I. Introduction

Since time immemorial shellfish has been an important source of human nutrition. The molluscan shellfish probably antedates all other foods in this respect. The tremendous waste-heaps of primitive tribes—
coastal American Indians, Swiss lake dwellers, Scandinavian and Siberian fur settlers—predominantly contain shells of oysters, mussels, etc. The long empirical traditions, therefore, bear strong evidence of the special merits of this group of aquatic organisms.

Modern nutritional science has given much support to this evaluation. Innumerable publications are available giving one or another contribution to a broadened knowledge of the nutritive values of both crustacean and molluscan shellfish and also revealing the limitations and particular assets of special groups. Notwithstanding, shellfish have not received the attention they deserve on the part of most nutritionists. Very few broad and penetrating studies are available pertaining to any major group. Nevertheless, the present fragmentary information permits some conclusions of general validity and, in other cases, the reviewing may have the function of spotting inadequacies and inconsistencies.

One complication was encountered in preparing this review. Unfortunately, the word fish is not infrequently used to cover all aquatic organisms eaten as food, inclusive of shellfish. It was not possible to go through all the studies which convey pertinent information on shellfish. There is, therefore, the obvious risk that some essential material and important information may be missing. This is particularly true insofar as abstracters or reviewers only occasionally index such information under the specific headings of shellfish, crustaceans, mollusks, shrimp, oysters or mussels, etc.

II. Protein Content

A. General

As a whole, the muscle tissue of shellfish usually ranges lower than that of most fish in total protein content; the crustaceans generally rate highest (27.1-22.0%), followed by the mollusks. In this latter case, mussels and squids (12.0%, 9.8%) rank higher than gastropods (9.9%). Exceptions seem to be the large squid "jubia," eaten in Spain, and with a protein content of 15.7% (Ferreyra Risso, 1953), and the Japanese ear-shell (see Table I)—24.6%. These general rules were confirmed by Intengan et al. (1956), who found that crustaceans in general had a protein content equivalent to that of fish, while, on the average, molluscan shellfish give values half as large. Some selected figures further illustrate these generalizations (Table II). Table III constitutes a selection of papers giving data on the protein content of various shellfish—see also the comprehensive bibliography by Van der Rijst (1950).

On a dry basis, the often-quoted figures are 85-88% for crustaceans and 44-49% for mollusks such as oysters (Lee and Pepper, 1956). The
II. SHELLFISH PROTEIN—NUTRITIVE ASPECTS

TABLE I
APPROXIMATE COMPOSITION OF THE MEAT OF SELECTED MARINE ANIMALS

<table>
<thead>
<tr>
<th>Marine animal</th>
<th>Crude protein (%)</th>
<th>Marine animal</th>
<th>Crude protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ear-shell</td>
<td>24.6</td>
<td>Whale (red meat)</td>
<td>21.0</td>
</tr>
<tr>
<td>Octopus</td>
<td>17.1</td>
<td>Dolphin</td>
<td>16.8</td>
</tr>
<tr>
<td>Oyster</td>
<td>13.1</td>
<td>Herring</td>
<td>14.6</td>
</tr>
<tr>
<td>Clam</td>
<td>11.3</td>
<td>Cod</td>
<td>16.9</td>
</tr>
<tr>
<td>Sea cucumber</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>7.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


TABLE II
PROTEIN PERCENTAGE IN SELECTED SHELLFISH

<table>
<thead>
<tr>
<th>Species</th>
<th>Latin name</th>
<th>Protein (total N × 6.25)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustaceans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crab</td>
<td><em>Cancer pagurus</em></td>
<td>22.4</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td></td>
<td><em>Chionectes phalangium</em></td>
<td>19.4</td>
<td>Hatakoshi, 1932</td>
</tr>
<tr>
<td>Lobster</td>
<td><em>Homarus vulgaris</em></td>
<td>19.7-20.7</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Prawn</td>
<td><em>Leander serratus</em></td>
<td>22.8</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Shrimp</td>
<td><em>Crangon vulgaris</em></td>
<td>22.0-23.2</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Mollusks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oyster</td>
<td><em>Ostrea edulis</em></td>
<td>8.6-12.6</td>
<td>Krvarić, 1953</td>
</tr>
<tr>
<td>Mussel</td>
<td><em>Mytilus edulis</em></td>
<td>8.9-11.7</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td></td>
<td><em>Mytilus munahuensis</em></td>
<td>11.3-19.4</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td></td>
<td><em>Enoplachiton niger</em></td>
<td>24.7</td>
<td>Nexci Alferrano, 1954</td>
</tr>
<tr>
<td>Scallop</td>
<td><em>Pecten maximus</em></td>
<td>17.5</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Whelk</td>
<td><em>Buccinum undatum</em></td>
<td>17.5</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Winkle</td>
<td><em>Littorina littorea</em></td>
<td>18.0</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Cockle</td>
<td><em>Cardium edale</em></td>
<td>13.2</td>
<td>Reay et al., 1946</td>
</tr>
<tr>
<td>Squid</td>
<td><em>Loligo vulgaris</em></td>
<td>14.9-19.3</td>
<td>de Gouveia and de Gouveia, 1951</td>
</tr>
<tr>
<td>Octopus</td>
<td><em>Octopus vulgaris</em></td>
<td>17.9</td>
<td>Saavedra, 1949</td>
</tr>
</tbody>
</table>

Spanish crab (*Polybius henslowi*) has, however, a low value of 44.2% (Varela and Pujol, 1956). A Mexican paste made of crustacean larvae and partially dried is a potent protein source—55.5%.

B. CRUSTACEANS

Crustaceans range in protein content from 9.4 to 15.3%, according to Carteni and Aloj (1934). Most analytical data in numerous food composition lists do, however, give higher values, listing crustaceans such as crabs, lobsters, shrimp, in the same range as mammal meat, or even higher—22-17%. This discrepancy could be due to the fact that tables
### TABLE III
REFERENCES TO STUDIES ON PROTEIN CONTENT OF SHELLFISH FLESH

