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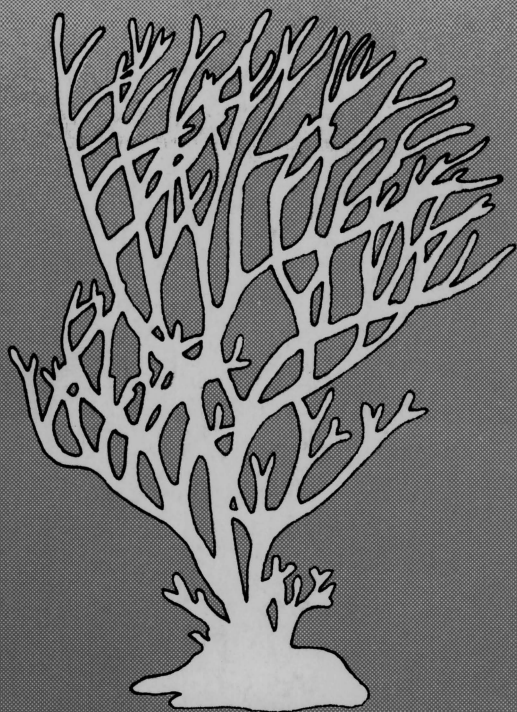
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Seaweeds in New York Waters: A PRIMER



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A PRIMER

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CONTENTS

ABSTRACT.....	iii
INTRODUCTION.....	1
TAXONOMY.....	2
REPRODUCTION.....	3
SOME SEAWEEDS OF NEW YORK.....	5
<u>Laminaria saccharina</u>	5
<u>Gracilaria tikvahiae</u>	8
<u>Agardhiella subлата</u>	12
<u>Codium fragile</u>	14
<u>Fucus vesiculosus</u>	16
SUMMARY.....	21

FIGURES

1. <u>Laminaria saccharina</u>	6
2. Life history of <u>Laminaria saccharina</u>	7
3. <u>Gracilaria tikvahiae</u>	9
4. Life history of <u>Gracilaria tikvahiae</u> and <u>Agardhiella tenera</u>	11
5. <u>Agardhiella sublata</u>	13
6. <u>Codium fragile</u>	15
7. Life history of <u>Codium fragile</u> ssp. <u>tomentosoides</u> .	17
8. <u>Fucus vesiculosus</u>	18
9. Life history of <u>Fucus vesiculosus</u>	20

ABSTRACT

Seaweed, already used to make phycocolloids, also has great potential as a source of both food and energy. It has been a mainstay of Oriental diets for centuries; and scientists in the United States and elsewhere are now experimenting with ways to use seaweed as biomass for conversion into methane gas--a promising alternative fuel. This idea is especially attractive because crops of cultivated seaweed would represent a renewable energy source. Also, seaweed mariculture is probably the only way to provide a stable supply of raw seaweed for the phycocolloid industry.

This primer gives the basic biological facts about seaweed. It then describes five common seaweeds found in New York State waters--their appearance, life history, and other characteristics. All five are promising candidates for commercial use in both the biomass and phycocolloid industries.

INTRODUCTION

Seaweeds are marine plants belonging to a group of organisms called algae. They may be small, microscopic, single-celled plants, or macroscopic, multicellular forms. They have no leaves, stems, or roots but they may have homologous structures, that is, structures that have a similar shape and position but may differ in function.

Seaweeds are most commonly found in relatively shallow water. Their vertical distribution ranges from a few meters above the low tide mark to depths as great as 200 meters in clear tropical waters.

As all plant life, seaweeds photosynthesize in the presence of sufficient light. Availability of proper light intensity and quality is a major factor regulating distribution and productivity of seaweeds. During daylight, algae take up carbon dioxide and convert it into oxygen and organic material, or biomass. The supply of carbon dioxide for the plant is in the form of gas when seaweeds in the intertidal zone are exposed to the atmosphere, and as bicarbonate when they are submerged in seawater. Seaweeds also respire, consuming oxygen and some of the organic material that is produced during photosynthesis. While photosynthesis occurs only in the presence of adequate light, respiration occurs in both light and darkness. There is a net production of biomass (growth) when, over a 24 hour period, photosynthesis is greater than respiration.

Species that live in deeper waters have adapted their light- capturing photosynthetic pigments to accommodate the altered quality (wavelength) and quantity (intensity) of light. As light passes through the water column, red light (longer wavelengths) is absorbed first. Blue light penetrates the farthest in clear oceanic water. Frequently, cooler, temperate, and nearshore waters contain much suspended sediment (from wave action on beaches and land run-off) and dissolved organic matter (some of which may be released by the seaweeds themselves) that further alters the quality of light with depth. In these instances, green light predominates at depth. In all cases, the intensity of light decreases with depth in a logarithmic fashion.

Seaweeds inhabiting the intertidal zone have developed additional features to permit survival in this harsh environment. They must be able to withstand variations in temperature, short immersions in seawater, and wave action. Adaptations to these conditions include thick external cell walls, heavier holdfasts, and more rapid nutrient uptake mechanisms. Most seaweeds are preferentially found on rocky substrates because of the greater stability of these substrates.

