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Edible Seaweeds — A Survey of the Industry and Prospects for Farming the Pacific Northwest

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Figure 1.—Sushi, a Japanese dish made from rice and other foods such as fish, vegetables, and seaweed. Note the nori in the upper left corner.

ABSTRACT — For centuries, seaweeds have been used by man throughout the world. They are presently used as food and as a source of chemicals. In Oriental communities, seaweeds are used primarily as food. The U.S. harvest is used mostly for the production of chemicals. Most edible seaweeds are imported from Japan and the Republic of Korea and retail at prices ranging from $2 to $56/lb. There is already an established market in the United States with opportunities for expansion. The availability of suitable growing conditions in Puget Sound, the presence of a large Oriental community, and the high prices commanded by seaweed products suggest that edible seaweeds can be grown and marketed successfully in the Puget Sound Basin.

INTRODUCTION

In China, the use of seaweeds was recorded as long ago as 3,000 B.C. Throughout the world, their use has continued through the ages although the Greeks and Romans had little regard for them. In Europe, as far back as the 12th Century, seaweeds were used as animal feed and fertilizer. During the 18th Century, seaweed ash was the main source of soda for making glass and soap. Burning kelp for soda thrived as an industry until it was discovered how to use salt as a more efficient source. The kelp industry then declined rapidly. Seaweeds have been used at times as sources of other chemicals, such as iodine, only to be replaced by other, cheaper sources as they became available.

Carrageenan, a gelling agent derived from Irish moss, *Chondrus crispus*, was first discovered in Ireland. Production in the United States began along the Atlantic coast about the middle of the 19th Century, expanded rapidly, and continues today.

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From 1911 to 1914 when imports of potash into the United States were greatly reduced, seaweeds were used as alternate sources. Surveys and subsequent harvests along the Pacific coast during this period showed that estimates of yield were overly optimistic (Scagel, 1961), a point to be considered in estimating potential production from wild stands.

Historically, the harvest of seaweeds in the Western world has varied with the demand for chemicals. Each time a cheaper, more convenient source was discovered, the seaweed market collapsed. Now seaweeds are used mostly for food, fertilizer, or as sources of agar, algin, and carrageenan. In the Orient, where seaweed is widely used as food, it is not a staple, but rather a seasoning and food supplement. In Oriental communities throughout the world, the demand for edible seaweeds is likely to increase as purchasing power and living standards rise.

In the United States, seaweeds are eaten primarily in Japanese communities located in large cities such as Los Angeles, Chicago, San Francisco, and Seattle. The sale of these seaweed products is expanding with the penetration of Japanese-type foods into gourmet markets. Most of the processed edible seaweeds are imported from Japan and are very expensive, retailing at up to $56.00/lb (net). However, home processing of seaweeds of good quality from the intertidal beaches is not uncommon among Japanese-Americans on the West Coast.

The three most common seaweeds used as food both here and in Japan are *Laminaria* (kombu), *Porphyra* (nori), and *Undaria* (wakame). Kombu

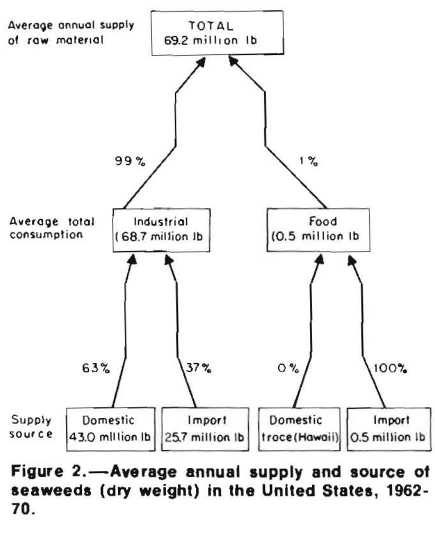


Figure 2.—Average annual supply and source of seaweeds (dry weight) in the United States, 1962-70.

is used as soup stock. Dried strips are eaten as snacks. Shredded and soaked in soy sauce, it serves as seasoning for rice dishes and is also boiled and eaten as a vegetable. Although taste is the main concern of those who eat seaweeds, the nutritional properties are likely to be beneficial (Taub, 1972). Kombu contains 6 percent protein, vitamins, and trace minerals (dry weight); nori (Japanese term for laver) contains 30-50 percent protein (dry weight) in addition to vitamins and minerals (Silverthorne and Sorensen, 1971). Analyses of several species of nori that grow in Puget Sound confirm this with similar ratios of protein (27 to 41 percent). Dried and pressed into sheets, nori is used to wrap rice rolls (Fig. 1) which are eaten by the Japanese somewhat as sandwiches are in the West. Small flakes of nori also flavor rice crackers, soups, and other dishes. Wakame is used as a vegetable in salads and soups.

In Japan, 65 percent of the wakame and almost all of the nori production comes from cultured stocks. In contrast, only about 30 percent of the kombu comes from cultured stocks.