<table>
<thead>
<tr>
<th>Shellfish</th>
<th>Country</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Crustaceans</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Greenland</td>
<td>Hjarde <em>et al.</em>, 1952</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>Lajthia, 1949</td>
</tr>
<tr>
<td></td>
<td>Netherlands</td>
<td>Havinga, 1959</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>Waheed Khan and Chuhtal, 1956</td>
</tr>
<tr>
<td></td>
<td>Peru</td>
<td>Velasco, 1946</td>
</tr>
<tr>
<td></td>
<td>Spain</td>
<td>Charro Arias and Vaamonde, 1942</td>
</tr>
<tr>
<td></td>
<td>United States</td>
<td>Lee, 1935</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nilson, 1943</td>
</tr>
<tr>
<td>Crabs</td>
<td>United States</td>
<td>Fellers and Parks, 1926</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lanham <em>et al.</em>, 1940</td>
</tr>
<tr>
<td></td>
<td>United Kingdom</td>
<td>Harry, 1936</td>
</tr>
<tr>
<td><em>Callinectes sp.</em></td>
<td>United States</td>
<td>Watson and Fellers, 1935</td>
</tr>
<tr>
<td><em>Chionectes sp.</em></td>
<td>Japan</td>
<td>Hatakoshi, 1932</td>
</tr>
<tr>
<td><em>Paralithodotes sp.</em></td>
<td>Japan</td>
<td>Matsui, 1916</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kondo and Iwamae, 1932</td>
</tr>
<tr>
<td><em>Platypichus sp.</em></td>
<td>United States</td>
<td>Watson and Fellers, 1935</td>
</tr>
<tr>
<td><em>Polybius sp.</em></td>
<td>Spain</td>
<td>Varela and Pujol, 1956</td>
</tr>
<tr>
<td>Prawns and shrimps</td>
<td>United Kingdom</td>
<td>Harry, 1936</td>
</tr>
<tr>
<td>Five species</td>
<td>India</td>
<td>Shaikhmahmud and Magar, 1957</td>
</tr>
<tr>
<td><em>Cancer sp.</em></td>
<td>Peru</td>
<td>de la Torre, 1952</td>
</tr>
<tr>
<td><em>Palinusus sp.</em></td>
<td>Italy</td>
<td>Carteni and Aloj, 1934</td>
</tr>
<tr>
<td><em>Bithynis sp.</em></td>
<td>Peru</td>
<td>de la Torre, 1952</td>
</tr>
<tr>
<td><em>Peneus sp.</em></td>
<td>Italy</td>
<td>Carteni and Aloj, 1934</td>
</tr>
<tr>
<td>Lobster</td>
<td>United Kingdom</td>
<td>Harry, 1936</td>
</tr>
<tr>
<td>Crayfish</td>
<td>United Kingdom</td>
<td>Harry, 1936</td>
</tr>
<tr>
<td><strong>B. Mollusks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Greenland</td>
<td>Hjarde <em>et al.</em>, 1952</td>
</tr>
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<td></td>
<td>Italy</td>
<td>Lajthia, 1949</td>
</tr>
<tr>
<td></td>
<td>Netherlands</td>
<td>Havinga, 1959</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>Waheed Khan and Chuhtal, 1956</td>
</tr>
<tr>
<td></td>
<td>Spain (Vigo)</td>
<td>Lopez-Bonito, 1955</td>
</tr>
<tr>
<td></td>
<td>United States</td>
<td>Nilson, 1943</td>
</tr>
<tr>
<td>Gastropoda (snails)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Helix sp.</em></td>
<td>Mexico</td>
<td>Villadelmar <em>et al.</em>, 1956–1957</td>
</tr>
<tr>
<td></td>
<td>Peru</td>
<td>Vásquez Castillo, 1953</td>
</tr>
<tr>
<td>Pelecypoda</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mussels</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Donax sp.</em></td>
<td>Brazil</td>
<td>Veloso <em>et al.</em>, 1951</td>
</tr>
<tr>
<td><em>Enoplochiton sp.</em></td>
<td>Peru</td>
<td>Nexci Alferrano, 1954</td>
</tr>
<tr>
<td><em>Mytilus sp.</em></td>
<td>Brazil</td>
<td>de Sigueira <em>et al.</em>, 1954</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>Tobias e Silva, 1955</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carteni and Aloj, 1934</td>
</tr>
<tr>
<td></td>
<td></td>
<td>del Monte and Gambetti, 1959</td>
</tr>
</tbody>
</table>
2. II. SHELLFISH PROTEIN—NUTRITIVE ASPECTS

Table III (continued)

<table>
<thead>
<tr>
<th>Shellfish</th>
<th>Country</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B. Mollusks (continued)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solen sp.</td>
<td>Netherlands</td>
<td>van de Velde, 1939</td>
</tr>
<tr>
<td>Venus sp.</td>
<td>Italy</td>
<td>Carteni and Aloj, 1934</td>
</tr>
<tr>
<td>Clams</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meretrix sp.</td>
<td>India</td>
<td>Venkataraman and Chari, 1951</td>
</tr>
<tr>
<td>Oysters</td>
<td>India</td>
<td>Venkataraman and Chari, 1951</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>New Zealand</td>
<td>Malcolm, 1927</td>
</tr>
<tr>
<td>Ostrea sp.</td>
<td>Japan</td>
<td>Masumoto et al., 1932</td>
</tr>
<tr>
<td></td>
<td>Portugal</td>
<td>de Gouveia and de Gouveia, 1951</td>
</tr>
<tr>
<td></td>
<td>Yugoslavia</td>
<td>Krvarić, 1953</td>
</tr>
<tr>
<td>C. MOLLUSKS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scallops</td>
<td>United States</td>
<td>Lee and Pepper, 1956</td>
</tr>
<tr>
<td>Cephalopoda</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loligo sp.</td>
<td>Italy</td>
<td>Carteni and Aloj, 1934</td>
</tr>
<tr>
<td></td>
<td>Peru</td>
<td>Ferreyra Risso, 1953</td>
</tr>
<tr>
<td></td>
<td>Mexico</td>
<td>Villadelmar et al., 1956–1957</td>
</tr>
<tr>
<td>Octopus sp.</td>
<td>Portugal</td>
<td>de Gouveia and de Gouveia, 1951</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>Carteni and Aloj, 1934</td>
</tr>
<tr>
<td></td>
<td>Peru</td>
<td>Saavedra, 1949</td>
</tr>
<tr>
<td></td>
<td>Mexico</td>
<td>Villadelmar et al., 1956–1957</td>
</tr>
<tr>
<td>Sepia sp.</td>
<td>Italy</td>
<td>Carteni and Aloj, 1934</td>
</tr>
</tbody>
</table>

on food composition frequently give the values referring to edible or eaten protein, while published individual papers have taken the entire soft part of the body into account. Busson et al. (1953) list crab, together with tuna, as the food with the highest protein content (for the former, 21%).

Dried Bombay prawns of five different species show varying content of protein, 66.1–51.3% (Shaikhmahmud and Magar, 1957).

C. MOLLUSKS

Eight different mollusks were analyzed by Carteni and Aloj (1934) and showed a protein range of 8.4 to 14.0%. As mentioned above, the Japanese ear-shell is exceptionally high—24.7%. So is a Peruvian mussel (*Enoplochiton niger*), with the same high value (Nexci Alferrano, 1954). This recommends it highly as food, particularly as its nutritive value is also high.

A differentiation should be made between the body liquid of the
mussels and the body tissues as such. The liquid of oysters is quite rich in organics, albumins (2 g./liter), peptides, and mucin (Baylac, 1907).

Scallops contain less protein than beef, lamb, chicken, or fish, according to Bell's investigations (1937).

The octopus stands high in protein content—17.9% according to Peruvian analyses (Saavedra, 1949). On the other hand, Ferreyra Risso (1953) considered cephalopods largely as having lower protein figures than crustaceans.

Taxonomically, the cephalopods are subdivided into cuttlefish, carrying the cuttle bone, squids, and octopi. They are all used as food in various parts of the world. It is deplorable that these three major groups are not always kept apart in nutritional studies. Frequently they are used synonymously or are not correctly categorized.

The general composition of squid protein as to myosins and their characteristics was investigated by Matsumoto (1958). Their protein resembles that of fishes with certain distinctive features.

As a whole, shellfish are equal to fish in protein content, but a few contain even more protein than do fish. Several molluscan shellfish, particularly gastropods, are appreciably lower in protein than fish. See Table I.

D. MEAT CONTENT

In several shellfish, more than the muscle tissues are eaten. What is termed meat is not always identical to the flesh in other animals. This has to be borne in mind when evaluating analytical data. The shells, nevertheless, constitute a major portion of the live weight (see Table IV), more so in mollusks than in crustaceans.

