TAMK UNIVERSITY OF APPLIED SCIENCES
Environmental Engineering

Final thesis

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OBSERVATIONS ON AGE-DIMENSIONAL STRUCTURE OF *FUCUS VESICULOSUS* - THE DOMINATING SPECIES OF WATERS AT THE BARENTS SEA AND THE KOLA BAY

Supervisor: Principle Lecturer Marjukka Dyer
Commissioned by Murmansk State Technical University, Murmansk, Russia
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ABSTRACT

This work is a continuous research of monitoring of age-dimensional structure of the population of *Fucus vesiculosus* – brown macroalgae dominant specie on the littoral zone of the Barents Sea and the Kola Bay. The survey was carried out during the years of 1999 and 2007. Algae samples were collected from two places of the Kola Bay: one at Abram-Mys and Belokamenka and the other being at Dalnie Zelency - the Eastern coast of the Barents Sea. The Standard Hydrobiological Method was used to study the populations of benthic animals and plants. During the low tide a wooden square frame 0.5 m x 0.5 m was used for gathering the algae, 5 samples in each place. All plants were divided into age groups and their length and mass were also monitored. The age was defined according to the amount of bifurcations of the alga.

The study of the biology and age-dimensional structure of the population of fucoids is necessary because these algae are one of the most important factors in the entire sea ecosystem and its health and dominance also contribute to their economical value. The obtained information shows that changes have indeed taken place and they arouse certain concerns. Therefore similar studies should be continued.

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Irina Stryuchkova	*Fucus vesiculosus* – ruskolevän ikärakenteeseen liittyviä havaintoja Barentsin Merellä ja Kuolan Vuonolla.
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TIIVISTELMÄ

Tämä työ on tutkimus *Fucus vesiculosus* - levän - Barentsin meren ja Kuolanvuonon alueella hallitsevana lajina esiintyvän ruskean makroleväpopulaatioiden ikärakenteesta. Kartoitus on tehty vuosina 1999 ja 2007. Levänäytteitä kerättiin kahdesta paikasta Kuolanvuonosta: Abram-Mysistä ja Belokamenkasta; vuonna 1999 myös Dalnie Zelencystä Barentsin meren itärannikolta. Tavanomaisia hydrobiologisia pohjaeläinten ja - kasvien tutkimusmenetelmiä käytettiin näytteiden käsittelyyn. Laskuveden aikaan kerättyjen levänäytteiden keruu tehtiin 0.5 m x 0.5 m suuruisen kehikon avulla viidestä eri paikasta kustakin näytteenottokohdasta. Kaikki leväyksilöt jaettiin ikäryhmiin ja jokaisesta mitattiin sekä pituus että paino. Ikä määriteltiin levän jakautumien lukumäärän mukaan. Fucoidien biologian ja väestön ikärakenteen tutkiminen on erittäin merkityksellistä, sillä nämä levät ovat yksi tärkeimmistä meren ekosysteemin osista. Levien terveydentila ja hallitsevuus vaikuttavat myös niiden kaupalliseen arvoon. Saadut tutkimustulokset osoittavat että muutoksia on todellakin tapahtunut ja että ne herättävät huolia. Siksi tämäntyyppisiä tutkimuksia tulisi jatkaa.

FOREWORD

The Roman poet Virgil is quoted as saying that “there is nothing more vile than seaweeds” /9/

This research took several years and the results were interesting and educative. There are many people, to whom I am most grateful. First, thanks go to my teachers: in Murmansk - Elena Shoshina and Sergei Zavalko, who organized the work and expeditions for picking up samples and in TAMK – Marjukka Dyer, my supervisor, for her advice and help in writing my final thesis. And an individual thank goes to Galina Bryukova who provided me with all necessity equipment.

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Tampere, May 2008

Irina Stryuchkova

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The gender structure of the populations of plants and animals shows the level of reproduction and mortality in the population; it reflects the characteristic of vitality condition of the species. According to the gender structure of dominating species in the area it is possible to make conclusions about man's influence and also forecast changes of the community in general.

Information about age-structure and numerical growth of some communities and populations, especially dominated species, is very important for understanding of growing of coastal formation.