TAXONOMY

There are seven groups of algae, known as divisions. Of these, only three contain macroscopic, marine forms, that is, seaweeds. The division Chlorophyta, or green algae, contains approximately 7,000 species, of which 13% are marine. The division Phaeophyta, or brown algae, has about 1,500 species, of which 99% are marine. The green algae predominate in the tropical oceans. The red algae dominate the tropical/subtropical climes, whereas the brown algae are mostly found in cooler, temperate waters.

Classification by division is based mainly on the presence of dominant color pigments, although differences in major modes of reproduction, types of storage products present, and composition of the cell wall are also divisional characteristics. Further breakdowns are due to more minor differences of the same types as above.

REPRODUCTION

Reproduction and life histories of seaweeds are a rather complex affair. There are three general types of reproduction which occur in seaweeds: vegetative, asexual, and sexual.

Vegetative reproduction occurs by simple fragmentation of the thallus. Fragments consisting of only a few cells, or pieces of branches, may separate from the parent plant and settle onto the substrate. Here these fragments may reattach, or continue as free-living material, and may grow into large plants. Fragmentation may be induced by damage to plant tissues resulting from temperature extremes, abrasion, or wave action.

Asexual reproduction involves the production of special reproductive spores. These spores may be produced by any number of cells in the thallus, or in specialized structures. (This will be discussed in greater detail later.) The main feature of asexual reproduction is that these spores contain the same genetic material as the plant that produced them, that is, the offspring are genetically identical to the parent plant. The released spores settle onto an appropriate substrate and germinate to grow into adult plants. This type of reproduction is common in green and brown algae.

Sexual reproduction may be observed in green, red, and brown seaweeds. It involves the production of gametes in specialized structures, the names of which differ among the classes of algae. Hence, these structures will not be described until the different seaweeds are introduced. Male and female gametes may be produced on the same plant (monoecious) or on two separate plants (dioecious). The gametes may be motile by use of flagella, or nonmotile, depending on the alga. Green algae usually have motile male and female gametes. In brown algae, the male is usually motile while the female is not. In red algae, neither the male nor the female gamete is motile. The gametes may be of similar (isogamous) or dissimilar (anisogamous) size. The egg, or female gamete, may be released to the water before fertilization, or remain attached to the parent plant. When male and female gametes are borne on the same plant, there may be self-compatibility or self-sterility.

Another feature of sexual reproduction in seaweeds is the alternation between a sexual and asexual phase, called alternation of life cycles. The sexual phase that produces gametes may involve the same sized adult plant as the phase that produces spores asexually (isomorphic),

as in many red and green algae. If the two stages are of distinctly different size upon maturity, then this is called heteromorphic alternation of life cycles. The stage that produces gametes is called the gametophyte stage, while that which produces spores is called the sporophyte stage.

SOME SEaweEDS OF NEW YORK

Laminaria saccharina

This brown alga is sometimes called sweet tangle or broadleaf kelp (Figure 1). It is widespread and may be the dominant plant of the subtidal fringe and subtidal zones of many cold-water shores worldwide. It grows attached to rocks, pilings, wharfs, ropes, and shells. Plants are commonly found in areas of strong surf. It is among the largest of the local seaweeds, attaining a length of up to 5 meters (about 16 feet).

The mature plant has a base consisting of a rhizoidal, or rootlike, filamentous holdfast with branches called haptera. The holdfast attaches the plant to the substrate and acts like a root but does not absorb nutrients as do roots of higher plants. The holdfast may have several stipes, or stems, of various lengths, usually 10 to 50 centimeters (4 to 20 inches). At the top of the stipe is a several meter long blade that may be up to 30 centimeters (1 foot) wide. Frequently, the edges of the blade have a ruffled appearance. The apex, or tip, of the blade may be partly eroded from wave action and old age--it is the oldest part of the blade.

Most growth in this plant occurs in a 10 to 30 centimeter (4 to 12 inch) long meristematic (actively growing) region at the base of the blade, just above where the stipe ends. Older parts of the blade also photosynthesize and grow, but contribute relatively little to increasing the size of the plant. Nonetheless, these older portions are very important to the nurture of the active growth region, especially during times of insufficient external nutrient supply or light availability or low temperature, for example, the winter months.

The plant normally reproduces during the fall months. Its mode of reproduction involves the two-phase life cycle shown in Figure 2. We recall that this type of reproduction is referred to as a heteromorphic alternation of life cycles. The large-bladed plant,

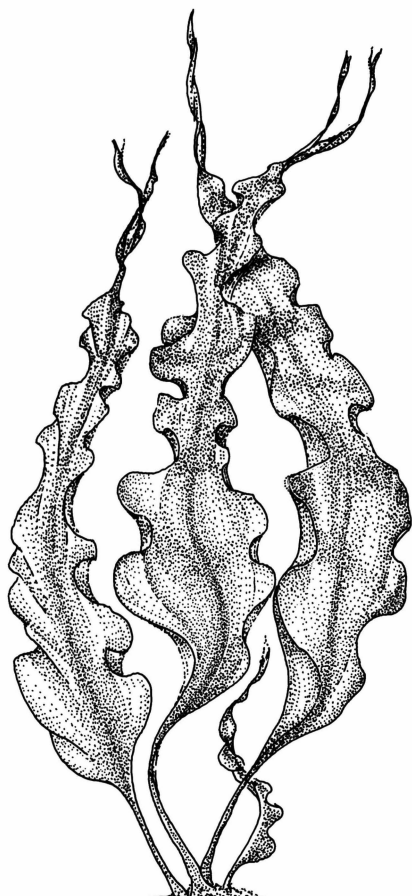


FIGURE 1 Laminaria saccharina.