<table>
<thead>
<tr>
<th>Shellfish</th>
<th>No. of samples</th>
<th>Edible portion (% of weight in shell)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crustaceans</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crab</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Lobster</td>
<td>3</td>
<td>44</td>
</tr>
<tr>
<td>Prawn</td>
<td>1</td>
<td>46</td>
</tr>
<tr>
<td>Shrimp</td>
<td>1</td>
<td>47</td>
</tr>
<tr>
<td><strong>Mollusks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oyster</td>
<td>42</td>
<td>11.8</td>
</tr>
<tr>
<td>Mussel</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>Scallop</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Whelk</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td>Periwinkle</td>
<td>1</td>
<td>22</td>
</tr>
</tbody>
</table>

* Source: Reay et al., 1946.
The meat content of Japanese oysters shows a sexual difference (Masumoto et al., 1932). Females have 30% more meat and twice as much fat.

E. Seasonal Changes

The composition of both crustacean and molluscan shellfish varies with season and particularly with the spawning time. Fat and protein generally build up to this major event, after which they drop.

In oysters the proportion of glycogen to protein is approximately reciprocal (Hatanaka, 1940). The energy content varies only slightly, attaining a maximum in late fall and early winter, with some differences between species (Masumoto et al., 1932, 1934; Tully, 1936; Krvarič, 1953).

The protein percentage increases in the spring and remains constant throughout the summer, but drops in the late fall (Krvarič, 1953).

Japanese oysters do not show the winter loss in weight and in protein (Sekine et al., 1929; Masumoto et al., 1932), probably because feeding is not arrested during the winter to the same extent as in Atlantic waters (Tully, 1936). The protein peak appears in the late summer in Pacific oysters, which appears to differentiate them from the Atlantic species.

The common blue mussel from the Vigo estuary shows a maximum amount of protein (13.4%) in the fall but a minimum (9.2%) in the spring in February (Fraga, 1958). With the scallop, the situation is almost the reverse: in the last half of April the protein figure reaches a peak and passes its maximum in the last half of November (López-Bonito, 1955).

Important, too, is the relationship between fat content and protein. In the scallop, this ratio has a maximum in February and a minimum in June.

In the oyster, there is a maximum in meat content, reached in December, and a minimum in January. A second maximum comes in March, after which there is a rapid decline to a second minimum in July. The protein content closely follows this same pattern, while glycogen shows the opposite trend. Recovery takes place in early autumn, where there is more plankton in the sea, as shown in the figures in the tabulation (gram on the average per individual).

<table>
<thead>
<tr>
<th></th>
<th>Total weight</th>
<th>Water</th>
<th>Solids</th>
<th>Lipids</th>
<th>Protein</th>
<th>Glycogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss between</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June and July</td>
<td>5.6</td>
<td>4.7</td>
<td>0.912</td>
<td>0.178</td>
<td>0.473</td>
<td>0.037</td>
</tr>
<tr>
<td>Gain between</td>
<td>6.3</td>
<td>4.7</td>
<td>1.602</td>
<td>0.100</td>
<td>0.606</td>
<td>0.219</td>
</tr>
</tbody>
</table>
Protein accounts for more than half of the loss as well as one-third of the gain (Sekine et al., 1930).

F. OTHER INVERTEBRATES

Sea cucumber flesh, as Table I indicates, has a protein content which is only one-third that of fish meat. Therefore, it is not looked upon as a protein source (Tanikawa, 1955), even though its aminogram compares well with that of fish meat. It may, however, have certain other merits revealed through recent research (see Section G).

The chemical composition of the meat of a sea cucumber (Stichopus japonicus) commonly eaten in Japan varies with the season. The water content (86–92% throughout the year) is greater than that of fish meat, which shows 75–85%. The amount of protein in the flesh grows, together with that of fat, from September to January and then drops in the period from February to May (Tanikawa, 1955).

Squid meat is composed of a more water-soluble protein than that of fish meat. Sea cucumbers show the opposite characteristic, having chiefly insoluble protein, viz., collagen, which dissolves in water only with difficulty. There is, however, some soluble protein in the network of the connective tissue (Tanikawa, 1955).

The edible part of the body of Stichopus japonicus—the body wall—is histologically not muscular tissue, but consists mainly of connective tissue, built into a network of collagen fibers. The amount of collagen in the meat protein is about three times that in fish meat. In this structure the fibers are encased body-fluid-carrying soluble proteins, e.g., myosin and myogen. The hydrating affinity of the meat is inferior to that of fish meat. Only a minor portion of the water is bound water. Therefore, the body of Stichopus japonicus, when left in a basket, loses a major portion of its water (Tanikawa, 1955).

G. GENERAL COMPOSITION

A few studies are available on the general composition of shellfish protein. In myosin solubility, lobster protein comes closest to that of the rabbit (Dubuisson-Brouha, 1953). Whereas the water-soluble proteins and nonmyosins of several fishes were equal in amount, the water-soluble protein of squid (77–85%) constituted a far greater percentage than the amount of nonmyosin (12–20%) (Matsumoto, 1955, 1958). Although the muscle protein of squid resembles that of fish, the properties of its myosins are distinct.

Crustacean proteins frequently are bound to sugars forming glucoproteins. Lobster protein contains 2.2% sugars, consisting of three parts glucose and eight parts of fructose, while crab protein has 2.8% sugars.
2. II. SHELLFISH PROTEIN—NUTRITIVE ASPECTS

in a ratio of four parts glucose to one part fructose (Kondo and Sarata, 1940).

The meat of *Stichopus japonicus* contains a large quantity of mucoprotein with chondroitin sulfuric acid as a component. In the studies of geriatrics the relation between the superannuating phenomena of muscle tissue and the decreasing of chondroitin sulfuric acid has been indicated. The Chinese have been eating sea cucumber since ancient days; this biochemical relationship might explain its popularity (Tanikawa, 1955).

The swelling, or the degree of hydration, of a protein shows a minimum at the isoelectric point, and increases to either side, acid or alkaline. This was demonstrated for fish by Tarr (1942), Noguchi et al. (1950), and Okada and Tada (1953, 1954). Takahashi (1955) showed the same effect with collagen. The swelling of fish meat has a minimum value at the isoelectric point (pH 4–5) and a maximum value at either the alkaline side (pH 10–12) or the acid one (pH 2–3). In the presence of salts, the swelling is enhanced on the alkaline side, but is reduced on the acid side (Tarr, 1942, and Okada). Meat of sea cucumbers shows no peak of protein swelling in acid solution as does that of fish (Tanikawa, 1955).

The flesh of sea cucumbers shrinks rapidly when immersed in water at temperatures between 45° and 55°C. and contracts about 50% at 70° to 80°C. In this respect it resembles the collagen-rich fish skin (Takahashi, 1955), which shrinks in the temperature range of 37° to 55°C. Fish meat shows a peak of swelling on both sides of the isoelectric point (pH 4–5). Sea cucumber differs in this respect, with no maximum in hydration in the acid region (Tanikawa, 1955). This may be explained by the aforementioned high content of collagen.

III. Biological Value

Jones (1926) found the ratio values of (gain in weight)/(gram of protein) for shrimp, clam, and oyster to be 2.2, 2.1, and 1.3, respectively. Lanham and Lemon (1938) established values (see tabulation) for the relative growth-promoting effect. Both oyster and shrimp exhibit good nutritive value.

<table>
<thead>
<tr>
<th>100</th>
<th>90</th>
<th>80</th>
<th>63</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oyster</td>
<td>Shrimp</td>
<td>Cod</td>
<td>Beef</td>
</tr>
<tr>
<td></td>
<td>Pilchard</td>
<td>Shad</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red snapper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Crab protein tested for the growth effect on experimental rats was superior to casein. Its biological value was on the same level as beef
Prawn protein had a good biological value (74) but lower than that of hake (Pujol and Varela, 1958).

