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Utilization of Algae for Food, Fodder and in Agriculture

by

Peter K Robinson

Lecturer, Plant Biochemistry

Lancashire Polytechnic, Preston, PR1 2TQ, UK

Telephone Preston (0772) 22141

TELEX 677409 LANPOL

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PREFACE

The author is particularly grateful to the numerous national embassies which have given assistance in providing information for this report; to the Hatfield Polytechnic for providing facilities during the preparation of the report; and to R.Cannell, A.L.Mak and A.Owsianka for assistance in checking the document. Thanks must also go to Valerie and Philippa for their patience and understanding whilst this work was in preparation.

1. INTRODUCTION

This review provides an overview of the current usage of algae and algal products for both human and animal food (including some aspects of medicinal uses), and in agriculture as a fertilizer. Though emphasis will be placed on the marine macroalgae (henceforth called seaweeds) throughout, relevant work on both the freshwater macroalgae and fresh- and seawater microalgae will also be presented. The text is divided into three main parts. The first part (section 2) considers the nutritional value of seaweed products, both to man and to animals. The second part (sections 3-6) outlines current world production and consumption of seaweed products and identifies the species used and the technologies adopted. The third part (sections 7-8) considers future developments in the usage of seaweed, and includes possible strategies for the further development of seaweed utilization.

2. NUTRITIONAL VALUE OF SEAWEEDS

It seems wise to begin this review by considering what nutritional value seaweeds actually have, and whether in the context of current UN stategies, they do indeed constitute a useful group of organisms which might be further exploited by the 'developing countries'.

Seaweeds, as any other plants, are known to contain large amounts of water, with dry matter comprising carbohydrates, proteins, fats, vitamins and minerals.

2.1. Water With the exception of the algae which are coated with calcium carbonate, the mean water content of seaweeds usually varies from 58-85% of their total weight (Vinogradov, 1953). In comparison, most fresh fruit and vegetables have water contents within the range 75-97% total weight (McCance & Widdowson, 1960).

2.2. Carbohydrate Generally about 50-70% of seaweed dry weight is carbohydrate. Studies have shown that algae do contain monosaccharides (e.g. glucose and fructose) and oligosaccharides (e.g. sucrose, trehalose and maltose). Generally, however, these sugars have been found at such low levels that they contribute little to the nutritional value of the seaweeds. In comparison, the polysaccharides are the major component of seaweed carbohydrates, constituting about 65% of the dry weight of most edible algae (Tiffany, 1958).

Table 1. summarizes structural data on seaweed polysaccharides.

Starches identical or very similar to those found in higher plants occur in the chlorophytes (true starch), rhodophytes (floridean starch), and cyanophytes (myxophycean starch). These starches are highly digestible and are thus of great nutritional value.

Cellulose, mannan, alginic acid and xylan all contain frequent beta-1,4 linkages which make them highly indigestible to man and any other non-ruminant animals. Similarly, agar and carrageenan (beta-1,3 and beta-1,4 linked units), laminaran (beta-1,3 linked glucose), and fucoidan (beta-1,2 linked fucose) are all indigestible to humans. However, ruminants, with a gut flora capable of hydrolysing the beta-1,4 linkages of cellulose, may derive some nutritional advantage from mannan, alginic acid, xylan, agar and carrageenan. Studies have also shown that laminaran (beta-1,3 linked glucose) is of nutritional value to ruminants (further considered in section 4.2).

Unfortunately, because of the low digestibility of many of the seaweed polysaccharides, a major proportion of seaweed biomass is of negligible nutritional value to both man and non-ruminant animals. Johnston (1966) thus concluded that the seaweeds could be dismissed as a high class source of carbohydrate.

Further information on algal carbohydrates is reviewed by Meeuse (1962), Kreger (1962), O'Colla (1962), Cragie (1974) and Mackie and Preston (1974).

TABLE 1. STRUCTURES OF ALGAL POLYSACCHARIDES

POLYSACCHARIDE	STRUCTURE
STARCH	alpha-1,4 and alpha-1,6 linked glucose units
CELLULOSE	beta-1,4 linked glucose units
MANNAN	beta-1,4 linked mannose units
ALGINIC ACID	beta-1,4 linked guluronic and manuronic acid units
XYLAN	beta-1,3 and beta-1,4 linked xylose units
LAMINARAN	beta-1,3 linked glucose units
AGAR/ CARRAGEENAN	beta-1,3 and beta-1,4 linked units of galactose and 3,6-anhydrogalactose (and sulphated derivatives)
FUCOIDAN	beta-1,2 and beta-1,3 linked fucose units

TABLE 2. PROTEIN CONTENT OF SEAWEEDS.

SPECIES	PROTEIN CONTENT (Nx6.25) (%DRY WEIGHT)	SOURCE
Chondrus crispus	26.5	Citharel and Villeret, 1964
Enteromorpha linza	22.3	Tressler, 1923 (1)
Gelidium latifolium	15.3	Citharel and Villeret, 1964
Laurencia pinnatifida	23.3	Citharel and Villeret, 1964
Laminaria sp.	7.65	Tressler, 1923 (1)
Porphyra tenera	30-36	Tressler, 1923 (1)
Rhodymenia palmata	21.4	Citharel and Villeret, 1964
Ulva lactuca	18.3	Tressler, 1923 (1)
Undaria pinnatifida	14.3-18	Tressler, 1923 (1)

(1) corrected for water content (abridged in Chapman (1970).

<u>2.3. Protein</u> Seaweed protein leve..s are shown in table 2. Levels vary greatly between species, but several species have total protein levels as high as terrestrial vegetables. Table 3 presents data on the amino acid composition of seaweed proteins, showing that they are valuable sources of many essential amino acids. Seaweeds are thus potentially useful protein sou..ces, particularly in areas/countries dependent upon plants as the main source of dietary protein.

<u>2.4. Fat</u> Seaweeds have very low fat contents in comparison with animal sources (table 4). Comparison with levels in vegetable sources is, however, more favourable. The fatty acid composition of seaweed fats is similar to that of terrestrial vegetables. Saturated fatty acids such as palmitic (C-16), myristic (C-14) and stearic (C-18), and unsaturated fatty acids such as oleic (C-18), palmitoleic (C-16) and gadoleic (C-20) are the commonest (Fogg, 1952). Such low levels of easily assimilated fats could thus be matabolized but would play a relatively small part in the nutritional value of the plants.

TABLE 3. AMINO ACID COMPOSTION OF ALGAL PROTEINS

AMINO ACID	SOURCE OF PROTEIN			
	Ulva sp. (1)	Laminaria sp. (1)	Fucus sp.(2)	FAO ref (1)
ESSENTIAL				
ARGININE	7.5	16.1	9.4	-
HISTIDINE	1.2	1.6	1.6	-
ISOLEUCINE	-	-	3.0	4.2
LEUCINE	5.2	2.5	5.0	4.8
LYSINE	0.0	0.0	6.0	4,2
METHIONINE	0.0	0.0	0.4	2.2
PHENYLALANINE	2.3	1.0	2.6	2.8
THREONINE	-	-	3.3	2.8
TRYPTOPHAN	0.3	1.1	-	1.4
VALINE	5.2	5.1	3.0	4.2
NON-ESSENTIAL				
ALANINE	6.5	6.4	5.4	-
AMIDE N	-	-	15.3	-
ASPARTIC ACID	4.1	1.9	9.0	4.2
CYSTINE	1.8	3.4	TRACE	-
GLYCINE	0.8	2.7	5.4	-
GLUTAMIC ACID	7.6	7.3	11.2	-
PROLINE	7.0	7.6	3.3	-
SERINE	-	-	3.5	-
TYROSINE	0.0	1.9	1.2	2.8
TOTAL N	49.5	58.6	88.6	33.5

(1) Data from Volesky *et al.* (1970). (2) Data from Fowden (1962)

TABLE 4. FAT CONTENT OF SEAWEEDS.

SPECIES	FAT CONTENT (%DRY WEIGHT)
Enteromorpha linza	2.00
Laminaria sp.	1.50
Porphyra tenera	1.0
Undaria pinnatifida	0.4
Ulva lactuca	0.05

Data from Tressler (1923), corrected for water content.

2.4. Vitamins Table 5 summarizes data from the reviews of Levring et al. (1969) and Chapman (1970) on seaweed vitamin levels.

Chapman (1970) reports that, weight for weight, 'dulse' (Rhodymenia palmata) contains 50% of the vitamin C of oranges, whilst some Fucoids and Porphyra are even richer. Chapman (1970) also reports that the Angmagssalik Eskimos obtain 50% of their vitamin C from algal sources.

Algae also contain considerable amounts of beta-carotenes - precursors of vitamin A. Chapman (1970) reports that the vitamin A content of Ulva is comparable with that of cabbage, whilst the unicellular diatom Nitschia is extremely rich in the vitamin and is probably the source of the vitamin in fish-liver oils. Santillan (1982) found that the blue-green microalga Spirulina (dried) contained 1700mg/kg beta-carotene - equivalent to 283 mg/kg retinol eqivalent, and superior to the retinol content of many green vegetables.

Holick (1984) demonstrated that (micro)algae photosynthesize provitamin D, and suggested that algae may be a rich natural source of the provitamin, which could be used to manufacture the vitamin itself. In comparison to the concentration of vitamin D in fish-liver oils, however, seaweeds are a poor source.