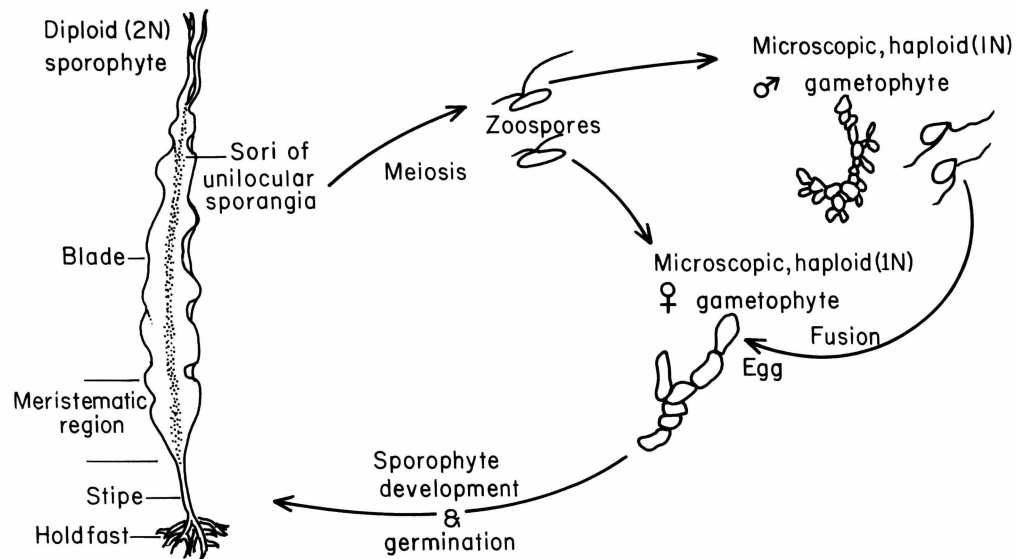


FIGURE 2 Life history of *Laminaria saccharina*.

known as a sporophyte, develops a darkened, raised region along the center line of the blade. These regions are also known as sori. Each sorus (singular) has many unilocular sporangia, or unicellular structures that produce four or more haploid zoospores (spores that have 1N chromosomes) by meiosis (the process that reduces the chromosome number of the adult diploid, or 2N, sporophyte). The process of spore production is also called sporogenesis.

These spores germinate into haploid gametophytes that are typically filaments of only a few cells in length, that is, almost microscopic. These gametophytes become fertile in the presence of white or blue light; they do not become fertile in red light, but can become fertile after subsequent exposure to white or blue light. Under appropriate light conditions, gametophyte germination and production of male and female gametes occur within a period of a few days (2 to 10), depending on temperature and light intensity.

Separate male and female gametophyte plants exist, that is, the species is dioecious. The released gametes fuse into a zygote (now 2N) and germinate into a plant that will become the large sporophyte. Occasionally, the holdfast and stipe of adult sporophytes will survive for more than one year and grow out the following fall (perennial). Most of the plants found in New York waters are annuals, that is, they die back during the summer months after spore release.

Gracilaria tikvahiae

This red alga is sometimes called sea string and it is commonly found in shallow estuarine waters. The plant is bushy in appearance (see Figure 3) and ranges from a yellowish-red to purple in color. Plants that have an adequate amount of nitrogen are more purple. Specimens may be found attached to small stones, pilings, ropes, and shells, or partly embedded in sand. Frequently, large masses of unattached material may be found lying on the bottom. The branches are cylindrical and feel slippery to the touch.

The taxonomy of the genus has undergone recent changes for a number of different species found along the coast of eastern North America. G. verrucosa, also known as G. confervoides, was reported to occur along the east coast. Another species, G. foliifera variety augustissima had also been reported to occur along this coast. McLachlan recently examined material from verrucosa and foliifera var. augustissima collected along the east coast. He concluded that the foliifera var. augustissima here did not even resemble the original