Seaweeds, like other plants, contain carbohydrates, fats, and proteins. The carbohydrates are not very sweet and do not bring about a significant increase in blood sugar when eaten. The proteins, similar to those of land plants, are useful for human nutrition. Although they do not contain much fat, at least one unsaturated fatty acid necessary for human health is usually present along with vitamins (A, B-complex, and C) and minerals (sodium, iodine, and trace elements), which are important in human nutrition. Although synthetically iodized table salt is abundant and cheap, many people prefer natural combinations of these minerals as found in seaweeds.

In addition to the nutritive value of seaweeds, Dr. Stanley Skoryna, of the Gastro-Intestinal Laboratories of McGill University in Montreal, Canada, has found that sodium alginate from ingested seaweeds assists the selective absorption of calcium over strontium so that calcium is absorbed through the intestinal wall while 50-80 percent of the strontium (including the dangerous isotope Sr^{90}) is bound by the alginate and is harmlessly excreted (Taub, 1972).

Studies of mammary cancer in laboratory animals and humans show that the higher the level of iodine in the tissues, the lower the incidence of cancer (Eskin, 1970). Adding seaweed products to the diet is a simple, effective way to provide iodine therapy.

HARVEST AND MARKETS

World Production

In 1961 the worldwide harvest of seaweeds amounted to 1.2 million metric tons (mt), wet weight, and increased in 1970 to 1.7 million mt. Average annual increase for the period was 4.3 percent. Silverthorne and Sorensen (1971) estimated that Asia currently produces 72.3 percent of the total with the Peoples Republic of China producing 35.8 percent, Japan 29.5 percent, and the Republic of Korea 7.0 percent. The United States produces 7.5 percent of the total world harvest.

U.S. Production and Supply

In the United States, seaweeds are used mainly for the production of agar, algin, and carrageenan. In addition, some seaweeds are used for fertilizer and meal. The quantity, sources, and uses of seaweeds in the United States are shown in Figure 2.

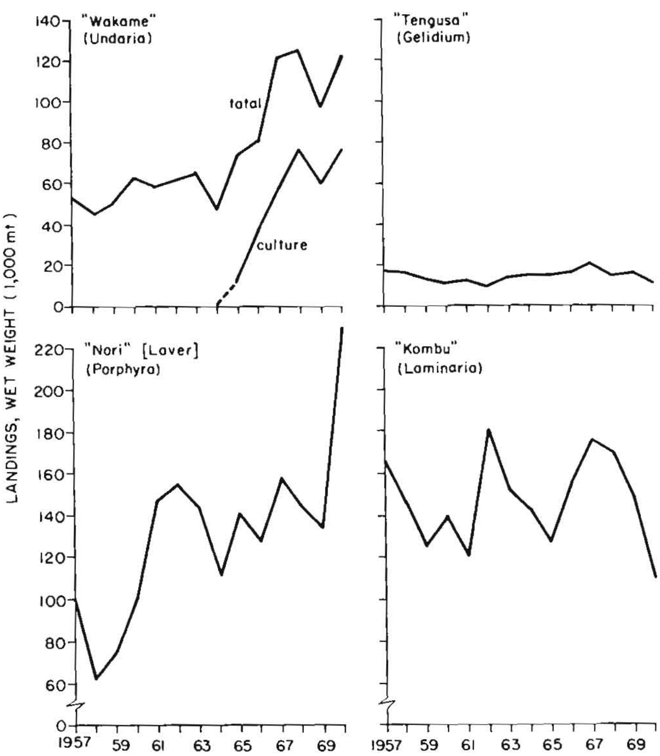


Figure 3.—Japanese production of edible seaweeds during 1957-70. Source: Ministry of Agriculture and Forestry, 1972a.

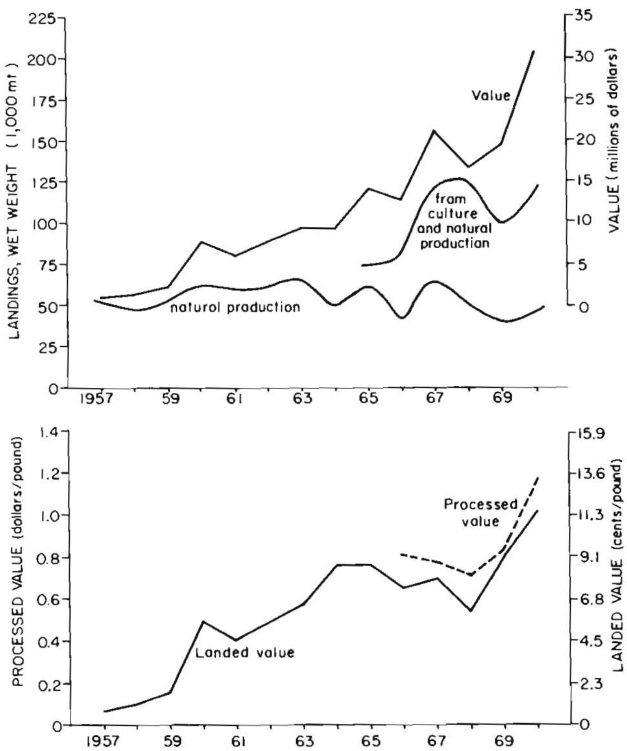


Figure 4.—Japanese production and value of "wakame," *Undaria*, 1957-70. Source: Ministry of Agriculture and Forestry, 1972a and 1972b.

