lameness, crooked legs, death) in male and female mink offered a diet containing 0.3 percent phosphorus and 1.0 percent calcium (Ca/P=3.3). No deficiency symptoms were observed in the present study suggesting adequate metabolism of phosphorus, likely due to net utilization, despite the high Ca/P ratio (3.48).

D. Strain Differences

Male dark and sapphire mink showed very close agreement in final weights in all groups except 3E and 3F. At the higher levels of shrimp waste supplementation sapphire males were smaller than dark males especially on the SM diet. This may have been due to differential strain responses to the high calcium, low fat diets or experimental error resulting from the small number of sapphire mink sampled. Conversely sapphire females were larger than dark females on all diets except the control.

XI. ECONOMIC CONSIDERATIONS

A. Fish Carcass Standard

In order for crustacean waste by-products to be economical as mink feed, prices would have to be less on a protein and fat basis than feedstuffs currently being used (assuming similar protein and fat quality). Table 28 illustrates what prices would have to be before the experimental materials tested could be used economically relative to fish carcass, a common feedstuff in mink rations. For example, 793.2 g of SM and 58.34 g of tallow would be necessary to equal the amount of protein and fat in 453.6 g (one pound) of fish carcass. Using August 2, 1976 prices for fish carcass (17.35¢/lb, dry basis) and tallow (18¢/lb) the price of SM, adjusted to take into account the cost of tallow supplementation, could not exceed 8.59¢/lb (dry basis) or 49.5 percent the cost of fish carcass.

Cost of bagged and frozen USW used in this study was approximately 21.68¢/lb (dry basis). Shrimp waste was obtained free from the processor; therefore, this cost reflects bagging, freezing and transportation charges. With current markets, USW at this price is obviously uneconomical especially in view of sorting by the animals. However, cost to individual mink ranchers would vary considerably depending on several factors, including proximity to processing plants, mode of transport and storage facilities. It is also possible to wet-grind shrimp waste which would prevent sorting but would add to the cost.

TABLE 28. AMOUNT OF MATERIAL AND TALLOW NECESSARY TO PROVIDE 210.9 grams protein and 92.53 grams fat. Costs are given relative to fish carcass and are adjusted to include tallow supplementation.[1]

	Dry Basis				
	Amount (grams)		Cost (cents)/453.6 grams		
Material	Material	Tallow[2]	Material	Limit[3]	Percent[4]
Fish carcass	453.6	0	17.35[5]	--	100.0
USW	825.8	62.9	?	8.16	47.0
SM	793.2	58.3	?	8.59	49.5
SSM	620.5	61.6	?	10.89	62.8
CPC	310.6	91.1	?	20.05	115.6

[1] Calculations based on analyses in Table 13.

[2] Price of tallow (100% fat basis) = 18¢/453.6 grams (August 2, 1976 price).

[3] Cost/453.6 grams cannot exceed this limit if experimental materials with tallow supplementation are to be less or equally expensive as fish carcass on a protein and fat basis.

[4] Limit cost as a percentage of fish carcass cost when tallow = 18¢/453.6 grams.

[5] August 2, 1976 price.

Expenses for drying, grinding, sieving and protein extraction are not available as these treatments were done on an experimental basis. All treatments would add to raw material costs, although handling, transportation and storage charges may be somewhat reduced due to decreased volume. A 1974 study on the economic feasibility of a publicly financed shellfish meal plant on the southern Oregon coast (Anonymous 1974) reported that a maximum projected market price of 7.5¢/lb for shellfish meal would not be adequate to meet production costs. From an economic vantage, the nutritional value of shellfish waste as a mink feed, compared to feedstuffs now being used, does not appear high enough to warrent any of the treatments evaluated in this study, at present or in the forseeable future.

It should be noted also that cost analyses were considered only on a protein-fat weight basis and not on a nutritional basis. Fish carcass would be more desirable as a feed due to its higher protein-fat density as compared to the shrimp products. Almost twice as much tallow supplemented USW would have to be consumed over fish carcass in order for protein and fat intakes to be equal. Feed consumption limits and reduced feed efficiency with high feed intakes may prevent animals from obtaining the same nutritional benefits as on a diet with a higher nutrient density.

B. Soybean Meal Standard

SM used in this study would not be economically competitive with soybean meal (44 percent CP), on a protein weight basis, unless priced under 60.5 percent of the cost of the soybean meal (Table 29). Based on

TABLE 29. AMOUNT OF MATERIAL NECESSARY TO PROVIDE 199.6 GRAMS PROTEIN.

	Dry Basis			
		Cost (cents)/453.6 grams		
Material	Amount (grams)	Material	Limit	Percent
Soybean meal[1]	453.6	11.11[2]	---	100.0
SM	750.7	?	6.71	60.5

[1] Contains 44 percent protein; 90 percent dry matter.

[2] August 3, 1976 price.

August 3, 1976 prices (Portland, Oregon), SM would have to cost less than 6.71¢/lb (dry basis).

C. General

At present, wet-ground shrimp waste appears to be the most economically desirable mink feed waste product. Other treatments would likely overprice waste products commensurate to their nutritive value. The wide distribution of shellfish processors is a major obstacle to creating a central, high volume waste processing facility which might be able to operate economically and offer competitively priced products. High costs prevent small, local facilities.

Chemically extracted shellfish protein is the highest quality feed product which can be derived from waste. If chemical extraction techniques were to become economical on a large scale, demands from pet food manufacturers and other interests would almost certainly price shellfish protein concentrate out of the mink feed market.

XII. CONCLUSIONS AND RECOMMENDATIONS

1. At the levels tested, waste materials did not adversely affect health or general condition of the animals and had minor, if any, effect on fur color and quality. There was, however, some indication color and quality may be reduced with higher levels of the shrimp waste products.