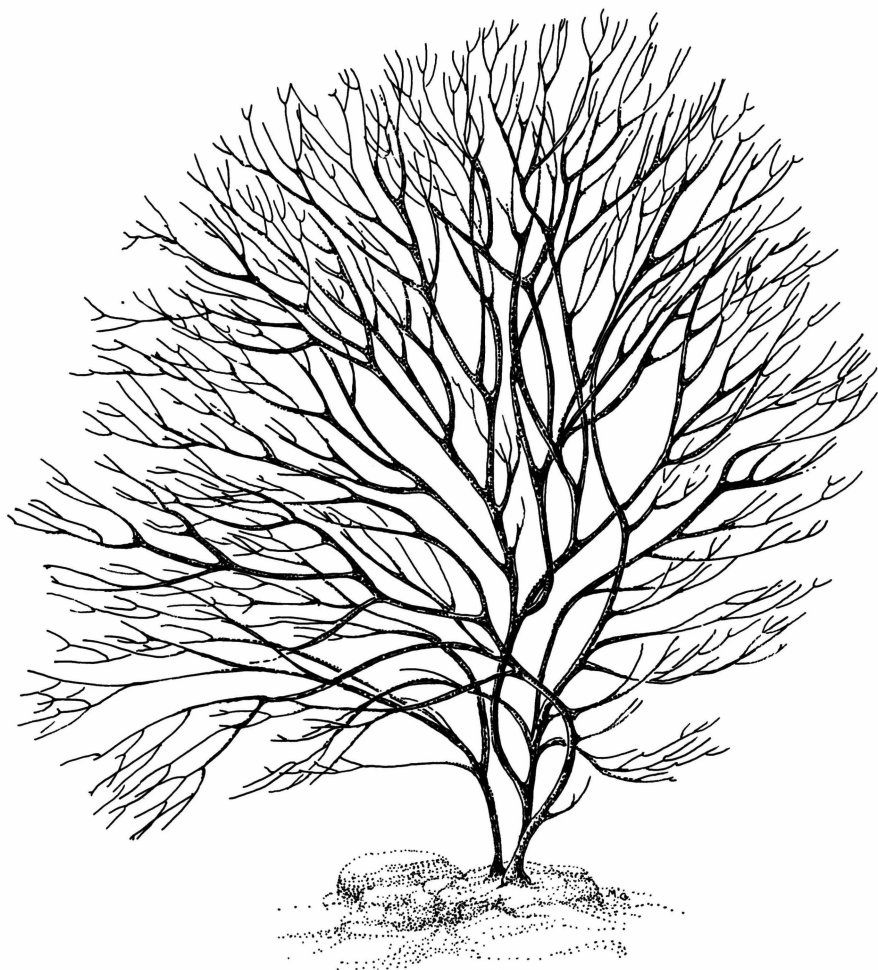


FIGURE 3 Gracilaria tikvahiae.

type--species G. foliifera described in Great Britain. Further, he found no difference between the local foliifera species and verrucosa found locally. He renamed this material previously described as "verrucosa" and "foliifera var. augustissima" as the species tikvahiae.

The abundance of naturally occurring plants in New York is low, again due to the general lack of rocky or firm substrates. Many species of Gracilaria are commercially harvested worldwide for extraction of agar compounds.

Much work has been reported on this species (mostly under its old names) regarding growth and photosynthesis under a variety of light, temperature, nitrogen, and salinity conditions. Further, some knowledge exists concerning the nitrogen requirements and the chemical composition of the species.

As with most red algae, the genus has a rather complex mode of reproduction. Asexual reproduction may occur through fragmentation. One frequently finds asexual strains growing in nature and such material is almost always found unattached to the substrate.

Sexual reproduction in the genus occurs, involving three phases (Figure 4). The life history includes free-living male and female gametophytes (haploid) and one free-living tetrasporophyte (diploid), so called because these sporophytes produce four (tetra) spores per reproductive cell. Male/female gametophytes and tetrasporophytes are the same size when mature (isomorphic). The gametophytes are, of course, haploid while the tetrasporophytes are diploid. A diploid carposporophyte is also produced. This phase is actually attached to the haploid female gametophyte, and consists of the fused male and female gametes that develop into a structure similar to a fruit in higher plants (more about this later).

The free-living diploid plant (tetrasporophyte) develops specialized structures called tetrasporangia that are cruciately divided into four cells, that is, divided into two or three planes at right angles to each other (see Figure 4). These are scattered throughout the surface of the thallus. Meiosis results in the production of haploid tetraspores. Upon their release, these spores germinate into male or female gametophytes. The mature male gametophyte produces spermatangial cells that give rise to spermatia, or sperm. The spermatangia are usually found in pits on the thallus surface. The female gametophyte produces specialized cells called carpogonia, or egg cells. The nonmotile male sperm is released to the water column and settles on a hair-like projection

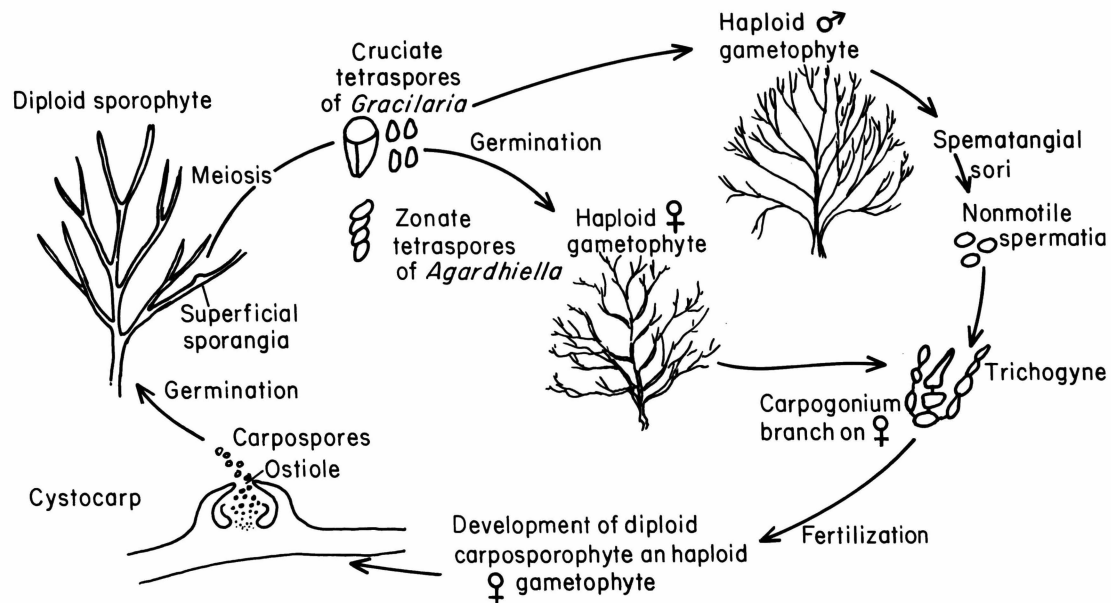


FIGURE 4 Life history of *Gracilaria tikvahiae* and *Agardhiella tenera*.