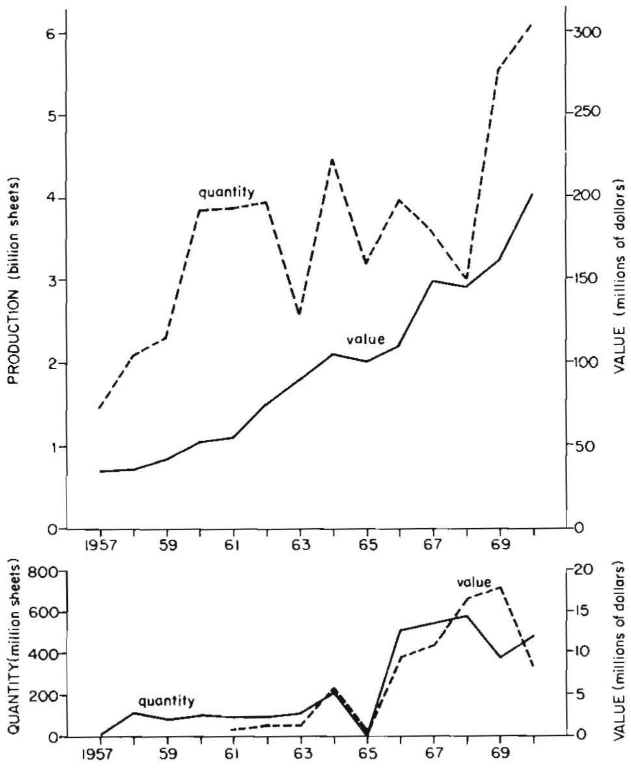


Figure 5.—Japanese production and imports of processed "nori" sheets, by quanity and value during 1957-70. Source: Ministry of Agriculture and Forestry, 1968a, 1968b, 1970, 1972a, 1972b.

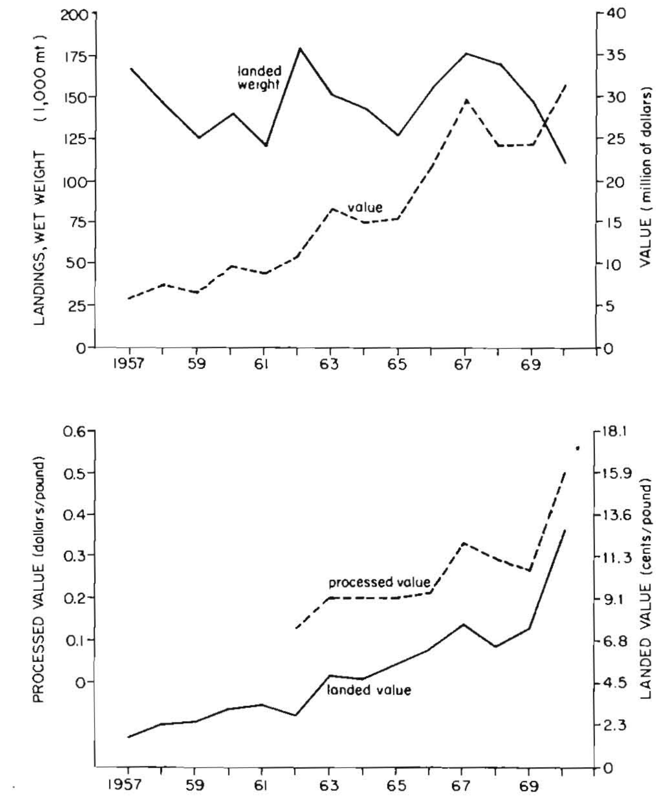


Figure 6.—Japanese production and value of "kombu," *Laminaria*, 1957-70. Source: Ministry of Agriculture and Forestry, 1972a and 1972b.

The Alaskan harvest of herring eggs-on-kelp (kazunoko-kombu), which is mostly exported to Japan, has not been included. This is classified in economic reports as fish eggs. For 1965-66 the value of this fishery was $500,000 (Anonymous, 1960-1970).

The present U.S. production of seaweeds for food is very small. Small amounts are harvested and sold fresh in Hawaii, some are processed for use by the health-food industry, and the rest are gathered by individuals for personal use. Almost all of the edible seaweeds sold in the United States are imported.

The quantity, value, and source of imported seaweed food products during 1964-71 are presented in Table 1. These imports serve the needs of Oriental communities (primarily Japanese and Korean) in the United States and consist mostly of dried nori and wakame. In Seattle, sample retail prices for dried and packaged seaweed products in 1973 were:

1) Nori—$10.31 to $56.00/lb (average $34.39). A container of seasoned nori, weighing 0.6 oz (net) and cut into small sheets, sold for $1.75.