During this work the population of brown macroalga *Fucus vesiculosus* was studied. It is dominant specie on the littoral zone of the Kola Bay and the Barents Sea and it is also a very important raw material for industry.

The research was done with samples collected in three different places at the Murmansk's coast: East of Murmansk and the other two in the littoral area of the Kola Bay in 1999 and 2007.

The main points of this work are:

- To study age-dimensional structure of the population of Fucus vesiculosus in different parts of Murmansk coast.
- To show the changes and differences of the population because of the anthropogenic pollution.
- To compare age-dimensional structure of populations from different places and collected in different years.

In the following chapters these points will be discussed.

2 SEAWEEDS

2.1 What are Seaweeds?

Seaweeds are classified as algae. Algae have evolved into a diverse group of photosynthetic organisms, ranging in size from microscopic single cells to complex, multicellular seaweeds many meters long. Their cellular structures, their cell arrangements to form multicellular bodies called thalli, and their pigments for photosynthesis vary greatly. Both algae and land plants have photosynthetic system based on chlorophyll *a*, but algae lack plants' complex reproductive structures. In development, algae do not form embryos within protective coverings the parents produce. Also, algal reproductive structures do not have sterile cells – all cells are potentially fertile. None are formed exclusively to provide protection or nutrition during development. The algae also include a few "colorless" or nonphotosynthetic species that are closely related to photosynthetic species. /9/

2.2 Ecologic diversity

Algae are important photosynthetic producers and grow in both freshwaters and marine environments. They are major producers of oxygen and organic material in aquatic environments. As a result of converting inorganic material into compounds that heterotrophic organisms can use, algae are the first step in many food chains.

Seaweeds are part of a complex ecosystem involving many different types of animals. Of course, many of the finer seaweeds are valuable food sources, yet the largest species are not grazed on to a great extent. In the case of *Laminaria*, for example, dominated communities, only about 1% of the talus is directly eaten by herbivores such as gastropods, sea urchins and fish. Bits and pieces constantly break off from the main thallus and provide food for debris feeders such as crabs, sea cucumbers and amphipods. The smaller fragments are rich provisions for filter-feeding organisms (mussels, barnacles, tunicates, anemones and polychaete worms). Plankton feeders, such as copepods will also digest these smaller fragments of the algae. Detached seaweeds washed up on the shore are another valued resource. The tide line of partially rotted vegetation is key to their survival

Even larger organisms utilize seaweeds, including the herbivorous green turtles that eat both seaweeds and sea grasses. Some seabirds use floating mats of seaweed to rest upon and soft seaweeds make excellent nesting material. Most spectacularly, grey whales strip the invertebrates off giant kelps, by running the fronds through their baleen plates. /9/

2.3 Brown algae (Phylum Phaeophyta)

The brown algae, an almost entirely marine group, contain the most conspicuous seaweeds of temperature, boreal (or northern), and polar waters. Although there are only about 1500 species, most of which are marine; the brown algae dominate rocky shores throughout the cooler regions of the world. Most people have observed seashore rocks covered with rockweeds, the common name for members of the brown algal order *Fucales*. For many people it is the larger brown species, often referred to as "kelps", that best conjure up the image of seaweed. These seaweeds (*Laminaria* is one of them) are several meters long with large leathery fronds held on slender. In clear water, brown algae flourish from low-tide level to a depth of 20 to 30 meters. On gently sloping shores, they may extend 5 to 10 kilometers from the coastline. /2/ /5/ /9/

Though they are a monophyletic group, brown algae range in size from microscopic forms to the largest of all seaweeds, the kelps, which are as much as 60 meters long and weigh more than 300 kilograms. The basic form of a brown alga is a thallus (from Greek *thallos*, "sprout"; plural: *talli*) – a simple, relatively undifferentiated vegetative body. Kelp's thallus has three main parts: a rootlike holdfast, which anchors the thallus to the substrate; a stemlike, often hollow stalk called a stipe; and various numbers of flattened blades, which provide most of the surface area for photosynthesis. In the past, brown algae have been classified into orders on the basis of thallus structure. However, recent molecular and cellular studies have revealed that thallus organization is not a good indicator of brown algal relationships. Closely related species of brown algae may have quite different thallus organization, and unrelated genera may appear structurally similar. /2/ /5/