(trichogyne) of the carpogonium. The male nucleus migrates down the interior of the trichogyne and fuses with the nucleus of the carpogonium. The zygote undergoes cell division (mitosis) and forms a diploid mass of cells that is called a cystocarp. When the cystocarps are fully developed, we refer to it as the carposporophyte generation of the life cycle. Many diploid carpospores may be released from this structure and these germinate into tetrasporophytes to complete the life cycle. What triggers the onset of these various life cycles is poorly understood. Temperature and light intensity/quality and day length are known, but not in a quantitative sense, to affect the process.

The plants grow from apical cells, that is, the youngest portion of the plant is its numerous tips. The plants grow most rapidly during the summer months, when temperatures exceed 15°C.

Agardhiella subлата

This red alga has no known common name. It is found in shallow estuarine waters, just below the low tide mark. Its appearance (morphology) is very similar to Gracilaria (see Figure 5), with only some minor differences in the tapering of its branches. This character is, however, very variable. The only real way to distinguish Agardhiella from Gracilaria is by microscopic examination of the structure of apical cross sections.

Plants are typically about 10 to 20 centimeters tall and are found attached to small stones in the shallow subtidal. One occasionally finds dense stands where sufficient substrate is available. Plants are usually a rosy-red color, with tinges of green often found at the apices.

The taxonomy of this species has also undergone numerous changes in the recent past. The original type species tenera was originally described from Long Island. In 1973, the genus and species names were changed to Neoagardhiella baileyi (Kützting) Wynne and Taylor. In the late 1970s this change was negated, and the material is now officially A. subлата (C. Agardh) Kraft and Wynne.

A considerable amount of work has been published about this plant under its old and new names. Most of this information deals with nitrogen nutrition and chemical composition. Agardhiella is a possible commercial source of carrageenin.

The mode of reproduction of the species is also very similar to that of Gracilaria (see Figure 4). The

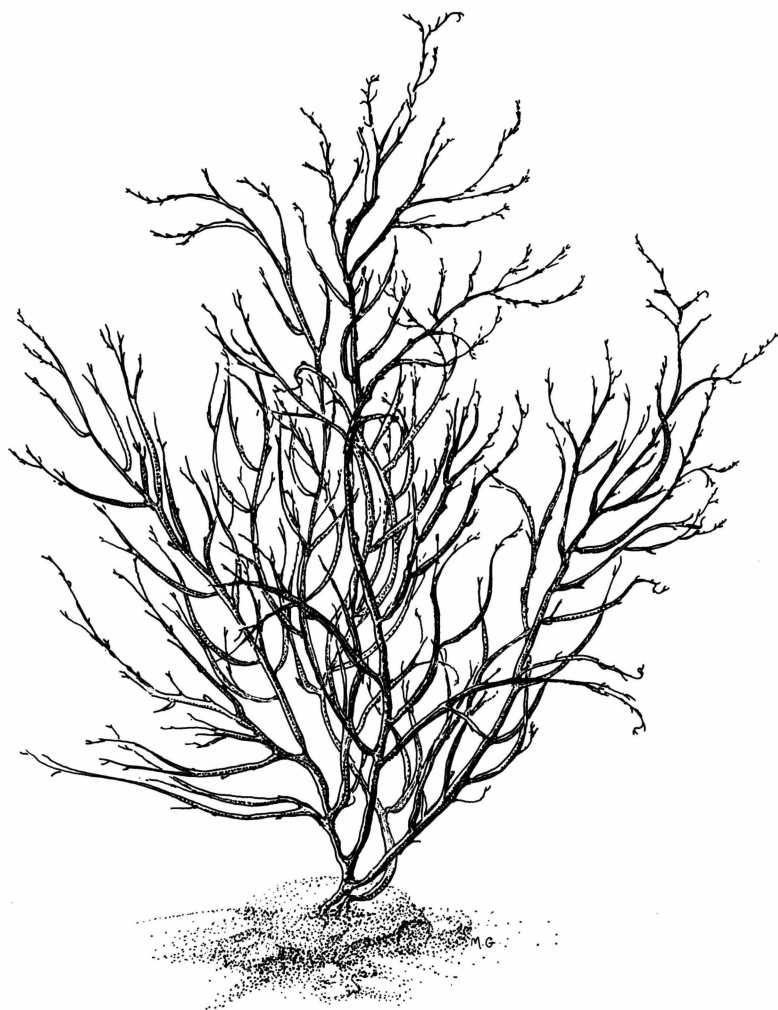


FIGURE 5 *Agardhiella subblata*.

tetrasporophytes and gametophytes are isomorphic, that is, they have the same size and appearance. The spermatangia occur as patches near the apices of branches and the tetrasporangia are zonately divided, meaning that the four spores produced in each sporangium are lined up in a row. The cystocarps are very prominent, creating 1 to 2 millimeter ($< 1/10$ inch) bulges about the thallus. Production of the cystocarps appears to occur during the early summer (locally) and tetraspores appear in late summer to early fall.