Table 1.—U.S. imports of prepared edible seaweed products[1].

	Net Weight (lb)				Value ($)[2]			
Year	Japan	Republic of Korea	Other	Total	Japan	Republic of Korea	Other	Total
1964	283,592	49,203	179,774	512,569	408,472	78,415	16,897	503,784
1965	267,254	47,946	49,396	364,596	479,865	84,896	16,616	581,377
1966	231,676	34,827	71,915	338,418	412,628	73,321	19,444	504,393
1967	294,518	130,057	45,615	470,190	489,703	185,260	20,786	695,749
1968	269,936	61,599	359,126	690,661	509,734	173,245	62,789	745,768
1969	257,477	28,464	31,085	317,026	469,804	114,166	11,076	595,046
1970	292,142	165,876	15,506	473,524	611,204	455,168	16,088	1,082,460
1971	358,348	71,350	126,856	556,554	585,942	199,816	42,146	827,904
Average	281,868	73,665	109,909	465,442	495,919	170,411	25,742	692,060
Percent of total	61	16	23	100	72	25	3	100

[1]U.S. Bureau of the Census (1964-71).
[2]Assumed to be the FOB value, i.e., the cost or price at the manufacturing point or country of origin.

2) Wakame—$9.55 to $31.04/lb (average $17.01).

3) Kombu—unprocessed, $2.08 to $6.36/lb (average $5.00); sliced and processed, $4.52 to $34.06/lb (average $17.10).

Increasing numbers of Japanese businessmen and tourists in the United States have increased the demands for these products. The U.S. Immigration and Naturalization Service lists the following statistics on the number of nonimmigrant Japanese who entered the United States from 1965 to 1971 (Immigration and Naturalization Service Annual Report, 1965-1971):

	1965	1971	Average annual increase 1965-71
Japanese government officials	1,399	2,541	190
Temporary visitors for business	20,193	61,473	6,880
Visitors for pleasure	18,090	181,012	27,154
Other	15,980	42,660	4,447
Total	55,662	287,686	38,671

Since Japanese Americans and nonimmigrant Japanese visitors create most of the U.S. demand, areas where the incidence of people of Japanese

Table 2.—Japanese production, trade, and consumption of seaweed products[1].

Year	Domestic production	Imports	Total supply	Exports	Domestic consumption: Human food	Animal feed	Total
			Thousand metric tons, dry weight				
1961	85	12	97	2	61	34	95
1962	100	8	108	1	82	25	107
1963	85	10	95	1	70	24	94
1964	72	10	82	1	62	19	81
1965	81	12	93	1	70	22	92
1966	94	21	115	2	81	32	113
1967	105	18	123	2	105	16	121
1968	101	14	115	3	90	22	112
1969	89	15	104	3	77	24	101
1970	104	15	119	5	96	18	114
Avg.	91.6	13.5	105.1	2.1	79.4	23.6	103.0

[1]Data source: Ministry of Agriculture and Forestry (1968b, 1972b).

Table 3.—Average value per pound of selected seaweed and products in Japan (annual average for 1966-70)[1].

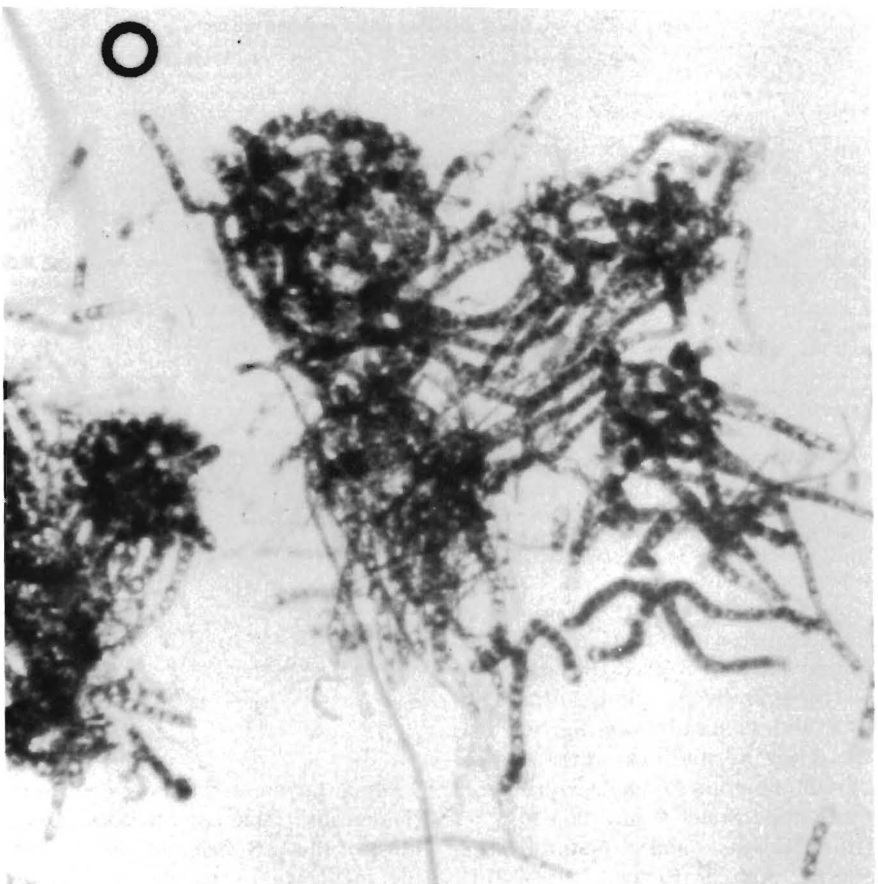
Product	Landed value (wet weight)	Processed value (dry weight)
	Dollars per pound	
Kombu, *Laminaria*	$0.08	$0.32
Wakame, *Undaria*	0.08	0.85
Nori, *Porphyra*		
Black sheet	na	0.82
Mixed sheet	na	0.71
Green sheet	na	0.27
Pieces	na	0.80
Nori seedlings	0.28	