Brown algae cells typically contain numerous disk-shaped, golden-brown plastids that are similar both biochemically and structurally to the plastids of *Chrysophytes* and diatoms, with which they probably had a common origin. In addition to chlorophylls *a* and *c*, the chloroplasts of brown algae have large amounts of fucoxanthin, a carotenoid accessory pigment that gives the members of this phylum their characteristic dark-brown or olive-green color. The reserve storage material in brown algae is the carbohydrate laminarin, which is stored in vacuoles. /5/ /8/

The thallus of the rockweed *Fucus* divides into branches (dichotomous branching) and has air bladders near the ends of its blades. The pattern of differentiation of *Fucus* otherwise resembles that of the kelps. *Sargassum* is related to *Fucus*. Some species of *Sargassum* remain attached, where in others the individuals form floating masses in which the holdfasts have been lost. Both forms occur within certain species. *Fucus* and *Sargassu*m and some other brown algae grow by means of repeated divisions from a single apical cell and not from a meristem located within the body, as is characteristic of the kelps. /5/

Peter H. Raven (1999) makes the observations that “the life cycle of most brown algae involve an alternation of generations and, therefore, sporic meiosis. The gametophytes of the more primitive brown algae, such as *Ectocarpus*, produce multicellular reproductive structures called plurilocular gametangia. They may function as male or female gametangia or produce flagellated haploid spores that give rise to new gametophytes. The diploid sporophytes produce both plurilocular and unilocular sporangia. The plurilocular sporangia form diploid zoospores that produce new sporophytes. Meiosis takes place within the unilocular sporangia, producing haploid zoospors that germinate to produce gametophytes. Unilocular sporangia, along with algin and plasmodesmata, are defining features of the brown algae.” /5/

Fucus and its close relatives have a gametic life cycle as do the diatoms and certain green seaweeds. Understanding the evolutionary pressures that stimulated the origin of gametic life cycles in these protists may illuminate the early appearance of the gametic life cycle in our own metazoan (Gk. *meta*, “between”, + *zöion*, ”animal”) lineage. *Fucus* and other brown seaweeds may contain large amounts of phenolic compounds that discourage herbivores. Other brown seaweeds tend to produce terpenes for the same purpose. /5/

2.3.1 Fucus vesiculosus

Division = Phaeophycophyta

Class = Phaeophyceae

Order = Fucales

Family = Fucaceae

Genus = Fucus

‘

Figure 1: *Fucus vesiculosus*

Fucales are plants of sturdy construction, parenchymatous externally, but often with a filamentous medulla. They grow from an apical cell group in the adult branches; sporophytie, the sporangia carried in superficial conceptacles with branched paraphyses; the potential mega- and microspores after meiosis continuing to divide and passing through a cytological gametophyte phase; when matured the sporangia discharging their now gametangial contents in coherent masses from the conceptacles; these disintegrate in the water, liberating gametes, the antherozoids fertilizing the eggs in a free state. /8/

Fucaceae - plants with dichotomous or pinnate strap-shaped branches, often with buoyant air bladders; reproducing by eggs and antherozoids liberated in the water from morphologically heterosporous sporangial structures which undergo meiosis and subsequent mitoses in conceptacular cavities of receptacular portions of the thallus. /8/

Fucus is a cold sea water alga, probably the most familiar of all seaweeds, which is found attached to rocks along the shores. For this reason it is popularly called a rockweed. It occurs between the low and the high tide marks covering the rocks of the intertidal zone thickly. The plants are slippery on account of the copious mucilage spread on their surface and thus are treacherous to walk on. The genus comprises a number of species which usually occur attached to rocks by a hold-fast in the intertidal zone where they often show a distinct horizontal zonation (bands). Each band consists of almost a pure stand of a member of the *Fucales*. The majority of species are inhabitants of the sea coasts of the North temperate and Arctic regions. They are left high and dry above the water line at low tide and covered at high tide. The two common species are *F. vesiculosus* and *F. serratus*. The former is characterized by the swollen receptacles, paired air bladders and smooth margin of the frond, while the latter by the flattened receptacles and serrate margin *Fucus spiralis* lacks air bladders. The receptacles are irregularly swollen and have a sterile border. All the species are common seaweeds. They are perennial, some of them living for as long as four years. /6/ /8/