Seaweeds also contain most of the water soluble B complex vitamins, and the fat soluble vitamins A, E and K.

TABLE 5. VITAMIN CONTENT OF SEAWEEDS.

VITAMIN	AMOUNT IN DRY SEAWEED (PPM) (1)	DAILY REQUIREMENT (2)	MINIMUM WEIGHT OF DRY SEAWEED FOR DAILY REQUIREMENT
THIAMINE (B1)	0.27-7.2	0.3-1.3mg	41-181g
RIBOFLAVIN (B2)	0.84-23.08	0.4-1.8mg	17-78g
NICOTINIC ACID	1-68.33	5-21mg	73-307g
PANTOTHENIC ACID	0.18-12.5	...	...
FOLIC ACID	0.046-8.5	...	...
FUCOXANTHIN	90-469	...	...
BIOTIN	...	...	...
CHOLIN	...	...	...
PYRIDOXINE (B6)	...	...	...
COBALAMIN (B12)	0.004-2.8	...	...
ASCORBIC ACID (C)	30-2674	20-60mg	7-22g
A (RETINOL EQUIV)	...	0.3-1.2mg	...
D	0.01	7.5-10ug	750-1000g
E (TOCOPHEROL)	10-340	...	...
K	10-14.2	...	...

(1) Data are ranges quoted in reviews by Levring et al. (1969) and Chapman (1970).

(2) DHSS (1979)

Seaweed vitamin concentrations appear high when compared to those of terrestrial plants in, for example, the MAFF 'Manual of Nutrition' (1976). It must be noted, however, that values in table 5 are expressed on a dry-weight basis, whilst those in nutritional texts are usually expressed on a fresh-weight basis. Thus, algae only make a substantial contribution to the total daily vitamin requirements when large amounts (dry-weight) are consumed. The Japanese average daily consumption of 10g dry-weight per person, for example, will supply substantial amounts of vitamin C and also considerable amounts of vitamins B2, B1 and A. The vitamin content of seaweeds may therefore make a particularly great nutritional benefit to those individuals on a cereal diet without an adequate intake of fresh fruit and vegetables.

2.5. Minerals Elemental analysis of seaweeds has been thoroughly reviewed by Vinogradov (1953) and more recently by Yamamoto et al., (1979)

Undoubtedly the most publicised algal mineral is iodine. Seaweeds are about 1000 times richer in iodine than are other plants (Klincare et al., 1967) and in some of the brown seaweeds the concentration may reach 30,000 times that in seawater and may constitute 1% of dry weight (=10,000ppm). The prevention of goitre (enlarged thyroid) by dietary consumption of seaweed iodine has already been clearly established.

Table 6 presents further details of seaweed iodine levels. Individuals typically require 0.2mg iodine per day, which could be provided by the consumption of about 20mg dried iodine-rich

TABLE 6. MINERAL CONTENT OF SEAWEEDS

MINERAL	AMOUNT IN DPY SEAWEED (PPM) (1)	DAILY REQUIREMENT (2)	MINIMUM WEIGHT OF DRY SEAWEED FOR DAILY REQUIREMENT
MAJOR MINERALS			
CALCIUM	2300-316000	1.1g	3.5g
PHOSPHORUS	200-2800	1.4g	500g
SULPHUR	...	0.85g	...
POTASSIUM	300-35700	3.3g	92.4g
SODIUM	200-66600	4.4g	66.1g
CHLORINE	...	5.2g	...
MAGNESIUM	300-36500	0.34g	9.3g
IRON	58-3020	16.0mg	5.3g
TRACE ELEMENTS			
FLUORINE	...	1.8mg	...
ZINC	18-340	13.0mg	38.2g
COPPER	6.1-27.7	3.5mg	126.4g
IODINE	18-11580 (3)	0.2mg	17.3mg
MANGANESE	4-337	3.7mg	11.0g
CHROMIUM	0.50-2.83	0.15mg	53.0g
COBALT	0.24-2.51	0.3mg	119.5g
ALUMINIUM	57-3320	...	...
SILICON	1120-21800	...	...
BORON	8-337	...	...
TITANIUM	2.4-178	...	...
VANDAIUM	0.66-10.1	...	...
NICKEL	0.23-5.64	...	...
GALLIUM	0.02-0.64	...	...
STRONTIUM	20-11500	...	...
MOLYBDENUM	0.06-1.16	...	...

(1) Yamamoto et al. (1979)

(2) MAFF (1976)

(3) Chapaman (1970)

seaweed.

The regular consumption of seaweeds in the diet may also provide significant amount of other vital minerals. For example the Japanese daily consumption of 10g dry-weight seaweed will supply considerable amounts of dietary calcium, iron, magnesium and manganese.

2.6. General Seaweeds have thus usually been consumed for their mineral and vitamin contents. Much of the seaweed carbohydrate is not readily digestible by the human gut, and whilst seaweeds do contain proteins comprising substantial amounts of essential amino acids, they are no better in this respect than many terrestrial vegetables.

Generally therefore, seaweeds have been used in the developed countries (especially the Far East) as garnishes to various dishes, with the nutritional value coming from mineral and vitamin contents (in a diet already rich in protein and carbohydrate). In the developing countries, however, one may envisage seaweeds not only supplying minerals and vitamins, but also some of the essential amino acids deficient from cereal dominated diets.

3. CURRENT USAGE OF ALGAE AND ALGAL PRODUCTS FOR HUMAN FOOD

3.1. World Production

Details of the quantity and value of world seaweed production have been variously published, the last major study being that of the FAO leading to the publication of findings by Michanek (1975) and Naylor (1976).

Michanek (1975) estimated recent harvests of red and brown seaweeds to be in the order of 2.1 million tonnes per annum, and Naylor (1976) made an estimate of 2.4 million tonnes per annum (for 1973) and estimated this to be worth $765million. More recent data (FAO, 1984) shows that world seaweed production is now around 3.2million tonnes per annum. Based on a 5% per annum inflation rate from Naylor's overall value of $320/tonne this would give current production a value of $1,700million per annum.

As regard the subject of this paper - algae and food - it is even more important to note that over 95% of the first-hand value of these crops is attributable to the sale of semi-processed edible products in Japan, Korea and China (Naylor, 1976). In comparison, seaweeds harvested for use by the phycocolloid industry account for only 3% of the first-hand value of seaweed products (Naylor, 1976), even though this industry actually uses 50% (by weight) of the harvested seaweed (Neish, 1979).

The value of seaweeds for human consumption was thus more than $700million in 1973 and may now be nearer $1600million (95% of 1983 FAO tonnage, inflation corrected)

3.2. Regional Consumption

3.2.1. Introduction

Human consumption of seaweeds falls into three broad categories.

1/ In the 'West' (Europe and North America) seaweeds were once commonly consumed, but such usage has declined dramatically over the past 50-100 years. Current use is thus largely restricted to the use of phycocolloids by the food industry, though this may be extensive (table 7).

2/ In contrast, seaweeds are still regularly consumed in the 'Far East'. They are, however, largely considered to be a luxury and are used as an additive or garnish to more bulky foods, rather than making a major contribution to the staple dietary requiremants for protein or carbohydrate. (In section 2., however, we saw that small quantities of seaweeds may provide considerable amounts of vitamins and minerals). For example, the utilization of (dried) seaweed by the Japanese is estimated to be only 10g/person/day (Kirby, 1953) or 1kg/per/annum (Naylor, 1976).

TABLE 7. SOME USES OF PHYCOCOLLOIDS IN THE FOOD INDUSTRY

KEY . NO USE
X USE

USAGE	PHYCOCOLLOID		
	AGAR	CARRAGEENAN	ALGINATE
DAIRY			
Ice-cream stabilizer	X	X	X
Milk shake	X	X	X
Sherbets	X	X	X
Instant puddings	.	X	X
Cottage cheese	.	X	X
Cream cheese	X	X	X
Whipped cream	.	X	X
Yoghourt	X	X	.
BEVERAGES			
Fruit juices	.	X	X
Beer foam stabilizer	.	X	X
Beer clarification	.	X	X
Wine fining	X	X	X
Ageing of spirits	.	X	.
BAKERY			
Doughnuts	.	X	.
Meringues	X	X	X
Fruit fillings	.	X	X
Pie fillings	X	X	X
MEAT/FISH			
Canned meat/fish	X	X	X
Coated jellied meat	.	X	X
Sausage ingredient	.	X	.
MISCELLANEOUS			
Jams/preserves	X	X	X
Processed baby food	.	X	.
Soups	X	X	X
Synthetic potato chips	.	.	X
Artificial cherries	.	.	X

Data from Glicksman, 1962.

Seaweeds thus form only 0.5% of the total vegetable matter consumed in Japan (Chapman, 1970). This low volume usage of seaweed (cf. terrestrial) biomass must always, therefore, be realised when evaluating the nutritional gains from such products.

3/ In many 'developing countries', especially in Africa, but also in areas of Asia and South America, seaweed utilization for human food seems to have been overlooked. In many areas this may simply be attributable to the lack of coastline, yet in countries possessing coastal stretches, social or economic factors may be involved.

3.2.2 Seaweeds used

Throughout the world, and in the Pacific islands in particular, over 100 species of seaweeds are eaten. Table 8 summarizes data on a generic basis. Information on species eaten by humans is given by Bonotto (1979).