The "patexo" (*Polybius henslowi* Leach) is a crustacean, abundant during certain months along the Galician coast of Spain. Dried, it is used as a meal. The biological value of its protein is low. Even negative values were obtained in rat experiments (Varela and Pujol, 1958).

The oyster is outstanding as one of the marine proteins best suited to man—conforming to his specific requirements in this respect. This explains its use in therapeutic diets (Le Gall, 1948). Oyster protein was superior to that of seven fish studied, and surpassed shrimp. Beef was inferior when measured by the effect of extracted proteins on rat growth (protein efficiency ratio) (Lanham and Lemon, 1938). In the brackish lakes of the coastal regions of Brazil, the Brazilian mussel (*Mytilus manuhuensis*) is commonly eaten by the poor. Its protein is equal to casein in nutritive value (de Sigueira et al., 1954). Along the Peruvian coast is found another mussel (*Enoplochiton niger*)—"barquillo"—with a high protein content (24.7%) and of superior quality, as measured in experimental growth studies (Nexci Alfersano, 1954).

Flesh of a kind of cuttlefish ("variika") and crab ("tara bagani"), when tested against the proteins of horse, whale, and fish as to their effect on the normal growth curve of rats, compared favorably (Suzuki et al., 1912).

**IV. Amino Acid Composition**

**A. General**

Shellfish muscle tissue is generally characterized by its high content of nonprotein nitrogen (Campbell, 1934–1935). In the first and second decade of this century, a breakdown of the shellfish proteins through hydrolysis was done experimentally, together with similar analyses of other flesh tissues used as food (see Part I of this chapter). The close similarities between shellfish protein and that of other flesh products, whether vertebrate or invertebrate, were noted. Within these "two groups" deviations were few. Furthermore, shellfish protein, whether crustacean or molluscan, is composed of much the same constituents (Beach et al., 1943; Duchâteau et al., 1959) (see Table V). Leont′ev and Markova (1936) reported that the curves for racemization of proteins from major proteins of invertebrates were almost identical, thus constituting an indirect evidence of their similarity. This contrasts with the specific character of the pool of free amino acids. Differences in the proteins presumably exist in their molecular build-up. A list of studies from various parts of the world on the amino acid composition of shellfish is given in Table VI.
Table V
PER CENT CONTRIBUTION OF AMINO ACIDS TO TOTAL NITROGEN OF SELECTED PROTEINS FROM MUSCLE TISSUE

<table>
<thead>
<tr>
<th>Food</th>
<th>Arginine</th>
<th>Histidine</th>
<th>Lysine</th>
<th>Phenylalanine</th>
<th>Tyrosine</th>
<th>Tryptophan</th>
<th>Serine</th>
<th>Threonine</th>
<th>Cystine</th>
<th>Methionine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pork</td>
<td>13.3</td>
<td>3.7</td>
<td>10.4</td>
<td>2.1</td>
<td>2.1</td>
<td>1.1</td>
<td>3.8</td>
<td>3.4</td>
<td>0.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Chicken (white flesh)</td>
<td>13.9</td>
<td>4.0</td>
<td>10.1</td>
<td>2.0</td>
<td>2.1</td>
<td>1.1</td>
<td>3.9</td>
<td>3.4</td>
<td>0.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Codfish</td>
<td>12.6</td>
<td>3.5</td>
<td>10.1</td>
<td>2.3</td>
<td>2.2</td>
<td>1.1</td>
<td>4.1</td>
<td>3.3</td>
<td>0.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Shrimp</td>
<td>13.2</td>
<td>3.1</td>
<td>10.0</td>
<td>2.5</td>
<td>2.3</td>
<td>1.1</td>
<td>3.3</td>
<td>2.9</td>
<td>0.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

a Source: Beach et al., 1943.
b The Sullivan method.
Scallops, fresh-water crayfish, and sea cucumbers all have an amino acid composition making their protein fully comparable to casein (Leont'ev and Markova, 1936).

Table VI

<table>
<thead>
<tr>
<th>Shellfish</th>
<th>Region</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crustacean</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lobster</td>
<td>Soviet Union</td>
<td>Taranova <em>et al.</em>, 1955</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>Airan <em>et al.</em>, 1953</td>
</tr>
<tr>
<td>Shrimp</td>
<td>India</td>
<td>Sarkar and Raha, 1954</td>
</tr>
<tr>
<td><em>Scylla</em> sp.</td>
<td>India</td>
<td>Airan and Karat, 1953</td>
</tr>
<tr>
<td><em>Chionecetes</em> sp.</td>
<td>Japan</td>
<td>Hatakoshi, 1932</td>
</tr>
<tr>
<td><em>Palinurus</em> sp.</td>
<td>Japan</td>
<td>Okuda <em>et al.</em>, 1919</td>
</tr>
<tr>
<td><em>Paralithodes</em> sp.</td>
<td>Japan</td>
<td>Okuda <em>et al.</em>, 1919</td>
</tr>
<tr>
<td><em>Peneus</em> sp.</td>
<td>Japan</td>
<td>Kondo and Iwamae, 1932</td>
</tr>
<tr>
<td></td>
<td>United States</td>
<td>Jones <em>et al.</em>, 1925</td>
</tr>
<tr>
<td></td>
<td>Mexico</td>
<td>Bachstez and Bustamente, 1955</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>Röhrig, 1905</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ackermann and Kutscher, 1907</td>
</tr>
<tr>
<td></td>
<td>Soviet Union</td>
<td>Taranova <em>et al.</em>, 1955</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>Kuo-Hao, 1926</td>
</tr>
<tr>
<td><em>Grapsus</em> sp.</td>
<td>Soviet Union</td>
<td>Leont'ev and Markova, 1936</td>
</tr>
<tr>
<td><strong>Crayfish</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>United Kingdom</td>
<td>Potts, 1958</td>
</tr>
<tr>
<td><strong>Molluscan</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Anodonta</em> sp.</td>
<td>United Kingdom</td>
<td>Potts, 1958</td>
</tr>
<tr>
<td><em>Mytilus</em> sp.</td>
<td>United Kingdom</td>
<td>Potts, 1958</td>
</tr>
<tr>
<td><strong>Scallops</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pecten</em></td>
<td>Soviet Union</td>
<td>Leont'ev and Markova, 1936</td>
</tr>
<tr>
<td><strong>Cephalopods</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Loligo</em></td>
<td>Japan</td>
<td>Okuda <em>et al.</em>, 1919</td>
</tr>
<tr>
<td><em>Omnmastrystes</em> sp.</td>
<td>Japan</td>
<td>Kōnosu <em>et al.</em>, 1957</td>
</tr>
<tr>
<td><em>Squid</em></td>
<td>Japan</td>
<td>Sugimura <em>et al.</em>, 1954</td>
</tr>
<tr>
<td><strong>Oysters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Belgium</td>
<td>Duchâteau <em>et al.</em>, 1952</td>
</tr>
<tr>
<td></td>
<td>Spain</td>
<td>Intengan <em>et al.</em>, 1956</td>
</tr>
<tr>
<td></td>
<td>Yugoslavia</td>
<td>Krvarić, 1953</td>
</tr>
<tr>
<td><strong>Gastropods</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Thais</em> sp.</td>
<td>Peru</td>
<td>Okuyama Bazan, 1953</td>
</tr>
<tr>
<td><em>Stichopus</em> sp.</td>
<td>Soviet Union</td>
<td>Leont'ev and Markova, 1936</td>
</tr>
<tr>
<td></td>
<td>Japan</td>
<td>Tanikawa and Ichiko, 1955</td>
</tr>
</tbody>
</table>

Crustacean protein is purported to show less tyrosine, arginine, and methionine than mammal protein does (Malikova, 1957).