The species which are attached to the rocky surface have a discoid holdfast. The plant body is a flat ribbon-like dichotomously branched structure. The ribbon-like fronds are costate i.e., they have a clear mid rib. The flattened segments do not remain so in the lower region of the thallus. Here they are destroyed by the swift currents except the mid rib which forms a stalk-like structure. Therefore, the so-called stalk of the *Fucus* plants is nothing but the mid rib minus flattened thallus. The ribbon-like thallus may be smooth as in *F. vesiculosus* or serrate as in *F. serratus*. In a section of the thallus, the following structures are visible under the microscope. /6/

Fucus vesiculosus Linnaeus (**Figure 1**) - plants often large, generally 3-9 dm. tall, but the tallus is a much smaller structure than that of *Laminaria*; attached by an irregular, lobed holdfast; branching usually dichotomous or a little irregular, often proliferous below, the branches above strap-shaped, about 10-15 mm wide, with a marked midrib throughout, but below denuded of the thin margins; scattered cryptostomata and vesicles 5-10 mm diam. usually prominent, the latter generally paired on each side of the midrib, or three together at a fork; receptacles terminal on the branches, single, paired, or forked, broadly lanceolate to obovate, usually 1.5-2.5 cm long; sexes in different individuals, the antheridia conceptacles orange when the receptacles are opened, while the oogonal conceptacles are olive-green. /6/ /8/

2.4 Use of algae

Microalgae and macroalgae have been utilized by man for hundreds of years as food, fodder, remedies, and fertilizers. Ancient records show that people collected macroalgae for food as long as 500 B.C. in China and one thousand of years later in Europe. /1/

People migrated from countries where algae have always been used as food and have brought this custom with them, so today there are many more countries all over the world where the consumption of algae is not unusual, Europe as well. /1/

There seems to be no end of sea-filled lotions and potions that promise to protect our skin from harmful pollutants, smooth away wrinkles, control cellulite and even help you to loose weight. Extract of algae is often found on the list of ingredients on cosmetic packages, particularly in face, hand, and body creams or lotions, but the use of algae themselves in cosmetics, rather than extracts of them, is rather limited.
Eating seaweeds is also heralded as effective against heart disease, water retention and rheumatism, while stabilizing blood sugar levels. Seaweed is also a superb source of minerals and vitamins. These claims are not new: ancient Japanese and Chinese manuscripts describe the collection of seaweeds and their use as medicines and food. Roman women used rouge prepared from *Fucus* species, and today there is a cosmetic cream whose main active ingredients is ‘Fresh Pacific Ocean Kelp’ and sells at over US$75 (£53) for a few teaspoons. /1/

Milled macroalgae, packed in sachets, is sold as an additive to bath water, sometimes with essential oils added. Bath salts with macroalgae meal are also sold. Thalassotherapy has come into fashion in recent years, especially in France. In thalassotherapy, macroalgae pastes, made by cold-grinding or freeze-crushing, are applied to the person's body and then warmed under infrared radiation. This treatment, in conjunction with seawater hydrotherapy, is said to provide relief fro rheumatism and osteoporosis. Mineral-rich seawater is used in a range of therapies, including hydrotherapy, massage, and a variety of marine mud and algae treatments. One of the treatments is to cover a person's body with a paste of fine particles of macroalgae, sometimes wrap them in cling wrap, and warm the body with infrared lamps. It is said to be useful in various ways, including relief of rheumatic pain or the removal of cellulite. Paste mixtures are also used in massage creams, with promises to rapidly restore elasticity and suppleness to the skin. The macroalgae pastes are made by freeze grinding or crushing. The macroalgae is washed, cleaned, and then frozen in slabs. The slabs are either pressed against a grinding wheel or crushed, sometimes with additional freezing with liquid nitrogen that makes the frozen material more brittle and easier to grind or crush. The result is a fine green paste of macroalgae. /1/

Much of the seaweeds industry (worth over US$550 million (£390 million) per year) is involved with the extraction of alginates and gums. These products are superb emulsifiers, gelling agents and thickeners, and seaweed-derived gums are found in pudding mixes, ice creams, toothpaste, medicinal creams, sauces and drinks. The seaweed gelling agents can be broken down into three major classes: agar, carrageenans and alginates. /1/