EUROPE In Europe, the widespread usage of seaweed as human food was discontinued about 50-100 years ago, as living standards improved and as other more palatable foods became available. In Scotland, young stipes of *Laminaria saccharina* were formerly sold as 'dulse', whilst *Rhodymenia* was a significant food item in Ireland (Naylor, 1976). In Iceland, *Rhodymenia palmata* known as 'sol' has been eaten since at least 961AD (Hallsson, 1964). *Rhodymenia* was apparently eaten raw, in a fresh or dried condition, or cooked like spinach (Dixon, 1973). The dried product formed the basis of an active commercial trade in the 12th Century

TABLE 8. SEAWEEDS CONSUMED AS HUMAN FOOD

KEY TO COUNTRIES/LOCALITIES

1 N W EUROPE (INC. UK AND ICELAND)
2 MEDITERRANEAN
3 E. CANADA
4 E. USA
5 W USA (INC. ALASKA)
6 CENTRAL AND S AMERICA (INC. CARIBBEAN)
7 AFRICA
8 HAWAII
9 CHINA
10 JAPAN
11 AUSTRALIA/ NEW ZEALAND
12 CENTRAL ASIA
13 INDO-CHINA
14 INDONESIA
15 PHILIPPINES

<u>KEY</u>

. NO USE
X USE

BROWN SEAWEEDS GENUS	COUNTRY OR LOCALITY														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<u>Alaria</u>	X	.	.	.	X	.	.	.	.	X	.	.	.	.	.
<u>Arthrothamnus</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Chnoospora</u>	.	.	.	.	.	.	.	X	.	.	.	.	X	.	.
<u>Chorda</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Chordaria</u>	.	.	.	.	.	.	.	.	.	X	.	X	.	.	.
<u>Cladosiphon</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Dictyopteris</u>	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.
<u>Dictyota</u>	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.
<u>Durvillea</u>	.	.	.	.	.	X	.	.	.	.	X	.	.	.	.
<u>Ecklonia</u>	.	.	.	.	.	.	.	.	X	X	.	.	.	.	.
<u>Eckloniopsis</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Eisenia</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Endarachne</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Eudesme</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Fucus</u>	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<u>Haliseris</u>	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.
<u>Heterochordaria</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Hijikia</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Hydroclathrus</u>	.	.	.	.	.	.	.	X	X	.	.	.	.	.	X
<u>Kjellmaniella</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Laminaria</u>	X	.	.	.	.	.	.	.	X	X	.	X	.	.	.
<u>Macrocystis</u>	.	.	.	.	.	.	.	.	.	.	X	.	.	.	.
<u>Mesogloia</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Myriocladia</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Nereocystis</u>	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
<u>Nemacystis</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Padina</u>	.	.	.	.	.	.	.	X	.	.	.	.	X	X	.
<u>Petalonia</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Sargassum</u>	.	.	.	.	.	.	.	X	X	X	.	.	.	X	X
<u>Tinocladia</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
<u>Turbinaria</u>	.	.	.	.	.	.	.	.	.	X	.	.	.	X	.
<u>Undaria</u>	.	.	.	.	.	.	.	.	X	X	.	.	.	.	.

RED SEAWEEDS GENUS	COUNTRY OR LOCALITY														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Acanthopeltis	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Acanthophora	.	.	.	.	.	.	.	.	.	.	.	.	.	X	X
Agardhiella	.	.	.	.	.	.	.	X	.	.	.	.	.	.	X
Ahnfeltia	.	.	.	.	.	.	X	.	.	.	.	.	.	.	
Asparagopsis	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.
Bangia	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Botryschia	.	.	.	.	.	.	.	.	.	.	.	.	X	.	.
Caloglossa	.	.	.	.	.	.	.	.	.	.	.	.	X	X	.
Campylaephora	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Carpopeltis	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Catanella	.	.	.	.	.	.	.	.	.	.	.	.	X	.	.
Ceramium	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Chondrus	X	.	X	X	.	.	.	.	X	X	.	.	.	.	.
Corallopsis	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.
Cystoclonium	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Digenea	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Dumontia	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Eucheuma	.	.	.	.	.	X	.	.	X	X	X	.	.	X	X
Gelidiella	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.
Gelidiopsis	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.
Gelidium	.	.	.	.	.	.	.	X	X	X	.	.	.	X	.
Gigartina	X	.	.	.	.	.	.	.	.	X	.	.	.	X	.
Gloiopeltis	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.
Gracilaria	X	.	.	.	.	.	.	X	X	X	.	.	X	X	X
Grateloupia	.	.	.	.	.	.	.	X	X	X	.	.	.	.	X
Griffithsia	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.
Gymnogongrus	.	.	.	.	.	.	.	X	.	X	.	.	.	.	.
Halosaccion	.	.	.	.	.	.	.	.	.	.	.	X	.	.	.
Halymenia	.	.	.	.	.	.	.	X	.	.	.	.	.	.	X
Hypnea	.	.	.	.	.	.	.	.	X	.	.	.	.	X	X
Iridea	X	.	.	.	.	.	.	.	.	.	.	.	.	X	.
Laurencia	X	.	.	.	.	.	.	X	.	.	.	.	.	.	X
Liagora	.	.	.	.	.	.	.	X	.	.	.	.	.	.	X
Meristotheca	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Nemalion	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Pterocladia	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Porphyra	X	.	.	.	X	X	.	.	X	X	X	.	.	.	X
Rhodymenia	X	X	X	X	.	.	.	.	.	.	.	.	.	.	.
Sarcodia	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.
Suhria	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.

GREEN SEAWEED GENUS	COUNTRY OR LOCALITY														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Caulerpa	.	.	.	.	.	.	.	X	.	.	.	.	.	X	X
Chaetomorpha	.	.	.	.	.	.	.	X	.	.	.	.	.	X	.
Codium	.	.	.	.	.	.	.	X	.	X	.	.	.	X	X
Enteromorpha	.	.	.	.	.	.	.	X	X	X	.	.	.	.	X
Monostroma	.	.	.	.	.	.	.	.	X	X	.	.	.	.	.
Prasiola	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.
Ulva	X	.	.	.	X	X	.	X	X	.	.	.	.	X	X

BLUE-GREEN ALGAL GENUS	COUNTRY OR LOCALITY														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nematonostoc	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.
Nostoc	.	.	.	.	.	X	.	.	X	.	.	X	.	.	.
Spirulina	.	.	.	.	.	X	X	.	.	.	.	.	.	.	.

Data from many sources, especiallly those of Johnston (1966), Levring et al. (1969), Chapman (1970) and Neish (1979).

(Dixon, 1973), but this has since declined and current usage appears to be minor and localized.

Porphyra has been extensively consumed in Ireland and Wales, and though this consumption has declined over recent years, small quantities are still eaten as 'laver bread'. The annual consumption of Porphyra in Wales has been estimated as 200 tons (Schmid and Hoppe, 1962), with much of the product being imported from England, Scotland and Ireland. Preparation of 'laver bread' includes freshwater washing, boiling for several hours (with 3 parts NaCl per 100 parts weed), draining, and mincing. Sold in this condition, it is then prepared by frying in fat, or it may be made into oatmeal coated cakes (Dixon, 1973).

CANADA AND USA There is still a trade in Rhodymenia palmata in the Canadian Maritime Provinces, where several hundred tons are harvested annually (MacFarlane, 1964) and where 40-50 tons dried product are marketed each year (Dixon, 1973). The dried product is apparently eaten raw.

The major harvesting of Chondrus crispus and Macrocystis in North America is not for food production, but to supply raw materials for the phycocolloid industry.

The inhabitants of the Hawaiian islands (USA) are known to eat large quantities of seaweeds which are collectively known as 'limu'. About 75 different species are used. Raw seaweeds are finely chopped and used as a relish in combination with other foods (Chapman, 1970).

SOUTH AMERICA Naylor (1976) reports that Ulva is particularly valued by the natives of Chile, where it is known as 'luche'. The alga is also eaten in Peru as 'lechuga de samba' (Levring et al., 1969). Durvillea antarctica is also eaten in Chile, where it is known as 'cochayugo', and is used both in soups and as a vegetable.

In equatorial America, the Indians reportedly eat 'yuyucho', a product prepared from the blue-green alga Nostoc commune (Lagerheim, 1892, in Chapman, 1970), whilst Spirulina is cultured and used in Mexico.

AFRICA Naylor (1976) considers that seaweeds are largely neglected as a direct source of food in Africa, and a more recent study of algal utilization in East Africa (Mshigeni, 1983) tends to support this suggestion. Chapman (1970), however, reports that Suhria vittata was used for jelly-making by early colonists in South Africa, and in Central Africa the freshwater blue-green alga Spirulina platensis is used by tribes in the Republic of Chad.

AUSTRALIA AND NEW ZEALAND Chapman (1970) refers to the use of Durvillea potatorum and D. antarctica by Australian aborigines. Preparation involves freshwater soaking, drying and roasting.

The New Zealand, Maoris evidently formerly used a variety of green seaweeds in salads and soups, and still consider Porphyra columbina a delicacy. Known as 'karengo', the Porphyra is prepared by steaming.