[1]Data source: Ministry of Agriculture and Forestry (1972a and 1972b).

Table 4.—Number of seaweed culture firms (or farming units) in Japan during 1958-70 by seaweed type[1].

Year	Nori	Wakame	Kombu
1958	61,606	—	—
1959	63,726	—	—
1960	68,667	—	—
1961	68,725	—	—
1962	65,852	—	—
1963	64,183	—	—
1964	62,406	—	—
1965	62,396	6,060	—
1966	62,567	10,094	—
1967	63,705	14,184	—
1968	66,261	15,357	—
1969	65,685	15,206	—
1970	63,309	18,735	1,126

[1]Data source: Ministry of Agriculture and Forestry (1970, 1972a).



descent is relatively high, such as Hawaii, California, Washington, Oregon, New York, and Illinois would be expected to be the main centers for marketing seaweed food products. Because there are over 600,000 citizens of Japanese descent in the United States and an additional 64,000 Japanese government officials and business people, the potential market for edible seaweeds of the kinds used in Japan seems to be substantial.

Japanese Production of Edible Seaweeds

Japan is probably the largest producer and consumer of seaweed food products in the world[1]. Annual production and consumption of seaweed for 1961-70 is shown in Table 2. Landings of the four primary seaweeds harvested in Japan for 1957-70 are shown in Figure 3. Landings of "tengusa," *Gelidium*, for production of agar have been fairly constant at 10-20,000 mt (wet weight) per year, whereas those of the other three seaweeds have fluctuated rather widely.

[1]According to Silverthorne and Sorensen (1971) the People's Republic of China leads the world in seaweed harvest. Information on product forms (food versus nonfood), however, was not available.

Figure 8.—The mature stage of *Porphyra*.

Figure 7.—Intermediate stage in the life cycle of *Porphyra* (conchocelis). The filaments usually grow on mollusk shells.

Wakame (*Undaria*) landings (Fig. 4) prior to 1965 came from natural production with an annual yield of 50-60,000 mt (wet weight). Since 1965, the increased production (to 120,000 mt) resulted from the institution of culture methods. By 1970, cultured wakame made up 65 percent of the total harvest of 122,000 mt. The value of wakame landings during this period increased steadily from approximately $1 million in 1957 to $31 million in 1970 as did the bulk price—rising from 1.0 cent/lb in 1957 to 11.5 cents/lb in 1970.

Nori is harvested almost entirely from cultured crops. The harvest more than doubled in weight during 1957-60, remained about level in 1961-68, and increased by about 5 percent in 1970 (Fig. 5). Values of Japanese production of nori and of imports from South Korea in 1957-70 are also shown in Figure 5.

Japanese production and value of kombu, *Laminaria*, in 1957-69 are shown in Figure 6. Although kombu has been harvested primarily from natural beds, increasing demand has stimulated the development of culture systems. In 1970, 234 mt were harvested from cultured beds.

The average value per pound (at the primary processor level) of selected Japanese seaweed products is shown in Table 3. The number of firms engaged in seaweed culture in Japan during 1958-70 is presented in Table 4. By far the largest number were engaged in nori culture, followed by those producing wakame and finally kombu.