Codium fragile

This green alga is also known as deadman's fingers, oyster thief, Sputnik weed, sea staghorn, and spaghetti grass. The species is found on both sides of the Atlantic and Pacific oceans in temperate zones. The species was introduced in the late 1950s to the eastern seaboard of North America. It is now found from New Jersey north to Maine in shallow estuarine waters. It was apparently accidentally introduced during shellfish transplants from Japan (via the west coast of the U.S.) or from Europe.

Plants are typically found attached to shells of clams and scallops, as well as pilings, small rocks, and ropes in water up to 5 meters (15 feet) deep, depending on water clarity. The species grows rapidly during the summer months, attaining a length of up to 70 centimeters (2 feet). It is bushy in appearance (see Figure 6) and spongy in texture.

The erect plant is actually a composite of many coenocytic (that is, multinucleate and lacking crosswalls) filaments. The siphonous (tubular) filaments apparently arise because cell walls between adjacent cells do not develop. This also results in the filaments having many nuclei (multinucleate). The filaments terminate in swollen structures called utricles that give the surface of the plant a cobbled effect. Occasionally, these utricles have colorless hairs associated with them. During the summer months, when conditions of high light intensities and warm temperatures prevail, plants photosynthesize rapidly. Oxygen gas bubbles become trapped between the filaments and colorless hairs, giving the plants buoyancy.

Some work has been published on the growth, reproduction, and nutrient requirements of this species in local waters. During the fall months (September to November) the large adult plant (diploid) releases zoospores, or swimmers. These months are the peak of spore release; however, release of spores may occur from May to December. Spore development begins when temperatures are from 12° to 15° C. Spores may also be

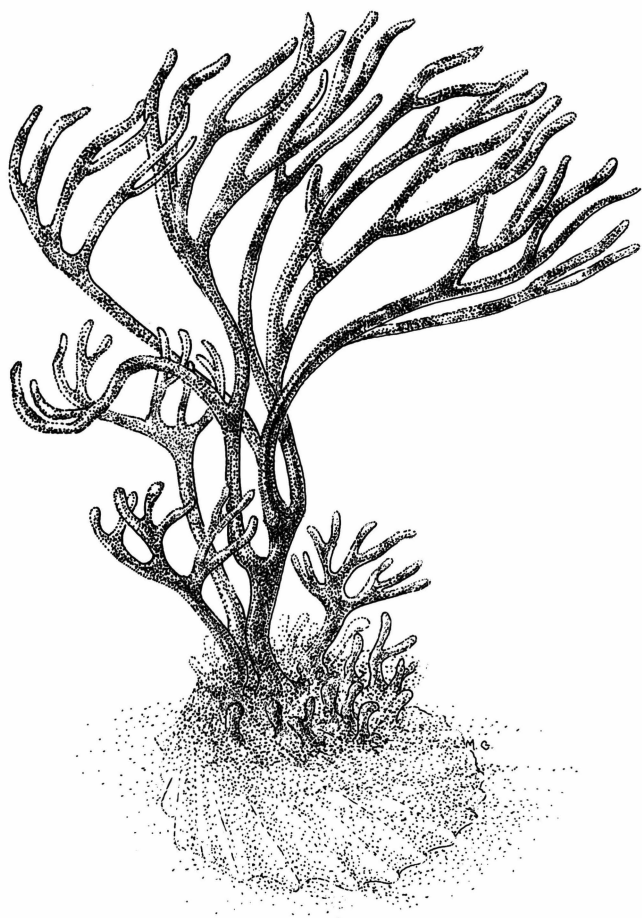


FIGURE 6 Codium fragile.

found during the winter months, but they are not viable upon release. Some workers claim that, in fact, these spores are anisogamous gametes (unequal in size). However, local work has failed to find any bimodal distribution in gamete size. There is also no evidence of gamete fusion to produce a zygote cell.

The diploid zoospores germinate directly, and produce a mat of prostrate filaments that overwinter (see Figure 7). During the spring, the filaments in these mats coalesce and grow into an erect thallus. The plants typically grow in a dichotomous fashion, that is, they develop branching at the apex that splits into two equal branches. Codium is not harvested for commercial use, but it is consumed in salads in some Far East countries.

Fucus vesiculosus

This brown seaweed is also known as rockweed, bladder wrack, lady wrack, sea ware, black tang and bladder fucus. The species exhibits a great degree of plasticity in morphological form. As the species name implies, it has vesicles, or air bladders on the thallus (Figure 8). These bladders are especially prominent in plants growing in sheltered intertidal locations. In more exposed regions, the plants may lack air bladders, making plants difficult to distinguish from the species spiralis. In fact, one frequently finds free-living, unattached plants in salt marshes that are referred to as F. vesiculosus var. spiralis because they may have bladders and the spiraled appearance implied by the name spiralis. Plants are normally attached to rocks, pilings, and shells in the intertidal zone above the low tide mark.