ASIA Excluding the major interest in seaweed utilization in the Far East, little can be found on utilization in the rest of Asia. Levring et al. (1969) report of Laminaria being eaten in the USSR as 'sea cabbage', of Chordaria being used in East Asia (in Kamchatka being called 'nebbpett'), and of Halosaccion also being used in Kamchatka. In Central Asia the blue-green alga Nostoc is consumed (Lagerheim, 1892, in Chapman, 1970)

In India various algae are used for medicinal purposes (Misra and Sinha, 1979) and this will be further considered in section 6.

Throughout the Far East - Japan, China, Korea, Indo-China, Indonesia and the Philippines - seaweeds are commonly used for human food. Table 8 reveals the diversity of seaweeds used in these areas. Tseng (1981), however, considers that only four genera - Porphyra, Eucheuma, Laminaria and Undaria - can truly be regarded as marine crop plants, since the amounts of these genera harvested from cultivated material actually exceeds that taken from wild populations.

Eucheuma is eaten in many parts of the Far East, but its cultivation is primarily for the production of carrageenan, thus the only marine crop plants cultivated for food are Porphyra, Laminaria and Undaria. The techniques of cultivating these three crops plants are considered in section 3.3.

3.3. Cultivation Techniques

Throughout the world, many of the seaweeds utilized for human food are not actually cultivated, usage simply depending on the harvesting of natural populations. However, mainly in the Far East, there have been efforts to extend the areas colonized by natural seaweed populations by blasting reefs and depositing rocks on areas with sandy bottoms. More recently the artificial cultivation of various edible algae has been practised. This section will therefore summarize the cultivation techniques used for edible seaweeds and will be restricted to the culture of *Porphyra*, *Laminaria* and *Undaria* practised in the Far East.

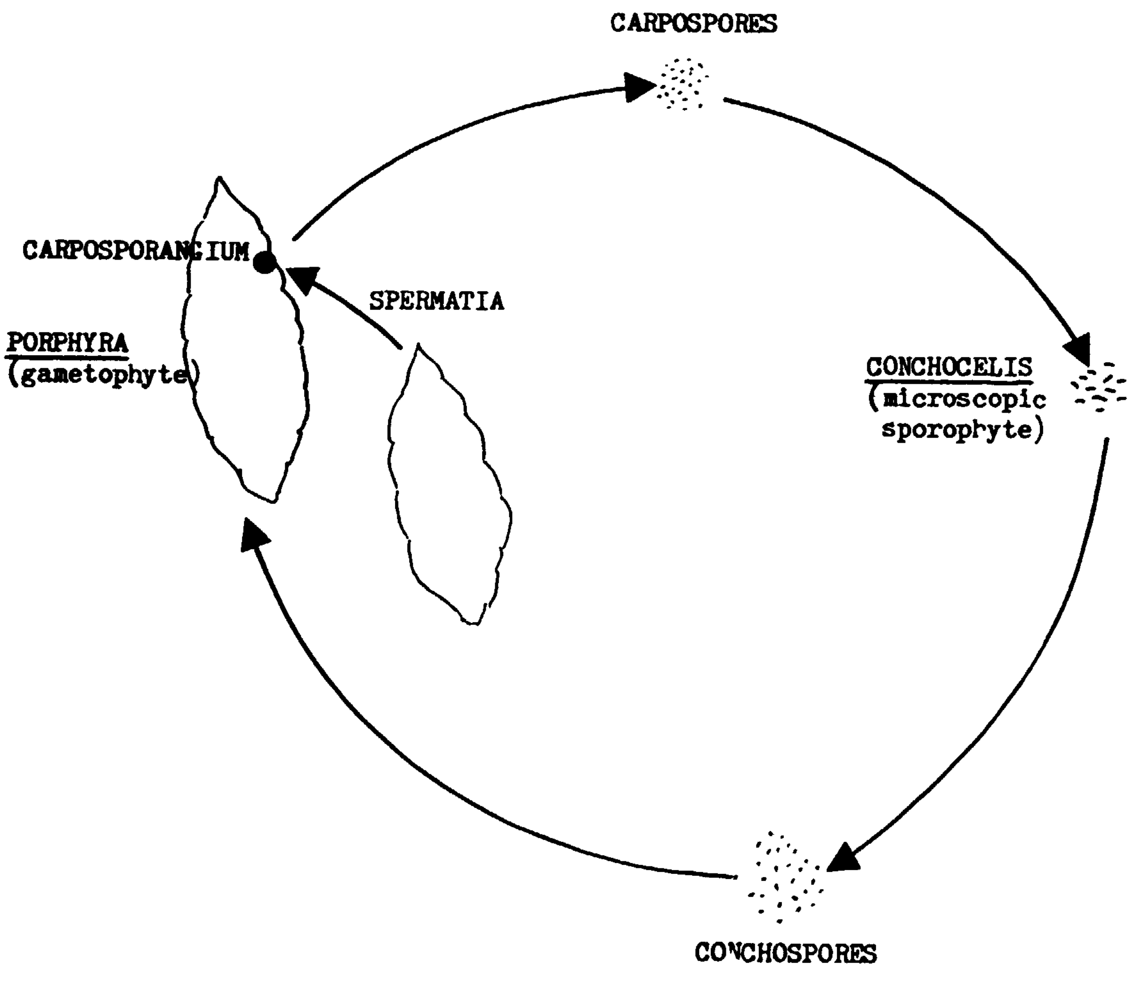
3.3.1. Cultivation of Porphyra

The life-history of *Porphyra* as elucidated by K.M.Drew in 1949 is shown in figure 1. Cultivation of *Porphyra* involves two main processes

1/ cultivation of the sporophytic *Conchocelis* phase

2/ cultivation of the gametophytic crop plant *Porphyra*

FIGURE 1. LIFE-CYCLE OF PORPHYRA



A. Mass culture of *Conchocelis* filaments

Cultivation of the *Conchocelis* phase takes place indoors. *Porphyra* carpospores are known to be released from between January and April, but culture of the *Conchocelis* filaments cannot be started until March or April in Japan (Miura, 1975) or May in China (Tseng, 1981), when the water temperature rises high enough for their growth.

A suspension of carpospores is first prepared by drying *Porphyra* thalli overnight, and then immersing them in seawater for 4-5 hours the next morning, or alternatively by filtering a suspension of crushed thalli. The carpospore suspension is then allowed to settle over a bed of oyster or scallop shells held in concrete tanks and covered with seawater to a depth of 20-30cm. Tank sizes vary; Miura (1975) reports of a small tank (51x36x30cm) containing shells layed side by side, and a large tank (3.6x1.8x0.6m) containing strings of shells. Generally about 15-150g mother thalli provide enough spores for a $3.3m^2$ area of culture tank.

It is usually necessary to add the nutrients nitrogen, phosphorus and potassium to the seawater, and to stir the tank a few times daily. Seawater is replaced as the pH rises to 8.5 units, but temperature is not controlled, and thus fluctuates with the air temperature. Light intensity and light period are both controlled carefully. The maximum light intensity is restricted to 3000 lx in the early part of the year (May-July) when the temperature rises to 23°C, and is then reduced further to 750 lx throughout July and August (when the water temperature rises to

28°C in mid-August, before declining) in order to delay sporangia formation. From August to September, sporangia formation is encouraged by keeping the light intensity at 750 lx and reducing daylength to 8-10hr/day as the temperature drops to about 23°C

B. Artificial seeding of Conchospores

Mass discharges of conchospores occur from October-December. These spores are used to seed the specially made cultivation nets which are nowadays usually synthetic. Spore discharges are periodic, occuring at about 2-week intervals during the early morning. Usually, therefore, seeding is carried out before 10am. The seeding of the nets can either be carried out in the culture tanks or in the sea. If seeding is performed in tanks, the net is simply placed over the *Conchocelis* and, since the conchospores are non-motile, either the water is agitated with compressed air, or the net itself is agitated, usually by wrapping it around a water-wheel shaped frame. Miura (1975) notes that the bubbling method enables the production of 300-1,000 seeded nets/day from a 2.7x1.8x0.6m tank, whilst the rotary frame method is able to produce 50-100 seeded nets/day per rotary frame.

Alternatively, mature *Conchocelis* bearing shells may be used directly, or placed in vinyl bags or in double layered *Conchocelis* nets, and used to seed the cultivation nets *in situ* in the sea. Generally 5-6 shells are needed to seed one cultivation net.

C. Spore germination

Nori nets (18x1.2m), which have received a conchospore inoculum either at sea or in tanks, are set out in the sea, where both germination and germling developement occurs.

These nursery nets are highly susceptible to contamination by other algae, (especially microscopic diatoms and the green seaweed Enteromorpha). However, since the Porphyra germlings are more resistant to dehydration than the contaminants, nets are arranged on poles (described further in section E) so that they are above the waterline for about four hours/day, or are floated on rafts which may be exposed as required (typically 0.5-3 hours every third or fourth day). Nursery nets may also be washed with pumped water, or beaten, to dislodge contaminants and prevent silting.

About 15-20 days after seeding, the germlings are visible to the naked eye; and after about 40-50 days the germlings are 2-3cm long. At this stage the nursery nets are set out in more open sea for cultivation, whilst others are stored in a freezer in case any replacement nets are needed.

D. Storage of nursery nets

As an 'insurance' against crop losses through bad weather, disease, contamination, or accidental damage it is now becoming increasingly common to store a percentage of the nursery nets (carrying 1-3cm long plantlets) in cold storage for possible later use.