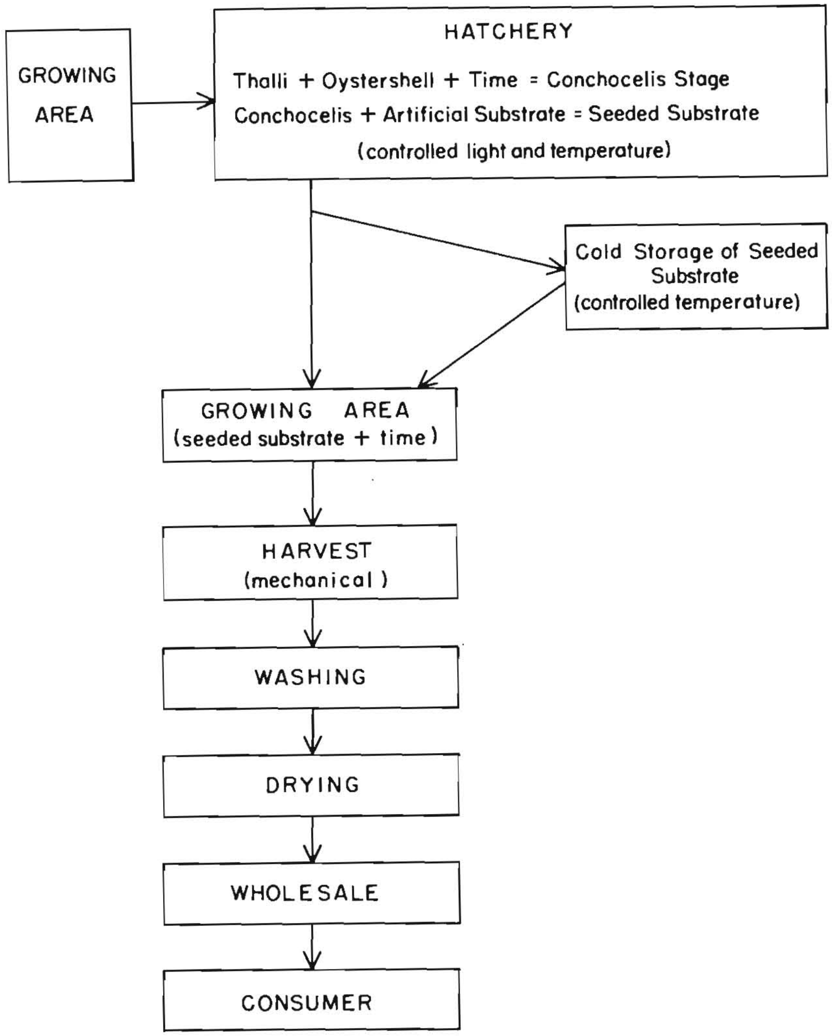


Figure 9.—Culture and processing of *Porphyra*.

POTENTIAL SEAWEED INDUSTRY IN U.S.

Growing shortages of food, fiber, and chemicals are forcing us to look more to the sea for new sources of these critical materials. The culture of seaweeds seems to offer opportunities for increasing our resource base for all three. It would also offer the opportunity for making better use of our living marine resources in territorial waters that are protected from exploitation by foreign powers.

The market for industrial products from seaweeds is well established in the United States, the raw material coming almost entirely from natural production of kelp and Irish moss. To be competitive, any system for culturing these seaweeds would have to produce a high-bulk, low-cost product. The price of raw kelp, *Macrocystis*, harvested from natural stands has been less than 1.0 cent/lb (Silverthorne and Sorensen, 1971). For Irish moss, *Chondrus crispus*, it has been 3.0 cents/lb wet weight (Anonymous, 1969). At these prices, culture of seaweed for industrial products would be difficult.

The development of culture systems for high-priced edible seaweeds, however, appears more attractive. Although the U.S. market for edible seaweeds is small compared with Japan's, the simplicity of processing edible seaweeds and the high prices that they command in U.S. markets suggests that culture and processing could be efficiently developed in the United States. If overhead could be kept low, the products could compete favorably with imports from Japan and Korea. Samples of several species of *Porphyra*, taste-tested by processors from Japan, were found to be comparable to the Japanese product. Small, family-operated businesses in the Pacific Northwest should be able to meet much of the U.S. demand for processed nori using species from the genus *Porphyra*.

Culture Systems

Nori has been cultured in the Orient since the 17th Century. Prior to that, it was gathered by fishermen from wild stands along the beach. The earliest method of culture was to place bundles of branches along the beach in early fall for collecting spores produced by mature plants. After several weeks, when growth of the thalli (leafy structures) was well underway the bundles were moved inshore