A considerable body of work exists concerning the productivity and physiology of this genus. Photosynthesis has been examined in some detail, along with nutrient uptake, biochemical pathways, and reproduction. Reproduction in Fucus is simple in one sense, but complicated in another sense because many of the so-called species are capable of interbreeding, leading one to question the validity of some species' status.

Growth in the species occurs at the apices of the generally dichotomously branched thallus. An apical cell controls the branching habit and in this plant is four-sided. This results in the flattened blade appearance of the genus. Other members of the order have three-sided cells that give them a more rounded thallus appearance (terete). The blade has well-pronounced midribs.

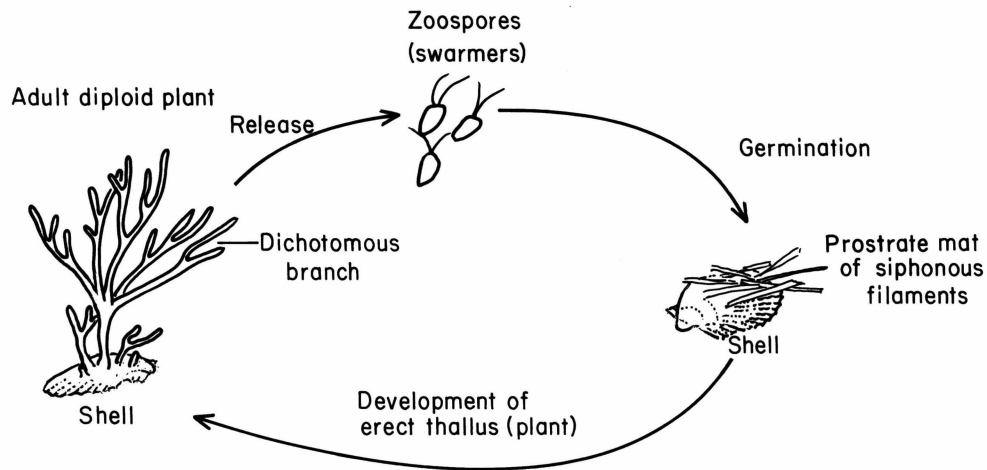


FIGURE 7 Life history of *Codium fragile* ssp. *tomentosoides*.

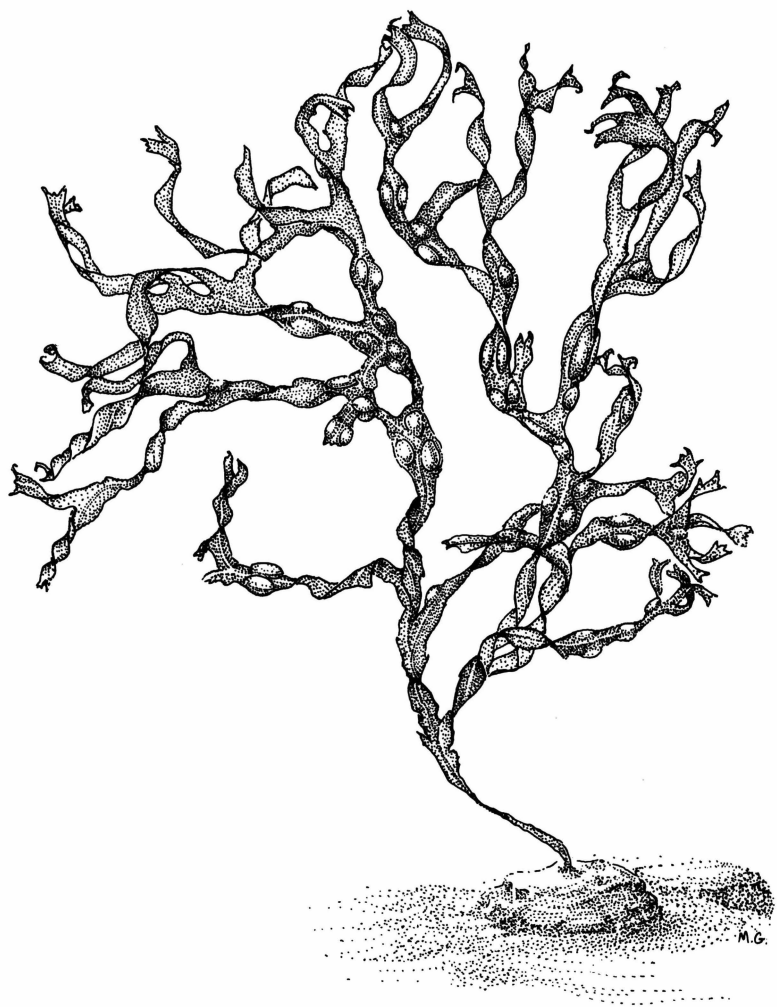


FIGURE 8 Fucus vesiculosus.

Reproduction (Figure 9) occurs in specialized, swollen structures called receptacles that are found at the apices of some branches. The sex organs are found in cavities, or pits, called conceptacles. These pits usually have minute hairs protruding from an opening (ostiole) that may be seen with the aid of a microscope. Inside the conceptacle are other hairs that are apparently responsible for the production of copious amounts of mucus that give the plants a slippery feeling to the touch.