To avoid damage to the cells upon cooling, the seaweed is dried, first by spinning the nets and then by dry air, such that the moisture content of the thalli is reduced to 20-40% of the normal wet-weight over a 3-4 hour period. To prevent further dehydration, nets are placed in polyethylene bags, boxed, and stored in a freezer at $-20 \pm 5^{\circ}C$.

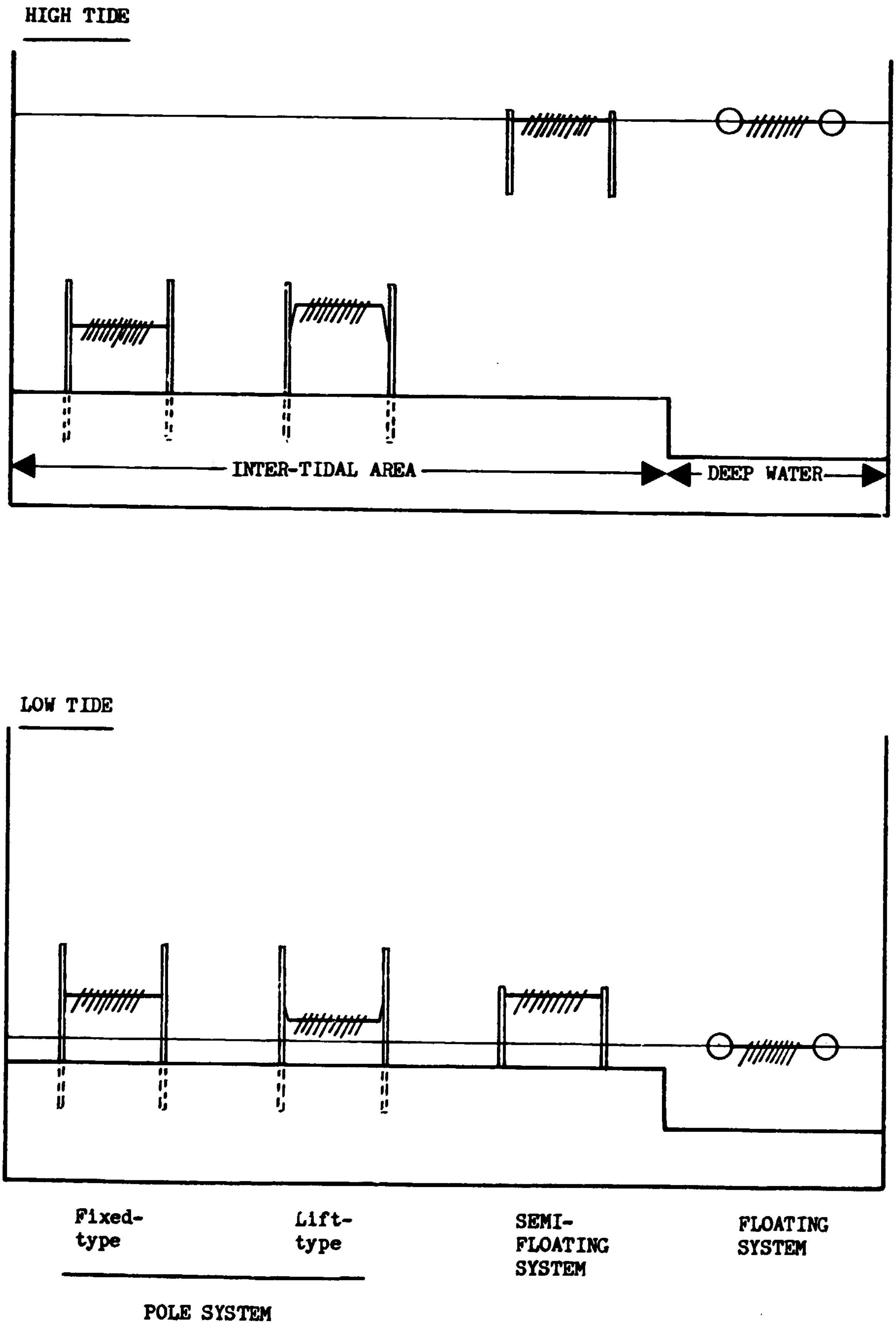
Nets are usually stored from October/November onwards for 1-4 months, though storage is possible for periods of up to 12 months.

E. Growing the *Porphyra* thalli

Several techniques of securing nets have been developed, each having particular advantages in certain geographical localities (figure 2).

The simplest system is the 'pole' method which is used only for intertidal cultivation. Poles are driven into the substratum and are used to secure the nets. As originally devised the nets were fastened tightly to the poles with short binding cords, thus being known as the 'fixed pole' type of culture. However, the method is only useful where the tidal range is 1-2m, and in areas with a greater tidal range (3-6m or more) the 'lift' type of pole system has been developed. With this technique the nets are given extra buoyancy by the provision of cylindrical floats, and are less tightly tethered to the poles, thus allowing the net to move up and down with the tides to some extent. The 'floating-raft' method is used for the production of *Porphyra* in deep waters, where the alga will still be suspended in seawater

FIGURE 2. PORPHYRA CULTIVATION



even at low tide. The 'semi-floating' raft method is a Chinese development which combines the advantages of the pole and floating-raft methods, and is used for intertidal cultivation. At high tide the raft floats on the surface, thereby providing good illumination for the algae, and at low tide the raft rests on the bottom by its short legs.

F. Harvesting

Porphyra thalli are harvested by thinning out the plants which have attained maximum length. Generally an 18x1.2m net will yield enough Porphyra to make 2,000 sheets of dried 'nori'. Harvesting can usually be repeated five times before the productivity of the net becomes unacceptably low, and in this event the net is replaced by a new nursery net from cold-storage.

Harvesting is largely manual, though various 'vacuum-cleaner' like devices have been used with some succcess.

G. Manufacture of 'hoshi-nori'

Harvested thalli are first washed thoroughly with seawater to remove contaminants, then chopped into small pieces and suspended in freshwater. The suspension is then poured into small rectangular wooden frames set upon a screen, and the wet sheets are hot-air dried to form sheets of 'hoshi-nori'.

The standard size of hoshi-nori is 20.2-21.2x17.5-19.0cm, and each sheet weighs about 3g. More than 6000million sheets were produced in 1970. Average consumption in

Japan was about 60 sheets/person/annum (Miura, 1975)

3.3.2. Cultivation of *Laminaria*

Laminaria is widely eaten in the Far East, as 'kombu' in Japan and as 'haidai' in China. As with *Porphyra*, two processes are involved in cultivation

1/ Cultivation of the microscopic gametophyte

2/ Cultivation of the sporophytic crop plant

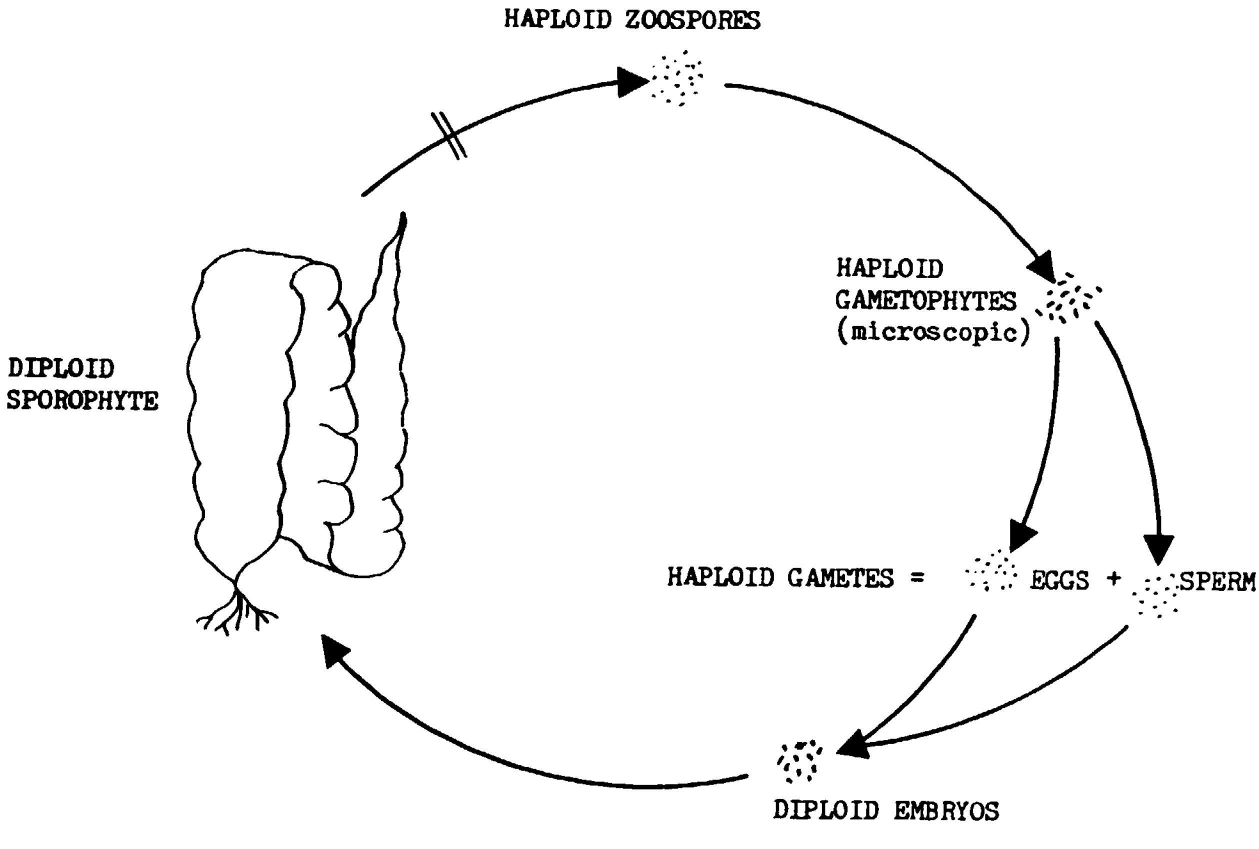
The life-cycle of *Laminaria* is shown in figure 3

A. Culture of the sporelings

Seeding takes place in indoor shallow tanks containing filtered, sterilized, seawater at 15°C to a depth of 10-15cm. Parent plants are first cleaned and are then hung in the air ovenight. They are returned to seawater in the morning whereupon the sporangial walls burst so as to liberate the zoospores. Frames of seeding cords or strings are then placed in the tanks and the actively motile zoospores adhere to the cords. The frames are then maintained in shallow tanks containing cooled nutrient enriched seawater so as to stimulate gametophyte growth. The gametophytes in turn produce the young sporophytes.