Agar, alginate (derivative of alginic acid), and carrageenan are three hydrocolloids that are extracted from various red and brown macroalgae. A hydrocolloid is a non-crystalline substance with very large molecules, which dissolves in water to give a thickened (viscous) solution. Agar, alginate, and carrageenan are water –soluble carbohydrates used to thicken aqueous solutions, to form gels (jellies) of varying degrees of firmness, to form water-soluble films, and to stabilize certain products, such as ice-cream (they inhibit the formation of large ice crystals, allowing the ice-cream to retain a smooth texture).

The use of macroalgae as a source of these hydrocolloids dates back to 1658, when the gelling properties of agar, extracted with hot water from a red macroalgae, were first discovered in Japan. Extracts of Irish moss (*Chondrus crispus*), another red macroalgae, contain carrageenan and were popular as thickening agents in the 19th century. It was not until the 1930s that extracts of brown macroalgae, containing alginate, were produced commercially and sold as thickening and gelling agents. Industrial uses of macroalgae extracts expanded rapidly after the Second World War, but were sometimes limited by the availability of raw materials. /4//1/

Agar is derived from red seaweeds, such as *Gelidium*, *Gracilaria*, *Hypnea* and *Pterocladia* that are harvested in many countries around the world including Chile, India, Mexico, California, South Africa and Japan. Currently, there is a world shortage in agar and it commands a high price in international markets. It is used most famously as a microbiological growth medium but is also used in the food industry. /8/

Carrageenans are extracted from a different group of red algae including *Chondrus* and *Gigartina*. The bulk of the carrageenan supply comes from seaweeds harvested from wild populations in Canada. /8/

Alginates are found in the cell walls of many of the larger brown seaweeds. The main producers of alginates are the USA, Norway, China, Canada, France and Japan, where species such as *Macrocystis*, *Ascophyllum* and *Laminaria* are harvested. The product ends up in a range of goods, from wound dressings to vivid fabric dyes. One company alone harvests over 250,000 tones (240,605 tons) a year of wild *Ascophyllum nodosum* and *Laminaria digitata* from around the coasts of Canada and Norway. Great efforts are taken to reduce the environmental impact of these operations, by limiting the frequency of harvesting and making sure that the seaweeds are cut so that the stumps are left behind to regenerate. /1/ /8/

Harvesting from the wild cannot satiate the world demand for certain species. A good example is nori or *Porphyra*, which in the UK is eaten as laver bread. In Japan over 60,000 hectares (148,480 acres) of Japanese coastal waters are given over to producing an annual crop of about 350,000 tones (344,470 tons), worth over a billion dollars. China produces about one third of this, making this somewhat unimpressive seaweeds the single most valuable crop grown by cultivation in the sea. The nori industry was revolutionized by the work of Kathleen Drew who discovered the *Conchocelis* phase in the life cycle of *Porphyra*. Nori farmers now seed the nets that are used to grow commercial *Porphyra* from choncospores released from the *Conchocelis* phase. However, it is no just *Porphyra* that has a huge industry geared to its cultivation and processing; *Laminaria* (Kombu), and *Undaria* (Wakame) are also cultivated in carefully controlled conditions and grown in colossal coastal farms where the growth and yield are optimized. /1/

One of the earliest uses of seaweeds was probably for feeding domestic animals; either by letting the animals graze on the shore at low tides, or by collecting the seaweed to make into feeds. Ronaldsay sheep on the northernmost Orkney Island, off the coast of Scotland, have a staple diet of seaweed. The sheep are confined to the foreshore by a drystone wall (the sheep-dyke) that runs around the island. During the lambing period the ewes are brought inside the dyke to feed on grass for three to four months before being returned to the shore. There are also many reports of undomesticated animals resorting to a diet of seaweed at times, including polar bears, rabbits, arctic foxes and wild deer. /1/

The use of seaweeds in agriculture has not just been confined to animal feeds. Seaweeds have long been used as fertilizers. Throughout history farmers living within access to the coast have collected drift weed as well as picking seaweed from the shore to use as soil conditioners and mulches. This still goes on today, although a much greater industry is the production of liquid fertilizers from seaweed extracts (mostly dried brown seaweeds). /4/