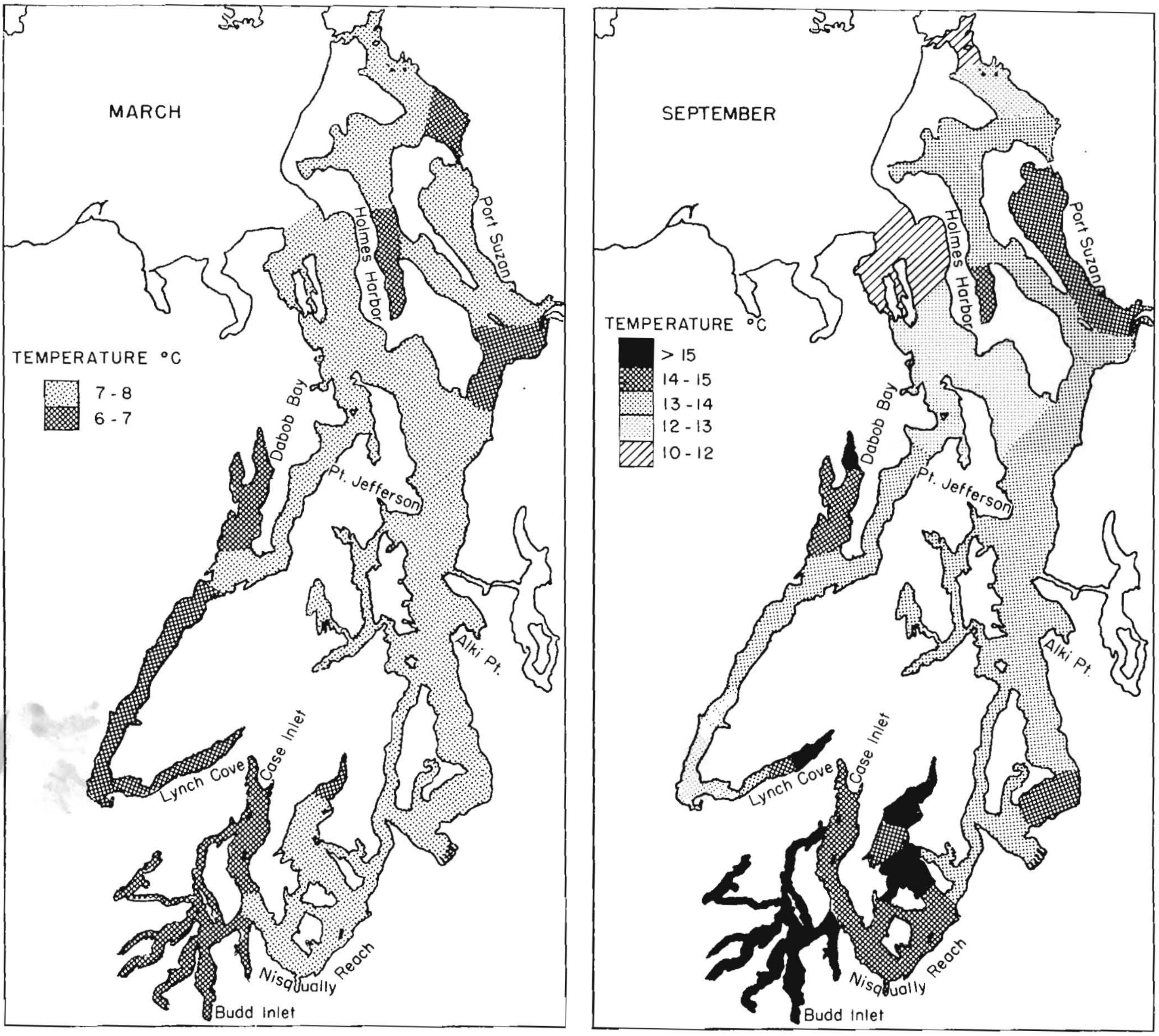


Figure 10.—Puget Sound surface temperatures in March and September.

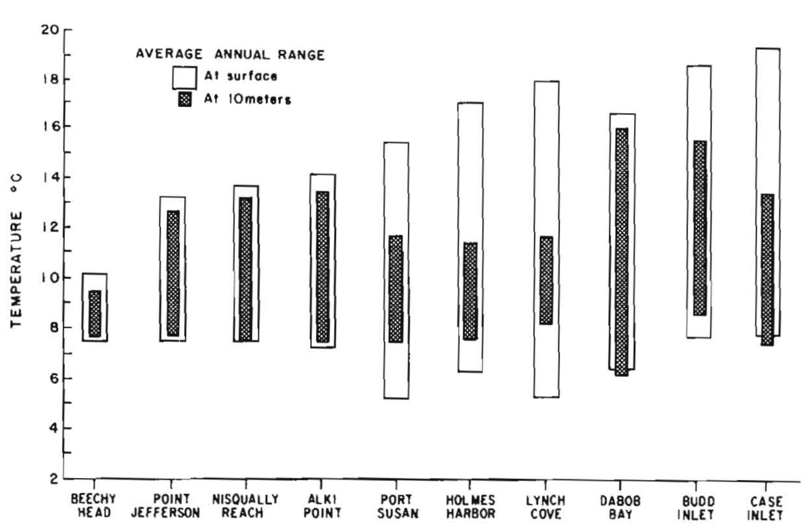


Figure 11.—Ranges of temperature at representative sites in Puget Sound.

near the mouths of rivers where there was an abundance of nutrients. Several harvests were made throughout the winter (Scagel, 1961).