The temperature requirement for the production of sporophytes from the gametophytes is about 13-15°C. Thus if the culture starts in Summer or early Autumn (as is practised

FIGURE 3. LIFE-CYCLE OF <u>LAMINARIA</u>



particularly in China) the water must be artificially cooled. In Japan, the culture of germlings is usually carried out from the end of August until the end of Novemeber (Kawashima, 1984).

Fluorescent lamps maintain light intensity within the range 3-6,000 lx and provide a 12-16 hour light-period. After about seven days the gametophytes mature and after about 10-15 days the new generation of embryonic sporophytes begin to grow. In about 45 days the sporophyte thalli are about 5mm long.

B. Culture of sporophytes

Seeding strings are cultured in the sea. This provisional outplanting may last for 7-10 days (Kawashima, 1984) or 1.5 months (Tseng, 1981). Strings are then cut into 5cm lengths and inserted into cultivation ropes at 30cm intervals for further cultivation. Typically, cultivation ropes are hung vertically at 2m intervals from the main line of a cultivation raft.

Throughout much of Japan, a two-year period of cultivation is used, which reproduces the natural two-year life-cycle of the biennial Laminaria varieties used. In southwestern Hokkaido, however, 'forced cultivation' is used, in which seedling production is carried out as early as possible (end of August to mid-September) and sporophytes are taken from the tanks to the sea as soon as the water temperature drops below 18°C (in October). The sporophytes are then grown through the winter months, and by thinning the attached plants and binding many of the more unstable holdfasts, a large biomass is produced in a short time. Plants are then moved nearer to the surface, and the vertical cultivation ropes are secured horizontally so as to allow better illumination.

In Japan such forced cultivation is apparently restricted to the southwest of Hokkaido, where winter conditions are not too severe and therefore allow the crop to be intensively managed. Within this area forced cultivation accounts for 92% of the total Laminaria cultivated (Kawashima, 1984). Tseng (1981) similarly refers to a single-year process in China, depending on the cultivation of summer sporelings, the manipulation of illumination, and the addition of fertilizers

3.3.3. Cultivation of Undaria

Cultivation and usage of Undaria has been reviewed by Saito (1975). Methods of culturing Undaria are essentially the same as those used for Laminaria except that Undaria sporophytes and gametophytes are more resistant to higher temperatures and do not therefore require the water to be artificially cooled in the sporeling tanks. Also Undaria is an annual plant (cf. Laminaria a biennial plant) which therefore does not require any forced cultivation.

4. CURRENT USAGE OF ALGAE AND ALGAL PRODUCTS FOR FODDER

4.1. World Usage

Chapman (1970) reports that seaweed is still fed regularly to animals in several countries throughout the world. Interestingly, most of these countries are European. Genera utilized are summarized in table 9.

TABLE 9. SEAWEED GENERA COMMONLY USED FOR FODDER

BROWN SEAWEEDS	RED SEAWEEDS
Alaria	Chondrus
Ascophyllum	Palmaria
Fucus	Rhodymenia
Laminaria	
Macrocystus	
Pelvetia	

Data from Newton (1951), Boney (1965) and Chapman (1970)

EUROPE In France, Rhodymenia is fed to cattle, and Laminaria saccharina fed to pigs.

In Finland, both Laminaria and Alaria are fed to cattle, and in Iceland, Rhodymenia palmata and Alaria esculenta are fed to dairy cattle without affecting the smell or taste of the milk produced. At least 10,000 ewes (= 1% total stock Icelandic stock) are still regularly fed on fresh seaweed (Hallsson, 1964).

In many of the Scottish isles, sheep and cattle are allowed to graze on Alaria, Laminaria and Pelvetia from the shores, and on North Ronaldsey (Orkney Islands), there is a local race of sheep which feed entirely on seaweed with little apparent harmful effect.

In Norway, sheep are regularly fed on seaweed, and Fucus, Chorda, Laminaria and Alaria are all fed to cattle.

REST OF THE WORLD Farmers in some parts of the USA regularly include 10% Ascophyllum meal in their cattle feeds. (see section 4.2). In New Zealand, sheep are reported to eat Cystophora, Sargassum and Hormisira, whilst in Hong Kong, Sargassum is used as a pig feed.

4.2. Products Used

Whilst in earlier times the use of seaweeds for fodder was restricted to coastal areas near to the source of supply, modern practice is to use dried and ground seaweed meal, which may be transported for use in coastal or inland areas. However, usage of seaweed meal is still largely restricted to coastal areas where, perhaps, prejudices against the use of such products may be less than in inland areas.

Seaweed meal is produced from the brown weeds Ascophyllum, Fucus and Laminaria. World production of seaweed meal is about 30,000ton/year, with Norwegian factories producing about 50% (Jensen, 1979). Other main producers are factories in Scotland, Eire, Denmark and North America. Jensen (1979), however, considers that the major output of seaweed meal goes to the alginate industry. The rest of the meal is used to feed cattle, pigs and poultry. The world value of seaweed meal is estimated as nearly $10million per annum (Jensen, 1979).

In Norway, two main methods of processing seaweed meal are practised i.e. natural drying, and rotary drum-drying (Jensen et al., 1968). Drum drying produces a product of consistant quality, with less susceptibility to microbial attack than naturally dried weed.

In Denmark, weed is cooked with superheated steam, then drained and compressed into cakes, which are vacuum-dried and then ground.

4.3. Nutritional Value

The nutritional value of algae has been considered generally in section 2. Here, therefore, we will restrict consideration to some of the 'seaweed-feeding' studies carried out on animals.

Raw seaweeds are known to provide trace elements, minerals, roughage and carbohydrate for livestock (especially ruminants), and indeed sheep have been known to live entirely on a diet of seaweeds. However, whilst earlier claims that up to 30% of the ration of pigs, sheep and cows may be replaced by seaweed meal, it is now considered better to provide not more than 10% of the ration with such material.

The feeding of 1.25% seaweeed meal in the ration of hens was found to reduce the incidence of thin shelled eggs from 3 to 1.9% (SSRA, 1967); whilst improved yolk colour and increased iodine content have also been observed in seaweed fed poultry (Jensen, 1966).

Nebb and Jensen (1966) found that *Ascophyllum* meal fortified with calcium, phosphorus and vitamin D compared favourably with commercial mineral and vitamin mixtures in feeding trials on dairy cows and pigs.

Studies by Black (1955) have shown the great variability in the digestibility of different seaweed meals; *Laminaria* was found to be particularly digestible to sheep and pigs, whereas *Ascophyllum* was poorly digested (even having some detrimental effects on protein digestion). Generally, work has shown that much of the nitrogenous material in seaweed is indigestible, and that the most important digestible component is laminaran, thereby explaining the high digestibility of *Laminaria*.

Chapman (1970) and Jensen (1972) provide further information on the usage of seaweeds for animal feedstuffs. There have, however, been some reports of the detrimental effects of seaweed-feeding. Jensen (1958) reports of cases of diarrhoea when animals were fed with large amounts of seaweeds. Toxic effects of *Ascophyllum nodosum* have been demonstrated in rabbits (Jones *et al.*, 1981), with rabbits fed on a diet containing 10% *Ascophyllum* demonstrating reduced haemoglobin, haematocrit and serum iron levels (the condition frequently being fatal). However, no deleterious effects were observed in rats and pigs on a similar diet. Studies in Iceland revealed a frequently fatal nervous disorder in newly born and young lambs (similar to 'swayback' i.e. enzootic ataxia) when their mothers had been fed large amounts of seaweed (up to 10kg/day/animal) during the latter half of their gestation period. This condition could be prevented by providing more hay, less seaweed and a copper sulphate supplement during the gestation period, and nowadays the disorder is much rarer than it was 30-40 years ago (Hallsson, 1964).

These studies do demonstrate, however, the need to closely monitor the effects of seaweed supplements on domestic animals, though if seaweeds are only contributing a small proportion of the total diet (<5%) less concern may be necessary.