Molluscan proteins showed lower values for valine, methionine, phenylalanine, lysine, and histidine than the muscle proteins of fish and crustaceans (Kōnosu and Mori, 1959). These observations were based on hard clams and abalone.
Both methionine and threonine were found to be lower (30-40% less) in both crustacean and molluscan shellfish as compared to most fish, both salt-water and fresh-water species (Hatakoshi, 1953).

B. CRUSTACEANS

Crustacean protein compares well in major amino acids with casein, beef, and egg albumen (Pottinger and Baldwin, 1940; Master and Magar, 1954).

The pattern of amino acid distribution in crustacean protein is relatively uniform (Kuo-Hao, 1926). Some slight differences, however, were observed (Kōnosu et al., 1958) (see also Tables V and VII). The amount of arginine is the most variable, ranging between 6.3% (blue crab) and 9.0% (prawn). The content of glycine, alanine, leucine, tyrosine, and phenylalanine of crustacean muscle proteins was at almost the same level as those of the ordinary muscle protein of fish. But the crustacean muscle shows a higher value of the acidic amino acids, glutamic and aspartic acids, and a lower value of valine, isoleucine, threonine, and lysine when compared with fish muscle (Table VIII). Master and Magar (1954) found no difference in lysine, nor did Taranova et al. (1955). Kuo-Hao (1926) obtained high lysine values in crabs, as did Kondo and Iwama (1932).

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Prawn</th>
<th>Lobster</th>
<th>Blue crab</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycine</td>
<td>4.7</td>
<td>4.6</td>
<td>4.7</td>
<td>3.0-5.5</td>
</tr>
<tr>
<td>Alanine</td>
<td>6.0</td>
<td>5.9</td>
<td>5.7</td>
<td>5.1-7.3</td>
</tr>
<tr>
<td>Valine</td>
<td>4.4</td>
<td>4.5</td>
<td>5.0</td>
<td>5.6-9.3</td>
</tr>
<tr>
<td>Leucine</td>
<td>8.6</td>
<td>8.6</td>
<td>9.0</td>
<td>7.4-9.4</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.8</td>
<td>4.1</td>
<td>4.7</td>
<td>5.0-7.9</td>
</tr>
<tr>
<td>Serine</td>
<td>4.2</td>
<td>4.9</td>
<td>4.9</td>
<td>4.6-5.5</td>
</tr>
<tr>
<td>Threonine</td>
<td>4.1</td>
<td>4.4</td>
<td>5.2</td>
<td>5.2-6.0</td>
</tr>
<tr>
<td>Methionine</td>
<td>2.8</td>
<td>3.2</td>
<td>3.0</td>
<td>3.1-3.7</td>
</tr>
<tr>
<td>Cystine</td>
<td>1.10</td>
<td>1.3</td>
<td>1.7</td>
<td>—</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>11.7</td>
<td>12.3</td>
<td>12.0</td>
<td>6.2-11.5</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>17.5</td>
<td>16.9</td>
<td>16.2</td>
<td>13.4-16.9</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>4.1</td>
<td>4.1</td>
<td>4.7</td>
<td>3.5-4.6</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.4</td>
<td>4.7</td>
<td>4.8</td>
<td>3.4-5.2</td>
</tr>
<tr>
<td>Proline</td>
<td>3.7</td>
<td>3.4</td>
<td>4.5</td>
<td>2.9-4.2</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>1.0</td>
<td>0.9</td>
<td>1.6</td>
<td>1.1-1.4</td>
</tr>
<tr>
<td>Arginine</td>
<td>9.0</td>
<td>7.4</td>
<td>6.3</td>
<td>5.9-6.9</td>
</tr>
<tr>
<td>Lysine</td>
<td>9.4</td>
<td>9.5</td>
<td>8.9</td>
<td>9.9-11.8</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.9</td>
<td>2.1</td>
<td>2.4</td>
<td>2.2-3.9</td>
</tr>
</tbody>
</table>

* Source: Kōnosu et al., 1958.
The histidine-arginine fraction is generally very high in crustacean shellfish (Kondo and Iwamae, 1932; Campbell, 1934–1935). Soviet studies found arginine and cystine higher in lobster and crab, exceeding the values for most fish and terrestrial meats.

### Table VIII

**Amino Acid Composition of Bombay Crustaceans**

<table>
<thead>
<tr>
<th>Amino acids</th>
<th>Prawn</th>
<th>Lobster</th>
<th>Fish (&quot;pakat&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methionine</td>
<td>4.6</td>
<td>2.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Lysine</td>
<td>18.5</td>
<td>17.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.6</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.6</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Leucine</td>
<td>14.3</td>
<td>11.3</td>
<td>12.5</td>
</tr>
<tr>
<td>Valine</td>
<td>4.1</td>
<td>2.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>5.6</td>
<td>4.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Cystine</td>
<td>1.4</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Arginine</td>
<td>8.3</td>
<td>7.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Threonine</td>
<td>4.6</td>
<td>5.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>0.4</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>1.0</td>
<td>0.8</td>
<td>1.4</td>
</tr>
</tbody>
</table>

*Source: Master and Magar, 1954.*

The Indian prawn "pak" has a good aminogram and is readily digested (Valanju and Sohonie, 1957); in fact, it exceeds casein in this respect.

The crustacean flesh (shrimp, lobster, crab, and crayfish), as well as that of mollusks, is practically devoid of creatine. Related compounds are found in place of creatine, e.g., in crustaceans the amino acid arginine which combines with phosphorus.

### C. Molluscan Shellfish

The first amino acid analysis reported was on a scallop. Chittenden (1875) found in the major adductor muscle of *Pecten irradians* a relatively large amount of free glycocoll. But Osborne and Jones (1909) found still more when analyzing the protein. The general amino acid composition of scallop protein closely resembled that of halibut and chicken. There was somewhat less of leucine and slightly more of phenylalanine and arginine.

Könosu and Mori (1959) compared the amino acid distribution of the proteins in the minced edible part of a hard clam (*Meretrix meretrix lusoria* Gmelin) with that of an abalone (*Haliotis gigantea* Gmelin), and found that they were rather uniform, but some slight differences were observed. The protein of abalone is richer in glycine, proline, and argi-
nine, but poorer in leucine, glutamic acid, tyrosine, and lysine. It was also found that the tryptophan content of the hard clam protein is higher. These molluscan proteins show a lower value of valine, methionine, phenylalanine, lysine, and histidine than the muscle proteins of fish and crustaceans examined in previous studies (Könosu and Mori, 1959).

D. CEPHALOPODS

Könosu et al. (1956, 1957) established that the content of essential amino acids in cuttlefish protein coincides greatly with that of teleost fish. Squid contained larger amounts of arginine, aspartic acid, glutamic acid, and leucine and exceeded most vertebrates in this respect (Sugi。

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Squid</th>
<th>Octopus</th>
<th>Sea cucumber</th>
<th>Sardine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (dry matter)</td>
<td>12.6</td>
<td>15.6</td>
<td>9.5</td>
<td>13.3</td>
</tr>
<tr>
<td>Amide</td>
<td>4.1</td>
<td>4.3</td>
<td>3.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Humin</td>
<td>3.3</td>
<td>1.5</td>
<td>11.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Arginine</td>
<td>20.0</td>
<td>17.1</td>
<td>11.2</td>
<td>11.9</td>
</tr>
<tr>
<td>Histidine</td>
<td>8.7</td>
<td>4.9</td>
<td>9.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Lysine</td>
<td>10.1</td>
<td>9.4</td>
<td>0.8</td>
<td>15.0</td>
</tr>
<tr>
<td>Cystine</td>
<td>0.9</td>
<td>0.6</td>
<td>0.9</td>
<td>0.2</td>
</tr>
</tbody>
</table>


mura et al., 1954) but was lower in histidine, lysine, and methionine. No differences were observed in other amino acids. It can be seen in Table IX that the content of lysine in squid not always is superior to that in fish.