The species is dioecious; egg cells are found only in conceptacles located on the same receptacle. However, it is common for male and female conceptacles to occur on the same plant. Eight egg cells are produced in each oogonium, or female reproductive structure, by meiosis and one mitotic division; these are haploid gametes. The male gametes are produced by structures called antheridia, similar to anthers in flowers of land plants. The primary nucleus of the antheridium undergoes one meiotic and four mitotic divisions, resulting in the production of 64 sperm cells that are biflagellate (two flagella, or hairs, that are unequal in size). The sperm, therefore, are motile, but the eggs are non-motile. There may be numerous antheridia and oogonia in each conceptacle. Male and female conceptacles are separated, but remember that they may occur on the same plant.

Release of the gametes occurs almost yearlong, but is rare during the winter months. Plants in the intertidal are subjected to temperature increases during sunny days, creating a desiccation of the cells of the thallus. This increases the pressure in the interior of the conceptacle, forcing the expulsion of gametes through the ostiole. The gametes may then fuse in the water column to form the zygote that settles almost immediately into a suitable substrate. The zygote germinates rapidly. If plants are subjected to rainfall when they are exposed at low tide, this too may increase the pressure inside the conceptacle because of osmotic pressure (salt and dissolved organic matter balanced between the inside and outside of cells) controlled by the tides; most release seems to occur during spring tide cycles (when the difference between high and low tide is maximum, that is, approximately once every month locally). Plants that live subtidally can also release gametes, and this may also be governed by tidal cycles. As the tides rise and fall, changes in hydrostatic pressure may force release from conceptacles. Some workers also believe that release in subtidal plants may be controlled by light intensity.

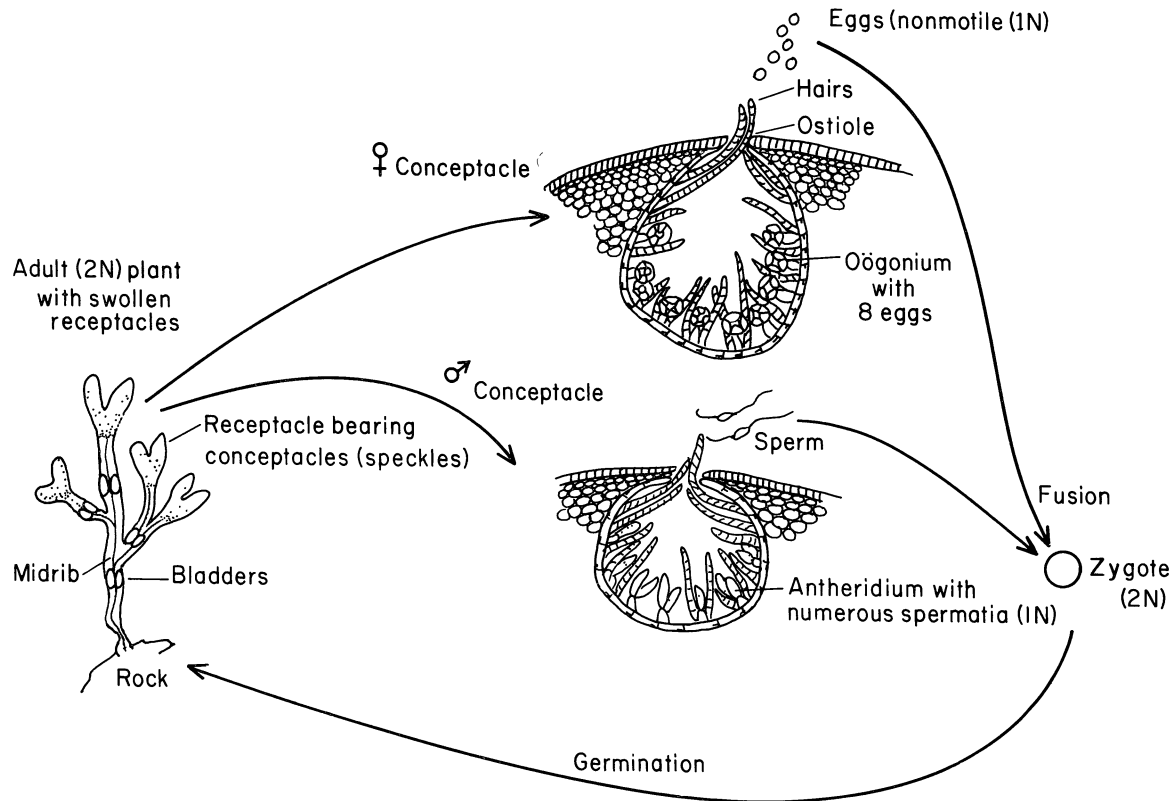


FIGURE 9 Life history of *Fucus vesiculosus*.

SUMMARY

These, then, are synopses of the biology for the five more common seaweeds found in New York waters. There are many others, but these five were chosen for description because they are promising candidates for commercial utilization. This utilization includes conversion to natural gas (biomass production) and use in the phycocolloid industry. The farming of these seaweeds (seaweed mariculture) for these purposes is being actively investigated in New York. Up to this point, no commercial scale mariculture of seaweeds is practiced in this country, while Far Eastern countries have extensive harvests of farm-grown seaweeds for food production. Most of the phycocolloid industry in the U.S. depends on local wild harvests, or the import of materials already processed overseas. The major concern of the industry is the lack of a stable supply of raw seaweed, owing to nature's unpredictable ways. Seaweed mariculture must be developed to facilitate both the biomass and the phycocolloid industries.

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