5. CURRENT USAGE OF ALGAE AND ALGAL PRODUCTS FOR FERTILIZER

5.1. World Usage

Probably the earliest reference to the usage of seaweeds for fertilizer comes from Roman writings from the 2nd Century AD (Newton, 1951), and since the 12th Century AD seaweed manures have frequently been used in several European countries. Seaweeds are usually collected from beach drift ('driftweed') or are harvested from wild (but occasionally managed) populations. For use as fertilizer, seaweeds may be used directly (dug into the soil), composted, or (increasingly nowadays) reduced to dry or liquid preparations. Seaweeds commonly used as fertilizers are included in table 10.

TABLE 10. SEAWEED GENERA COMMONLY USED AS FERTILIZERS

BROWN SEAWEEDS	RED SEAWEEDS
Alaria	*Lithothamnion*
Ascophyllum	*Phymatolithon*
Durvillea	
Ecklonia	
Fucus	
Laminaria	
Macrocystus	
Sargassum	

Data from Newton (1951), Boney (1965) and Chapman (1970)

FRANCE The greatest use of seaweed as manure is found in the 'ceinture dore' region of north-west France where $30\text{-}40m^3$ weed.hectare^{-1}.year^{-1} is applied. Driftweed, known as 'goemon epave', 'goemon de derive' or 'goemon d'echouage', is generally used. Collected seaweed is either dug into the ground fresh, or is sun-dried and stacked for later use.

In Brittany, the red seaweeds Phymatolithon calcareum and Lithothamnion coralloides are collected as 'marl'. These species are rich in calcium carbonate and are used on acidic soils to increase the pH. According to Blunden et al., (1975), 300,000 tonnes of marl are produced each year in Brittany alone, with further exploitation in North Africa, Denmark, Italy, Portugal and the UK.

EIRE Seaweed is fairly extensively applied to land used for potatoes, oats and on pasture. Fucus vesiculosus is particularly highly valued and in some areas it is cultivated for this purpose, by placing rocks and stones in sandy bays so that the seaweed can colonize.

ICELAND Traditionally, driftweed has been soaked in boiling water and allowed to decompose in heaps prior to use (Hallsson, 1964).

UK In various parts of the UK, driftweed and cut brown seaweed is used as manure for barley, potatoes, broccoli and green crops. Usually seaweed is composted prior to use, though in Scotland it is often used directly and is not even ploughed into the soil.

USA On the west coast of the US, large kelps are collected, chopped, and used wet. Commercial exploits to use dried weeds have met with limited success.

FAR EAST/PACIFIC In China, species of Sargassum are collected from driftweed and are used fresh, dried, or burnt and the ash applied to the soil. Crops involved include peanuts and sweet potatoes.

The Japanese also make use of seaweeds for manure, though many of the Japanese seaweeds are more highly prized as human food.

In New Zealand, Macrocystis, Lessonia, Ecklonia, Cystophora and Sargassum are used by coastal populations as manure.

SOUTH AMERICA Coastal farmers in Brazil use Hypnea, Ulva and Enteromorpha as coconut manure, whilst seaweeds are also used in Chile.

5.2. Products Used

Section 5.1 reveals that much of the current usage of seaweeds for fertilizers (manure) still involves the use of fresh weed by coastal populations. Section 5.3., however, reveals that seaweed fertilizers are useful, but the limiting factor preventing further usage is the cost of transporting large amounts of bulky material to inland regions. Since fresh seaweeds contain about 90%

water, one solution is simply to dry the weeds before transport. However, Chapman (1970) reports that American firms attempting such a process found great difficulties because of the viscosity of the algal exudates.

An alternative stategy, however, is to process the weed into a liquid manure. Well-known brands of liquid seaweed manures include 'Maxicrop' (marketed in the US as 'Seaborn'), 'Marinure' (also marketed as 'Algifert'), 'SM3' (also marketed as 'SM3-Soil Activator') and 'Alginure'. Maxicrop and Marinure are obtained by alkaline hydrolysis of Ascophyllum, whereas SM3 and Alginure are obtained from Laminaria and species of allied genera.

5.3. Value as Fertilizers

Fresh seaweed contains as much nitrogen, 80% more potash, and 33% of the phosphorus of farm manure; and should, therfore, always be supplemented with added phosphates (Chapman, 1970). Unfortunately, much of the nitrogen is not readily available, and for this reason Scottish farmers consider seaweed to have 40% of the value of farm manure. Because of its high potash content, seaweed is particularly suitable for root crops; and has the added advantage of being free from weeds and fungal contaminants.

In addition to the content of major elements, seaweeds also contain significant amounts of trace metals They may also contain various growth promoters (auxins, cytokinin, gibberellins), and various substances which inhibit pests and pathogens.

Senn _et al._ (1961) showed that seaweed imparted a degree of frost resistance to tomato plants, with treated plants being able to withstand 29°F, which killed the controls. Booth (1966) discusses further related findings which strongly support this claim.

Addition of seaweed extracts has been found to hasten the germination of seeds of various crop species, and Booth (1966) suggests that this might be attributable to the presence of gibberellins in the seaweeds. However, though Williams _et al._ (1981) did detect gibberellin-like activity in freshly prepared samples of three commercial seaweed extracts, they considered that the level of activity was insufficient to produce a physiological response at the concentrations used in agriculture and horticulture. Also, since the gibberellin activity diminished rapidly on storage, it was considered unlikely that any commercial extracts possessed significant activity.

In contrast, significant cytokinin-like activity has been clearly demonstrated in commercial seaweed extracts (Williams _et al._, 1981). The possession of such activity has been used to explain the effects of seaweed extracts in increasing the root weight, root sugar content and clarified juice purity of treated sugar beet (Blunden _et al._, 1981).

Various studies have shown that the addition of seaweed to soil results in an increase in nutrient content in crops, which is actually higher than that which can be accounted for by the added nutrients in the seaweeds. This effect of seaweeds in enhancing nutrient uptake is probably attributable to the activity of algal carbohydrates (or their constituent sugars) acting so as to chelate metal ions and make them more readily available to the crop.

The regular use of seaweed extracts has been shown to reduce the problems caused by a variety of fungal pests. Work has shown that seaweed extracts may eliminate 'black spot' from rose leaves, and may reduce mildew on turnip leaves and on melons. Extracts may also reduce 'damping off' in tomato seedlings and reduce the incidence of brown rot in peaches. The reasons for such effects are not always clear; Stephenson (1966), for example, demonstrated no direct fungicidal effect of seaweed extract even though an increased resistance to fungi was clearly demonstrated by the seaweed addition. It seems probable, therefore, that the seaweed extracts improve the general nutritional state of the plants so that they are unsuitable for fungal colonization, though the presence of some new and potent fungicides in seaweed extracts has not been totally ruled out, and Booth (1981) suggests that this activity might be attributable to the presence of kinetin (cytokinin) in the extracts.

Several studies have shown that plants treated with seaweed are less affected by insect pests such as aphids and the red spider mite. Stephenson (1966), for example, clearly demonstrated an increased resistance of various crops to insect contaminants when treated with liquid seaweed, even though no direct effect on the insects could be detected. Booth (1966) considers this evidence and concludes that such effects may result from the trace metal content of the weeds, since EDTA chelates of various metals (especially iron and magnesium) sprayed onto hops produced similar effects i.e. reduced insect pest problems.

However, as with the effects on fungal pests, one cannot rule out the effect being a result of the altered nutritional status of seaweed treated plants.

Chapman (1970) stated that whilst there is a considerable body of information on the the effect of seaweeds on the chemical composition of the soil, little is known about the effect on physical properties. Milton (1964), however, comments that the seaweed degradation products of alginate, fucoidan, etc. retain strong polar groups, and when a solution containing such is added to soil, the formation of aggregates is enhanced and the soil crumb structure is improved. In the special case of the seaweed soil conditioner, marl, Wildgoose et al. (1981) investigated its effects and suggested that it was superior to either lime or magnesium and calcium carbonate for conditioning purpose. No gibberellin, auxin or cytokinin activity could be detected in the marl and, since its organic content was low, it was concluded that its activity was probably attributable to its inorganic constituents.

There have been occassional reports of deleterious effects of seaweed fertilizers including excess manganese release in acidic soils, water-logging of soils treated with Pachymenia, and inhibitory effects on plant growth (Boney, 1965) .

6. CURRENT USAGE OF ALGAE AND ALGAL PRODUCTS FOR MEDICINAL PURPOSES

Since algae contain various minerals and vitamins their use has been closely linked with a healthy diet and, for example, the low incidence of goitre in the Far East is undoubtedly partly attributable to the preventative medicinal effect of iodine-rich seaweeds. Algae have, however, for centuries been considered useful for the treatment of various conditions and ailments. Indeed the first recorded usage of algal products comes from a herbal in the 'Materia Medica' of Shen-Nung (c. 2700BC).

Most of the uses of seaweed products for medicinal purposes are still restricted to herbal or holistic medicine. Yet current scientific research is showing that when many of the folk remedies are investigated, sound 'scientific' reasons for their activity can be found. For instance, the brown seaweed *Digenea simplex* had long been used as an antihelmintic in folk remedies long before the discovery of its active constituent L-alpha-kainic acid (a derivative of proline) which is a potent antihelmintic, especially against *Ascaris*. It would seem likely, therefore, that as scientific investigation into the pharmacologically active constituents of seaweeds advances, a convergence of herbal and western medical opinions might occur.