2. When waste materials were added to the diet at the expense of a component higher in fat, final body weights of males and to a lesser extent females, were reduced commensurate to the level of replacement and feed consumption increased. Fat supplementation would likely increase final weights and decrease feed consumption of mink fed low fat, crustacean waste diets. The effect of energy fortification on dietary protein level and protein intake must be considered, however, as a protein deficiency could result. Protein supplementation may be necessary.

3. Shellfish waste should be used only at low levels to prevent excess calcium from interfering with the utilization of nutrients in the diet. The results obtained in this study suggest the best guideline for determining the maximum level of waste supplementation is the Ca:P ratio of the diet. As long as $Ca:P \leq 2$ with the normal level of dietary phosphorous, calcium will probably have no major negative effects.

4. Sieving increased the percentage of protein in the shrimp waste but resulted in only a minor reduction in the percentage of calcium. It appears the major benefit derived from sieving is that

a smaller amount of waste (and hence less calcium) is necessary for supplementation on an equal-protein basis as compared to SM. At low levels of supplementation on an equal-protein basis ($Ca/P \leq 2$), SM, SSM and USW (if ground to prevent sorting) appear comparable. At higher levels, however, SSM results in superior growth. Base extracted shellfish protein appears to be a satisfactory protein supplement for mink. Unlike other waste products its use in the diet would not be limited by calcium level.

5. From an economic standpoint, wet-ground shrimp waste is probably the only shellfish waste product potentially valuable as a mink feed at the present time. Other treated waste products would likely be overpriced proportionate to their nutritional value as compared to feedstuffs now being used.

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APPENDICES

APPENDIX TABLE I. WEANING, ON TEST AND PELTING DATES.

Strain	Sex	Group	Date (1975) Weaning	On test	Pelting
Dark	Male	3A-3F	June 30	July 28	December 9
		3G	June 30	August 1	December 9
	Female	3A-3F	July 1	July 28	December 3
Sapphire	Male	3A-3F	July 8	July 28	December 2
	Female	3A-3F	July 8	July 28	December 2

APPENDIX TABLE II. MEAN BODY WEIGHTS.

Strain	Sex	Group	Mean weight (grams)				
			Weaning	On test	Aug. 25	Sept. 22	Oct. 20
Dark	Male	3A	798	1384	1878	2192	2376
		3B	800	1313	1652	1961	2157
		3C	802	1343	1730	2041	2176
		3D	820	1321	1616	2013	2217
		3E	814	1281	1438	1721	1947
		3F	804	1321	1388	1589	1805
		3G	816	1481	1795	2131	2331
	Female	3A	626	892	1113	1215	1338
		3B	644	868	968	1097	1175
		3C	625	852	976	1091	1140
		3D	621	847	917	1048	1137
		3E	614	885	895	1018	1114
		3F	627	853	846	968	1068
Sapphire	Male	3A	738	1176	1721	2115	2370
		3B	726	1122	1453	1816	2112
		3C	769	1186	1610	2057	2267
		3D	707	1142	1458	1880	2240
		3E	738	1131	1356	1676	1962
		3F	772	1189	1259	1532	1722
	Female	3A	585	777	997	1117	1261
		3B	608	810	951	1126	1190
		3C	586	807	981	1131	1214
		3D	592	794	902	1096	1244
		3E	608	810	888	1023	1123
		3F	627	839	883	991	1142

APPENDIX TABLE III. MEAN WEIGHT GAINS.

Strain	Sex	Group	Mean Weight Gain (grams) On test to Aug. 25	Aug. 26 to Sept. 22	Sept. 23 to Oct. 20	Oct. 21 to Pelting
Dark	Male	3A	494	314	184	47
		3B	339	309	196	72
		3C	387	311	135	158
		3D	304	397	204	120
		3E	157	283	226	255
		3F	67	201	216	202
		3G	314	336	200	20
	Female	3A	221	102	123	6
		3B	100	129	78	53
		3C	124	115	49	- 27
		3D	70	131	89	24
		3E	10	123	96	14
		3F	- 7	122	100	8
Sapphire	Male	3A	545	394	255	80
		3B	331	363	296	129
		3C	424	447	210	73
		3D	316	422	360	71
		3E	225	320	286	139
		3F	70	273	190	52
	Female	3A	220	120	144	33
		3B	141	175	64	62
		3C	174	150	83	- 32
		3D	108	194	148	- 8
		3E	78	135	100	53
		3F	44	108	151	71

APPENDIX TABLE IV. AVERAGE FEED CONSUMPTION PER MINK PER DAY, Groups 3A-3F (dry basis).

	Feed (grams)					
Group	Aug. 1 to Aug. 25	Aug. 26 to Sept. 22	Sept. 23 to Oct. 20	Oct. 21 to Dec. 1	Dec. 2	Dec. 3 to Dec. 8
3A	92.4	90.3	87.3	71.7	58.4	67.6
3B	93.2	100.8	100.4	87.9	76.8	84.8
3C	101.0	103.3	96.6	80.2	50.3	79.4
3D	90.1	98.1	102.4	89.8	68.0	79.3
3E	89.9	95.8	99.7	90.7	76.4	99.8
3F	95.5	96.5	105.9	102.8	85.4	87.9

APPENDIX TABLE V. AVERAGE FEED CONSUMPTION PER DARK MALE MINK (dry basis).

	Feed (grams)			
Group	Aug. 18 to Aug. 25	Aug. 26 to Sept. 22	Sept. 23 to Oct. 20	Oct. 21 to Dec. 8
3A	108.1	101.4	96.3	71.9
3E	111.3	119.2	120.0	92.5
3F	104.8	113.6	121.1	108.1
3G	102.7	108.4	103.5	85.7