E. MISCELLANEOUS INVERTEBRATES

The sea cucumber is characterized by high histidine values, but is very low in lysine and cystine (Table IX).

A compound toxic to protozoans, certain amphibia, fish, and mice was discovered in a sea cucumber common in the Caribbean, Actinopya agassizi. It was named holothurin (Nigrelli and Zahl, 1952).

F. SULFUROUS AMINO ACIDS

Okuda and Matsui (1916) reported that the sulfur content of crustacean flesh is higher than that in fish (1.2–2.8% sulfur in dried fish). Female crabs contain more sulfur. The sulfur in shrimp protein was studied in 1932 by Baernstein, its amount being only slightly higher than in halibut flesh.

Methionine, cystine, and cysteine were analyzed in four crustaceans from off the Peruvian coast. Both methionine (0.6–0.36%) and cystine
(0.52–0.26%) were high, while cysteine was low (0.12–0.06%) (de la Torre, 1952). Later, molluscan shellfish were investigated as to these same constituents, showing in broad lines a similar pattern. Squids, octopii, and mussels were studied also (Flores Castaño, 1953).

Cysteine and cystine are absent in shrimp, according to Ranke (1959).

Both crustacean and mollusks are rich in methionine. Squids and dried crustacean paste are high in methionine—approximately 3.2% of the protein, according to Villadelmar (1956–1957) (see tabulation).

<table>
<thead>
<tr>
<th>Source</th>
<th>Methionine content (% of protein)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oyster (Japanese)</td>
<td>0.25</td>
</tr>
<tr>
<td>Meretrix sp.</td>
<td>2.18</td>
</tr>
<tr>
<td>Mactura sulcatria</td>
<td>3.46</td>
</tr>
<tr>
<td>Squid</td>
<td>3.2</td>
</tr>
</tbody>
</table>

G. LYSINE

Lysine was reported higher in shrimp than in scallop muscles (7.7% as against 5.8%) (Jones et al., 1925). In general, crustacean protein is high in this important acid (Master and Magar, 1954).

Most shellfish used in Mexican diets are rich in lysine; 9.2–10.2%, according to Villadelmar (1956–1957). Sea cucumbers are poor sources of lysine (Tanikawa, 1955).

H. TRYPOTOPHAN

Blue crab contains 1.6% of tryptophan. This value is the highest encountered in any fish or crustacean (Kōnosu et al., 1956).

The content of tryptophan is higher in squids and snails than in blue crab (Villadelmar et al., 1956–1957). This was shown to be true for the large squid Loligo gahi (Ferreyra Risso, 1953).

I. TYROSINE

The large squid Loligo gahi, commonly eaten in Spain, is higher in tyrosine than most fish, namely, 0.39% of the flesh or about 2% on a dry basis (Ferreyra Risso, 1953).

J. GLUTAMIC ACID

Shellfish generally is as rich in glutamic acid as wheat flour, and consequently is a good source (Reyes, 1950). It exceeds most fish, although shellfish generally contain more of this amino acid than beef does.
K. Free Amino Acids

The first study on free amino acids was conducted on crabs (Ackermann and Kutscher, 1907; Suzuki, et al., 1912). In 1909, Suzuki and Yoshimura reported on free amino acids in lobster and squid. Okuda (1912) and Okuda et al. (1919) concluded that shellfish muscle is characterized by the lack of creatine, whereas vertebrates, including fish, commonly carry this compound. This was confirmed in later investigations (Campbell, 1934–1935; Fraser et al., 1952).

Arginine shows the reverse pattern, being abundant in extracts of shellfish, both crustacean and molluscan, but lacking in vertebrate muscle tissue. It is, however, present in large quantities in the muscle protein of both vertebrates and invertebrates. Arginine unquestionably is the mother substance of creatine. This leads to the conclusion that vertebrate tissues have the power to transform arginine into creatine, while the invertebrates lack this capability.

When comparing the free amino acid pool of a gastropod, Chinese crab, and lobster, certain specific characteristics were noticed for each of these, in spite of the fact that they all carried the same fifteen amino acids (Camien et al., 1951; Florkin, 1954; Duchâteau et al., 1954). The muscle protein does not change its composition parallel with variations in the free pool. Lobster flesh has a protein with a higher content of arginine, glycocoll, and proline, while the muscle protein of the snail is dominated by alanine and arginine.

Free amino acids and other similar compounds play an important part in the osmotic regulation of marine invertebrates. This has been confirmed for the whole muscle of Nephrops (Robertson, 1957) and for Carcinus, where they account for over 60% of the total osmotic activity (Shaw, 1958). Fraser et al. (1952) reported that the principal free amino acids in the flesh of lobster and crabs were proline, glycine, and the related taurine, with less glutamic acid and asparagine. An unidentified amino acid was found by Airan et al. (1953) in studies on East Indian lobsters.

Nonprotein nitrogen as a whole constitutes about 10% of the total N in teleosts, 20% in crustaceans and mollusks, and 30% in the elasmobranchs. Levels of free amino acids N was 300 mg./100 g. of wet muscle in crustaceans and mollusks, while in fish it was 20–40 mg./100 g. wet muscle (Velankar and Goindau, 1958b) (see Chapter 11 by Simidu in Volume I).

The fifteen nonprotein amino acids present in the flesh of crustaceans occur in higher concentrations in marine forms than in fresh-water species. Among the latter, the Chinese crab Eriocheir sinensis is a
poekilo-osmotic form which exhibits concentration changes depending on the external environmental waters (Edwards et al., 1955; Florkin, 1958–1959). In sea water the concentration is higher, in particular in proline and all other amino acids, with the exception or arginine. These animals return to their original concentration in fresh water as soon as they are returned to such an environment. The species belonging to a brackish form acquires a concentration in between that of fresh and marine waters. There have been indications that the pool of free amino acids plays a role in osmotic regulation of the tissue. The ordinary freshwater crayfish, however, which is not adapted to living in brackish water, does not show the same changes in water with a salt concentration half that of marine water; only the protein content is increased. The free amino acids remain unchanged (Duchâteau and Florkin, 1954, 1955a, b, 1956). This entire field of environmental effects on the composition of the pool of free amino acids has recently been reviewed by Waterman (1960).

Seventeen free amino acids were found in the muscles of three kinds of mollusks, the clam (Meretrix meretrix lusoria), the little-neck clam (Tapes japonica), and the soft-shelled clam (Mya japonica), and their variations during spoilage were determined by the microbiological method. For the purpose of comparison, the same determination was made on the muscle of the mullet (Liza haematocheila). The amino acid nitrogen accounted for about 52 to 63% of the extractive nitrogen in the molluscs, but only 29% of the mullet. The main components of the free amino acids were alanine, glycine, arginine, and glutamic acid in the muscle of three shellfish, while in the fish they were glycine, histidine, and alanine (Ito, 1959).