Another commonly used seaweed-derived soil conditioner is marl, the heavily calcified red algal species that grows in offshore beds. This is dredged from the sea floor and normally crushed to a powder before being sold. 8/8/

The benefits of seaweed-derived fertilizers and soil conditioners are well documented, although the commonly cited fact that they contain valuable stores of trace elements may applied in such dilute forms that the amount of trace elements derived from the seaweeds would be negligible. However, they have the advantage that they are free from terrestrial plant pathogens and fungi. /8/

Some seaweeds have exceptionally fast growth rates when light and nutrient supply is abundant. These are increasingly being harnessed as ‘biological scrubbers’ to clear effluent waters of a range of substances such as heavy metals or even high loadings of nitrates and phosphates. An example is the use of beds of *Ulva* to strip the nutrients from the very enriched waters being pumped from intensive fish farms, before the water is returned to the open sea. The *Ulva* is harvested when it reaches maturity, all the nutrients having been converted into seaweed. The seaweed can then be used as a fertilizer or soil conditioner. Where seaweeds are used as scrubbers to remove heavy metals, they concentrate the metals in a form that can be disposed of easily on harvesting. /8/

There is currently an interest in identifying ‘useful’ products and chemicals from marine organisms, including the seaweeds. The most state-of-the-art analytical techniques are used to isolate compounds that may be beneficial to humans as new drugs, antibiotics, cancer treatments and so on. Mankind has used seaweeds since at least the first records were made. Who knows what we will find when we analyze them some more. It is certain, however, that we will continue to eat seaweeds, use them in medicine, feed them to our animals and add them to our crops for some time to come. /9/

3 SPECIFIC GEOGRAPHYCAL FEATURES OF THE KOLA PENINSULA

The Kola Peninsula (Kol'skiy Poluostrov) is one of the most heavily militarized areas in the world and contains the world's largest concentration of nuclear weapons. The region has long been associated with large missile and nuclear submarine fleets and with the strategic advance post for military action against northern Europe and North America. The Kola Peninsula is one of the most important sources of minerals and fish products in Russia, is an important trade centre center, and contains the only non-freezing harbours in the Russian Arctic. The city of Murmansk is the largest city north of the Arctic Circle, with a population approaching a half million. The region also has some of the most serious environmental problems in Russia. With the collapse of the Soviet Union and a new military policy in Russia, the military importance of the Kola Peninsula will possibly decline and the economic aspects of the region assume greater importance. The economic factors and the favorable geographic location of the Kola region at the northern juncture of the European Economic Area and Russia give the region great potential. /14/

The Kola Peninsula is part of the Fenno-Scandian crystalline shield. The peninsula's geological origin, physical geographic aspects, outcrops of bed granite massifs, high dissection of relief, significant development of the aquatic network, great number of lakes, and relatively mild and damp climate are similar to the adjacent regions of Scandinavia and Karelia. From the north, east, and partially south the peninsula is washed by the waters of the Barents and White seas and in the west it borders on Finland and Norway. The Kola region is officially known as Murmanskaya Oblast' and the regional capital is Murmansk. The region is almost entirely situated above the Arctic Circle, with a total area of 144 900 km^2**.** The Kola region extends for 390 km from south to north (66° to 69°N) and about 550 km from west to east (28° to 41°E) and belongs to the "Northern Zone" of Russia. According to the Russian regional classification, the Kola Peninsula, despite its polar location, belongs to the "Near North," since it is well developed and populated, located relatively close to the country's industrial centers (1500 km from St. Petersburg, 1800 km from Moscow), and connected to them by a rail, road, and air network. /14/