Since the 1930's, large mesh nets (hibi) or split bamboo blinds (saku) have been used (Furukama, 1971). These usually measure 18.2 × 1.2 m, but can vary from 18.0 to 45.5 m in length and from 1.2 to 1.8 m in width. The hibi are set out in stacks of five at the mean tide level in early fall to collect spores. After the spores are set, the stacks are separated and the hibi moved inshore. Harvesting begins about 2 mo later. The largest plants

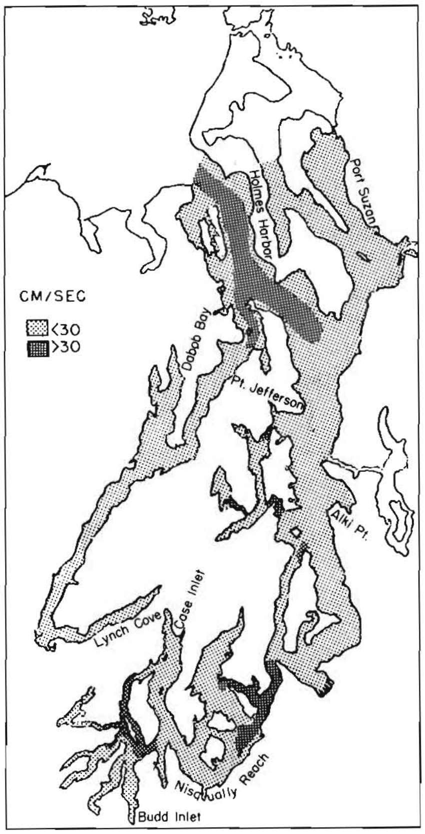


Figure 12.—Puget Sound seawater current flows.

are harvested first, allowing the small plants to continue growing. Usually three or four harvests may be made during winter and early spring (Kurogi, 1963).

The discovery by Drew (1949) of the conchocelis stage in the life cycle of *Porphyra* (nori) led to the development of new culture techniques. Under the proper temperature and light conditions, mature plants produce spores which attach to mollusk shells. These spores develop into a filamentous (conchocelis) phase (Fig. 7) that grows throughout the summer. When the temperature and light levels drop in the fall, spores are released from the conchocelis and attach to a suitable substrate to grow into leafy thalli (Fig. 8). This was the basis for the next step in *Porphyra* culture in which bags of oyster shells were hung beneath the hibi (netting used as substrate) for collecting spores. This led to the development of hatcheries, where it is now common practice to seed the hibi artificially (Fig. 9). In early spring chopped thalli are placed in tanks containing strings of oyster shells. Spores that set on the shells produce conchocelis which grow throughout the summer in the tanks. Very little care is required during this stage. In the fall, the water in the tanks is heated to forestall sporulation of the conchocelis until the hibi are ready. When the water temperature is allowed to fall below 23°C, the hibi are placed in the tanks for about 30 min. This is usually sufficient for a good set.

With the use of hatcheries, length of the growing season can be controlled by manipulating photoperiod and temperature, making it possible to spread the harvesting period over several months. By keeping the spore tanks in darkness for over 12 h each day and holding the water temperature to less than 23°C, sporulation can be accelerated to give an early start to the growing season. The growing season can be further extended by freezing the newly set spores at minus 20°C. These spores can be kept frozen for several months before setting them out. This technique also provides back-up seed stock in the event of the failure of early crops from disease or storm damage.

Potential For *Porphyra* Culture in Puget Sound

Puget Sound is well suited for the culture of *Porphyra*. These plants require water temperatures in the winter ranging from 5° to 10°C for growing the leafy thalli that can be processed into nori. For most of Puget Sound, winter temperatures range from 6° to 8°C and seldom go above 15°C in the summer (Fig. 10). Sea ice rarely forms and only in the very shallow bays does the temperature of the water consistently exceed 15°C in the summer. Figure 11 shows the maximum and minimum temperatures for some representative sites. Fed by runoff from the nearby mountains, the rivers flowing into Puget Sound carry down nutrients needed by marine plants. Currents in most areas are adequate for exchange of water and nutrients but not severe enough to cause damage or require extensive physical structures (Fig. 12). Although there is heavy cloud cover in the winter and spring, the light is sufficient for the growth of many seaweeds. One limiting factor in the growth of large leafy marine algae is the amount of stable substrate in shallow water. This is due to the sharply sloping beaches and the depths of Puget Sound. The natural substrates suitable for growing seaweed are usually restricted to the narrow intertidal or upper subtidal strips on rocky shores. Therefore, in order to utilize the waters of Puget Sound for seaweed production, an artificial substrate must be employed. Intensive, commercial culture of *Porphyra* in Puget Sound will require:

1) Development of hatcheries for controlled setting of spore.
2) Development of artificial substrates that could be used offshore.
3) Development of a mechanical harvesting system.
4) Development of a local processing capability (for making nori sheets).

Seaweeds would be very useful as a companion to other aquaculture crops such as the pen rearing of Pacific salmon in Puget Sound (Nyegaard, 1973). There are currently six salmon farms in operation, all located where water conditions would be suitable for growing seaweeds. Salmon growers possess equipment, manpower, and technology which could be readily applied to growing seaweed. Additional skills that a salmon grower would have to acquire to add seaweed to his production would be knowledge of seaweed life cycles, environmental conditions necessary to its growth, and of techniques for harvesting it.

CONCLUSION

There is already an established market for edible seaweeds in the United States that should increase. With the development of a system of offshore culture supported by spore hatcheries and a local processing capability, production of good quality nori in Puget Sound seems entirely feasible. Such a system should be able to satisfy current domestic consumption and produce a surplus that would be available for export to other countries.

ACKNOWLEDGMENT

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