Iced shrimps (and prawns) lose amino acids through leaching for 6 to 7 days. This in turn explains the reduced flavor (Velankar and Govindan, 1958a). Naturally, these losses may contribute to a somewhat lower supplementary value of these products.

True arginine was discovered in lobster muscle by Hoppe-Seyler (1933) in the d-form, not as the dl-form, which was earlier obtained from fresh-water crabs by Broude (1933). Kermack et al. (1955) encountered large amounts of free proline and glycine in fresh lobster muscle, smaller quantities of glutamine and alanine, and traces of aspartic acid, glutamic acid, histidine, lysine, threonine, and tyrosine. Camien et al. (1951) found somewhat more arginine, and less valine and leucine. In addition, Kermack et al. (1955) found taurine present to the extent of about 300 mg./100 g. wet muscle. The relatively small amount of histidine present is in striking contrast to the amount of this amino acid found in certain fish, particularly those with red meat.
Free glycine was detected early by Chittenden (1875) in scallops (Pecten irradians) and later by Kelly (1904) in P. operculans. It generally coexists with betaine. Large quantities have been demonstrated in starfish.

Proline is the mother substance of stachydine and has been found in lobster, squid, and shrimp.

Taurine is a common constituent of many kinds of muscles, and is not limited to molluscs, as some authors maintain, although the quantity predominates there. Shellfish are consequently richer than most fish in this particular compound (Okuda and Sanada, 1919) (see tabulation).

<table>
<thead>
<tr>
<th>Shellfish</th>
<th>Taurine in % of fresh flesh</th>
<th>Taurine in % of dry flesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustacea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neptunus pelagicus</td>
<td>0.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Palinurus vulgaris</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Mollusks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinna japonica (adductor muscle)</td>
<td>0.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Avicula martensii (mantle)</td>
<td>0.9</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Source: Okuda and Sanada, 1919.

Kelly (1904) estimated that taurine made up 5% of the dry matter of Mytilus muscle, corresponding to 100 millimoles/kg. water in the whole muscle. Arginine and taurine were identified in the marine gastropod Patella (Ackermann and Janka, 1954).

The concentration of amino acids in the salt-water Mytilus blood is only 2.5 millimoles/kg. water, but is lower, 0.5 millimole/kg. water in the fresh-water mussel Anodonta. Much higher values are encountered in the muscle tissue: in the Mytilus muscle 166.2 millimoles/kg. total water and in Anodonta 9.5 millimoles/kg. total water, but yet far less in the fresh-water forms (Duchâteau et al., 1952).

I. OTHER SHELLFISH PRODUCTS

In comparing the protein of muscle tissue with the chitin of crustaceans, basic differences have been noted. Both tyrosine and cystine are lower in chitin, when compared to muscle tissue (Airan and Thomas, 1953). In some crustaceans no arginine or cystine was found in the chitin (Airan and Karat, 1953; Airan and Thomas, 1954).

Octopine, containing chiefly arginine, has been isolated from squids, octopi and scallop muscles. Its nutritive value has not been investigated. Further information on this and related compounds is available in Chapter 11, Volume I.
V. Other Nutrients

Most shellfish are rich in calcium (Malikova, 1957). Also nutritionally significant is the fact that thiaminase occurs in some shellfish, both molluscan and crustacean. Shrimps (Peneus sp.) and some mussels are rich in this enzyme, while it is almost absent in most crabs (Jacobsohn and Azevado, 1947). The presence of this enzyme induces abnormally low thiamine values in the muscle tissues of such shellfish after death (Lubitz et al., 1943).

These factors may be important in the right interpretation of the biological and nutritive value of shellfish proteins.

VI. Digestibility

The digestibility coefficient of shrimp was found to be 67. The biological value of this protein was 69, and the net utilization coefficient 56. Thus, 1 kg. of shrimp meat yielded only 126 g. of fully utilizable protein. The corresponding figures for smoked cod flesh was 148 g. (Varela, 1955).

The digestibility of sea cucumber tissue is inferior to that of fish meat (Tanikawa, 1955).

In a comparative study covering fish and several shellfish, lobster consistently turned out to be the leading crustacean as to net utilization ratio (see Part I of this chapter) and digestibility. Octopus and ordinary mussel (Mactra helvacea) led in the molluscan group. Oyster was not tested. Squid is inferior to octopus (Pujol and Varela, 1958).

VII. Changes in Storage and Processing

A. Spoilage

The middle section of the intestines carries glands which excrete quite potent cathepsins. Independently of bacterial attacks, a proteolytic, rather rapid breakdown takes place in the vicinity of the viscera in the meat of crabs (Degkwitz et al., 1954).

During spoilage, there is a continuous increase in the concentration of leucine, isoleucine, valine, glutamic acid, aspartic acid, α- and γ-amino-butyric acid (Ranke and Bromstedt, 1954; Ranke et al., 1956), the two latter presumably being of a bacterial origin.

There are considerable changes among the free amino acids during spoilage. The total amount goes up as the mollusks spoil, the amount of free arginine falls rapidly, and glutamic acid decreases to some degree. Other amino acids increase slightly, but the change is not considerable (Ito, 1959).
Poisoning through mollusks constitutes a hazard. This is generally caused by toxic compounds emanating from dinoflagellates and is further discussed in Chapter 11 by Shewan. In other cases, mollusks may convey *Coli* and *Salmonella* infections. Large cleansing tanks with chlorinated water constitute an important countermeasure. In recent years there have been reports from Sweden, Mississippi, and New Jersey of oysters and clams having caused epidemics of hepatitis (Anonymous, 1961). These problems are further elaborated in Chapter 7 of this volume. A Japanese gastropod (*Nephenea arthritica*) carries a poisonous salivary gland which has to be removed prior to consumption (Asano, 1951–1952). Factors of this kind contribute to restrictions in the full use of shellfish as food.

Blackening of shrimp is due to enzyme activity, phenoloxidases forming melanins (Bailey, 1958). It has largely been overlooked that crustaceans can be subdivided biochemically into two major groups as to their hypodermic amino acids and their capability of forming melanin pigments (Drilhon and Busnel, 1950). The relative importance of individual free amino acids differs somewhat. In both groups, whether they can form melanin or not, glycocoll, alanine, and valine are the leading amino acids, but the composition becomes different when the acids are listed in order of importance:

<table>
<thead>
<tr>
<th>Without melanins</th>
<th>With melanins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyrosine</td>
<td>Aspartic acid</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>Proline</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td></td>
</tr>
<tr>
<td>Leucine</td>
<td></td>
</tr>
<tr>
<td>Histidine</td>
<td></td>
</tr>
<tr>
<td>Proline</td>
<td></td>
</tr>
</tbody>
</table>

For further discussion see Chapter 8, Volume I.

### B. FREEZING

Freezing had no effect on the nutritive value of crab proteins, according to Watson and Fellers (1935). The blue and the sand crab were studied.

### C. CANNING

In canning crab, the nutritive value of its protein was only very slightly reduced (Watson and Fellers, 1935). Both biological value and digestibility were largely maintained on a high level in the canning of blue crab, king crab and Dungeness crab (Lanham *et al*., 1940). In a broad comparative study it was established that the heat processing
employed in canning did not change the amino acid composition of
shrimp (Dunn et al., 1949; Nielands et al., 1949).

Not infrequently, crab meat, when processed through canning, turns
brown. This seems to occur at a high temperature when processed on
land, but at a low temperature when prepared on floating canneries.
Only when not completely fresh raw material is used does browning
occur at high temperatures.