An up-to-date review of the uses and potential of marine algal products in medicine is given by Hoppe *et al.*, (1979). In the space available here, it seems best simply to stress that seaweed products do have considerable potential medicinal uses, some of which are shown in table 11.

At this stage it would seem unwise, therefore, to discourage the use of seaweed extracts for medicinal purposes in countries which largely depend upon herbal type medicinal treatments. Rather we should encourage western scientists to elucidate the compounds responsible for any claimed effects.

TABLE 11. SOME PHARMACOLOGICALLY ACTIVE COMPOUNDS FROM SEAWEEDS

SOURCE	COMPOUND	EFFECT
Caulerpa lamourouxii	caulerpicin	anaesthetic
Chondria armata	domoic acid	antihelmintic
Chondria littoralis	chonalgin	antibiotic
Chondria oppositiclada	chondriol, cycloeudesmol	antibiotic
Digenea simples	L-alpha-kainic acid L-alpha-allokainic acid	antihelmintic antihelmintic
Eisenia bicyclis	laminarin-like polymer	anti-inflammitory
Laminaria angustata	laminine (amino acid)	hypotensive
Sargassum confusum	sargaline	hypoglycaemic
Sargassum natans	sarganin	antibiotic

7. 'NEW TECHNOLOGIES' AND FUTURE DEVELOPMENTS

Having considered some of the established 'traditional' algal technologies, the purpose of this section is to briefly review some of the emerging technologies and associated research relevant to the topic under consideration. It must be stated at the outset that it is not anticipated that the 'developing countries' would make any significant contribution to this research, but they could expect to benefit from it in the forseeable future.

7.1. Genetic manipualtion

Probably the most obvious improvement to current seaweed cultivation techniques is the use of new seaweed strains which possess more desirable traits (e.g. higher productivity, increased resistance to diseases, pests, or adverse environmetal conditions) It is apparent that such manipulation is in its infancy as regard seaweeds, and much of the seaweed harvested for use for food and phycocolloids is still essentially 'wild type' material. Yet the genetic manipulation of seaweeds need not involve 'high-tech' recombinant DNA technology (though this may have its part in future work). For the most part, plant breeding and selection programs are quite able to supply improved varieties of seaweed species.

The Chinese are probably the current world leaders in the practical breeding of seaweeds, and in particular Laminaria. Useful strains (e.g. Hai-Ching No1) were introduced as long ago as

1962, and through selection and inbreeding programs the Chinese have developed strains superior to wild-types in growth rate, iodine content and temperature tolerance. Both Cheng (1969) and Tseng (1981) review these developments. As well as utilizing natural variability, the Chinese have also induced mutants by X-ray irradiance and colchicine treatments. Fang et al. (1978) also report of a monoploid breeding programme for Laminaria, where monoploid female gametophytes are induced to develop parthenogenetically into sporophytes which then undergo spontaneous or induced chromosome doubling to form completely homozygous diploid sporophytes, therby allowing easy comparison of the desirability of individual genomes.

It has also been found that seaweeds readily hybridize across specific and even generic boundaries, thus the use of interspecific and intergeneric hybrids may offer potential advantages (though the phenotypes of these hybrids are virtually impossible to predict).

Perhaps the main disadvantage of such selection and breeding programmes is the time required before assessment can be made of the usefulness of a variety. Artificial recombination techniques offer advantages in this respect in that they can incorporate DNA into the genome without the necessity for sexual reproductive steps. Also, only DNA carrying the required sequences for expression of desirable traits may be introduced, making phenotype selection somewhat more simple than in conventional programmes. Such manipulation of algae is, however, still in its infancy. Manipulation of the prokaryotic blue-greens is possible through plasmid manipulation techniques, but vectors for the insertion of exogenous DNA into eukaryotic cells are less clearly developed - possibly eukaryotic algal viruses may have some use in this context. Eukaryotic algae have been manipulated, however, using protoplast fusion-somatic hybridization technology. Cheney (1984) reviews current work on this technology.

7.2. Tissue culture

This section strongly overlaps with the previous since tissue culture techniques are adopted in protoplast fusion-somatic hybridization programs. However, tissue culture may also simply be used for plantlet regeneration, and might allow the generation of seaweed for subsequent culture without depending on the production and fusion of sexual stages. Such techniques in enabling the production of clones might also standardize productivity and maturation time.

The use of tissue cultured cells could, in itself, enable production of useful biomolecules. However, this does not appear to be a viable process for the production of biomass (for food).

7.3. Novel Species and Novel Cultivation Techniques

Whilst it is likely that the chemical and drug industries will make further use of 'novel' seaweeds producing novel products, it would seem unlikely that novel species would either offer significant advantages and/or be readily accepted by the consumer, in relation to their use for human food. Related to this point, it is clear that microalgal culture is feasible. Microalgal specific growth rates are usually higher than those of seaweeds, and microalgal biomass may contain significantly higher levels of protein. However, wild microalgal populations are usually too dispersed and ephemeral to be harvested. Thus microalgal culture must be entirely artificial and carefully controlled, resulting in an expensive end product. The cost of microalgal production has been quoted as $0.57/kg by Tamiya (1978), $1/kg by Soeder (1978) and $0.15-0.25/kg by Oswald (1979). Microalgal protein is thus about 10-times more expensive than its soya bean equivalent. However, microalgal protein <u>is</u> produced in the USA, and in the Far East 1000 tons of microalgae are produced annually (Tsudaka <u>et al.</u>, 1978); in both cases the high cost of production is offset by the high price commanded by the product as a health food.

By linking algal production to traditional wastewater treatment technologies (e.g. sewage lagoons) the cost of production could be considerably reduced to about $0.01/kg dried product (Oswald, 1973), and such waste-grown algae may well be suitable for production of fertilizers and fodder. The use of waste-grown algae for human food is, however, unlikely to achieve widespread acceptance, owing to the possibilities of pathogen transmission, toxin bioaccumulation, and aesthetic considerations.

POSSIBLE STRATEGIES FOR DEVELOPING COUNTRIES

It is clear therefore that, on a global scale, the algae are a largely undeveloped source of nutritionally useful organisms. Considerable use of algal biomass is made in the Far East, yet in many of the developing countries, little or no use is made at all. Strategies for the development of 'seaweed industries' in these countries are outlined below. However, it must be stressed that the strategies outlined below may not be fully comprehensive and (like much of the rest of the document) are largely included so as to stimulate thought and discussion.

The actual industrial strategies required to develop an edible seaweed industry are reasonably clear, and include three broad options.

1/ First, there may simp[illegible] be increased exploitation of natural stocks which, on a local basis, may be adequate and useful for coastal populations.

2/ There may also be a more distinct management of natural stocks and the development of new areas for seaweed growth, including reef-blasting and the addition of rocks to sandy coastal areas. Such a philosophy may also be applicable in non-coastal areas where seaweeds could be grown in inland lagoons. In Taiwan, for example, 12,000 tonne (dry-weight) *Gracilaria* are produced annually from 300 hectares of ponds.

3/ The highest level of sophistication would probably be to develop seaweed culture technology as practised in Japan and China. This would require the ability to culture both the crop plant and the spore/germling stages. As regards the spore/germling stages, however, it may be possible to trade with countries already possessing the technology to produce germlings i.e. to import them, probably from the Japan or China. Payment for this service could be on a cash basis, or could comprise either a fixed amount or percentage of the total harvest produced.

The economic strategies relevant to the development of a seaweed industry are less certain. Currently, however, two major economic strategies are likely :-

1/ The first can be called 'self-use', and requires the algal product to be used within the country itself. This would subsequently ease the internal requirement for another food source which could then be exported (if it was also supplied internally) or (if it was imported) reduced amounts could be imported. In either case, seaweed production would improve the balance of payments. Chapman (1970) reports of such a rationale in Norway in the 1930's, where it was calculated that if each animal in the country were fed 500g seaweed meal per day this would be equivalent to 445,000 tons dry seaweed per year, i.e. equivalent to 20% of the annual Norwegian hay harvest.

2/ The second strategy is simply to grow seaweed products for export only. As regards food, export would be most likely to Japan, which already imports considerable amounts of seaweed. Japanese food products are, however, of a very high quality. Thus any embarkation upon this course of development would require the training of a skilful work force to produce an acceptable product. If this was achieved, a good price could be obtained for the product, and work in the Philippines (on Eucheuma) has already shown that a reasonable investment in seaweed technology can result in the rapid development of a major industry where previously there was little or none.

The problem in such development, therefore, is that of obtaining a skilful (and motivated) workforce able to grow high quality product. One possible solution to this problem stems from the current and anticipated difficulties of expansion of the Japanese seaweed industry itself. It is clear that the Japanese industry is now somewhat limited by the absence of further suitable coastline, and is also increasingly susceptible to the problems of pollution caused by the high population densities on the islands. It may be the case, therefore, that the coastlines of certain developing countries could be used (perhaps leased) by seaweed culture concerns from Japan (and also, perhaps, other interested countries) to expand for their own use, which could then lead to a rapid transferral of ability/interest to the indigenous population and lead to further development in the industry in those countries.

It is clear that some of these developments will occur naturally to supply local demands, whereas others may require significant government intervention to stimulate any development. Perhaps the main task, within the near-future at least, is therefore to educate governments and populations as to the potential uses of seaweeds and seaweed-based products.

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