The low-temperature treatment may give browning discolorations
even in meat from newly captured specimens. In both cases the browning
is due to the traditional Maillard reaction, the presence of both amino
acids and reducing sugar constituting prerequisites for such a reaction.
Their amounts are generally larger in meat that browns than in normal
packs. Browning is more often observed in canned products prepared
from hard-shell crab than from peeled crab. Crabs kept in ice water
showed less susceptibility than those held in crushed ice, presumably
due to leaching.

The presence of Cu++ in crab blood (body fluid) or Fe+++ in crab
meat accelerates the browning reaction. The greater the remaining
amount of blood in the meat, the greater is the degree of browning
(Nagasawa, 1960).

D. COOKING

Using the proteolytic breakdown through pancreatin as a test method,
it was established by Nomura (1953) that shellfish protein was more
readily digested in the raw stage than in the cooked forms. This is in
accordance with findings on fish, but in contrast to poultry meat and beef.

Okuda and Matsui (1916) reported that, in cooking, some volatile
sulfur compounds are formed in Kamchatka crabs. As female crab con­
tains more sulfur, its flesh is considered inferior for canning. Free amino
acids are lost in the cooking of shrimp (Ranke, 1959).

E. DRYING

Dried flesh of a crab (Polybius henslowi) common to the northwest
cost of Spain contained 44.2% of protein. Rat growth experiments
showed that the digestibility coefficient of its protein was 78.7 but that
the nutritive value was low.

The semidrying of prawns is a novel, more lenient method of preser­
vation. Such semidried prawns retained all the essential amino acids
(Chari and Venkataraman, 1957).

Dried mollusks, both fresh-water and salt-water species, are used as
poultry feed. This product contains 59-76% protein with a good amino
acids composition, but cystine is reported lacking (Zikeev, 1948). This particular amino acid is, however, readily synthesized by the hen.

Dried squid is a popular food in many countries. It is used as a base for soup stock. Normally this product maintains its protein quality well and also its stock of free amino acids. Yoshimatsu et al. (1958) reported the abundant presence of glycine, alanine, proline, and glutamic acid. Betaine is also a dominant ingredient.

The fresh meat of *Stichopus japonicus* is difficult to dry. The hydrating affinity of the sea cucumber meat is comparatively weak, but the meat nevertheless is very difficult to dry (Tanikawa and Yoshitani, 1955). This difficulty varies, depending on the drying temperature.

### F. Fermentation

Soy sauce is not infrequently made from shellfish, particularly cephalopods, through autodigestion. In comparing such sauces made from octopus and squid, only minor differences were observed in the amino acid composition of the final products (Table X). This seems to be true of both total diamino and monoamino acids, as well as the individual major amino acids, such as arginine, lysine, and histidine (Fukai, 1947).

<table>
<thead>
<tr>
<th>Acid-soluble N</th>
<th>Octopus %</th>
<th>Squid %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amino</td>
<td>14.6</td>
<td>13.3</td>
</tr>
<tr>
<td>Humin</td>
<td>2.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Arginine</td>
<td>9.4</td>
<td>10.9</td>
</tr>
<tr>
<td>Histidine</td>
<td>9.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Lysine</td>
<td>10.6</td>
<td>10.6</td>
</tr>
<tr>
<td>Cystine</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Total diamino</td>
<td>30.8</td>
<td>30.8</td>
</tr>
<tr>
<td>Total monoamino</td>
<td>52.4</td>
<td>52.7</td>
</tr>
<tr>
<td>Non-amino</td>
<td>4.9</td>
<td>1.3</td>
</tr>
</tbody>
</table>

* Source: Fukai, 1947.

### G. Hydrolyzates

Not only fish are fermented into pastes in Southeast Asia. Several shellfish are prepared the same way through a partial enzymic hydrolysis—about half of the protein is split into amino acids. Several such shellfish pastes are known from the Philippines, Cambodia, Laos, Indonesia, and Burma. The amino acid composition of the Burmese "ngapi seinsa" makes it nutritious human food (Blass and Richard, 1952; Duchâteau et al., 1953)—see Table XI.
TABLE XI

Amino Acids in the Shellfish Paste "Ngapi Seinsa"*  

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>% Dialyzable nitrogen</th>
<th>Amino acid</th>
<th>% Dialyzable nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine</td>
<td>9.3</td>
<td>Lysine</td>
<td>8.4</td>
</tr>
<tr>
<td>Arginine</td>
<td>5.8</td>
<td>Methionine</td>
<td>1.3</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>5.6</td>
<td>Phenylalanine</td>
<td>2.3</td>
</tr>
<tr>
<td>Guttamic acid</td>
<td>8.8</td>
<td>Proline</td>
<td>2.0</td>
</tr>
<tr>
<td>Glycocoll</td>
<td>8.5</td>
<td>Threonine</td>
<td>2.7</td>
</tr>
<tr>
<td>Histidine</td>
<td>2.1</td>
<td>Tyrosine</td>
<td>1.4</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.8</td>
<td>Valine</td>
<td>4.3</td>
</tr>
<tr>
<td>Leucine</td>
<td>5.9</td>
<td></td>
<td>73.2</td>
</tr>
</tbody>
</table>

* Source: Duchâteau et al., 1953.

VIII. Shellfish Meals

Crab and shrimp meal are increasingly used as animal feed, for as the corresponding industries grow, the amount of waste mounts. An efficient utilization of offal, shells, etc., is gradually becoming urgently needed from both the sanitary and economic points of view.

The biological value of crab meal (protein content 35%) is high (85.9). What is retained in the body is well utilized, but the digestibility (70.7) as well as the net utilization (60.2) is lower than corresponding figures for other marine organisms (Sure and Easterling, 1952). Crab meal is also a most satisfactory ingredient of chick or broiler rations (Parkhurst et al., 1942). Du Toit and Smuts (1941) placed crayfish meal (91) between that of whitefish (94) and herring (73), but Bronkhorst (1938) found crayfish meal better than fish meal. Good results with crayfish meal were also reported by van der Vyver (1951). Crayfish waste from processing plants in the west part of the Cape province constitutes a fine supplement in the feeding of hogs (Johnston and Bartel, 1932).

Both crab and shrimp meal are good when added to soybean meal (Anonymous, 1953) or equivalent to meal scrap in growth effect on hogs (Anonymous, 1952). In the analysis of shellfish meals, erroneously high values for protein are reported, unless a correction is made for the apparent protein contributed by chitin, an N-acetylated glucosamine polysaccharide (Brown, 1959).

The ordinary blue mussel (Mytilus edulis) has emerged as a particularly valuable feeding-stuff in the Soviet Union. Preserved with sodium bisulphite or dried, it stays well preserved. It promotes egg production and hog growth efficiently (Kudryavtsev, 1951). Harvesting of mussels for exclusive use in the raising of pigs is even contemplated (Zambriborsič, 1956).
The hunt for unknown accessory growth factors (see Chapter 2, Part I, this volume) is also extended to the field of shellfish meal. Indirect evidence points to their presence in this kind of meal when tested in poultry rations (Sullivan et al., 1960).

As part of a plan to make a constructive approach to the serious problem of the giant African snail (*Achatina fulica* Bowdich) in the Pacific islands, assays of the essential amino acids were made to determine the possibility of using “snail meal” as a source of animal protein in the feeds of poultry and livestock.

The value for arginine is nearly $2 \frac{1}{3}$ and for lysine more than $1 \frac{1}{2}$ times the value in whole egg. All other values, although appreciable and significant, fall below the values for whole egg. The deficiencies of oil cake meals could, nevertheless, be readily overcome through the addition of such snail meal (Mead and Kemmerer, 1953).

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