Development and settlement of the region have been influenced by its geographical position and climate. The Kola Peninsula is the most accessible part of the Russian Arctic and due to the influence of the Gulf Stream, which washes the northern shores of the peninsula with one of its peripheral branches - contains an ice-free coast and a relatively mild and stable climate. The presence of the Gulf Stream also explains the absence of permafrost. The climate is normally cool, with low summer and winter air temperatures: the average temperature in January is - 8°C along the northern coast and - 12 to - 15°C in the center of the peninsula. Winter is characterized by frequent blizzards, causing large snowdrifts. The summer is short, lasting only a few months, and is generally cool and rainy, with average June temperatures ranging from 8 to 14°C. February is the coldest and windiest month; July is the warmest and calmest. In winter the sun remains below the horizon between 1 December and 13 January (at Murmansk), while in summer the sun does not set between 23 May and 21 July (at Murmansk). /14/

Forests cover about half of the peninsula, ranging from northwest to southeast, and are composed of coniferous trees such as Scots pine and Norway spruce and deciduous trees such as birch, mountain ash, and alder. The severe climate and difficult soil conditions lead to slow tree growth, which, however, produces a dense, fine-layered wood suitable for furniture. The region's flora is varied and numbers about 600 species. The western and the central parts of the peninsula are the richest in plant species, where coniferous forest and mountain tundra vegetation are both found. The Kola Peninsula contains a variety of berries, such as cawberry, bilberry, cloudberry, and great bilberry, all of which are important wild foods, and there is a variety of mosses and lichens. Misuse of forest resources, industrial expansion, and the absence of pollution abatement measures, especially during the last 30-year period, have severely damaged the forests, especially in the vicinity of the large industrial centers of Murmansk, Monchegorsk, Olenegorsk, and the Pechenga area (including Nikel'). /14/

At present the Kola region is extremely militarized. Rapid militarization began after World War II and was associated with the beginning of the Cold War. The Kola Peninsula's important military-strategic position was the principal factor in siting military installations. The northern coast of the peninsula is one of the few warm-water coasts in Russia with direct access to the high seas. /14/

3.1 The most risky groups of pollutants

The most risky group of pollutants comprises pesticides and related chemical compounds. These substances are largely or entirely foreign to the marine environment and are usually designed to kill or incapacitate certain organisms (e.g. insects). Since nature has no or only very limited means for metabolizing or degrading these substances, they tend to accumulate and to exert long-term effects. Heavy metals rank second as potential hazards, particularly in estuaries and near the cost coast. Present concentrations of radioactive materials are considered to be below the threshold values for detrimental effects. Oil, i.e. petroleum and its derivatives, represents a product of nature, remobilized and thus made amenable to ecosystem degradation. Nevertheless, heavy oil spills have caused severe local damage. Refined oil, due to addition of toxic substances tends to exert more detrimental effects than natural oil. The ecological importance of "oil-pollution-derived" organic compounds that may interfere with chemical ecosystem integration and chemical communication among organisms remains to be investigated more fully. A number of synthetic organic compounds resist decomposition and thus cause long-term interference. While thermal deformations may represent a significant additional stress to the estuarine and coastal flora and fauna, especially near power-station outfalls, there appears to be no immediate danger yet to marine life in general. Domestic waters, finally, can cause local eutrophication, reduction of amenities, odour nuisance and related hazards, but are unlikely to inflict wider damage, unless they contain toxic substances. /3/

Sudden exposure to the most dangerous pollutants, even if these are only short-lived, often exerts greater immediately demonstrable effects that long-term exposure to subcritical pollution stress. The latter leaves time for compensatory regulations and adaptations and thus tends to mask any detrimental consequences that may occur. /3/

The most endangered sea areas are those near the primary sources of pollutant release: industrial sites on the coasts, especially in harbors, estuaries, and bays. Economically attractive in terms of trade, traffic and pollutant release, estuaries, mud flats, sheltered bays and fjords tend to be particularly vulnerable to pollution. Estuaries and mud flats have been shown to trap, retain, and accumulate pollutants in their sediments. At the same time they have important ecological functions for recruiting and supporting life in adjacent sea and land areas. Other highly endangered areas are the ecologically highly sensitive coral-reef and mangrove systems. Sea areas more or less separated from major oceanic water bodies, such as the Mediterranean, Baltic, and North Seas tend to suffer more that water bodies in the open oceans. Limited water exchange in these seas is often combined with supernormal pollutant inputs from major industrial nations. /3/

3.1.1 The sources of pollution of the Kola Bay

The beauty of the Kola Bay is striking when one overviews Murmansk city centre from the newly built Orthodox Church. The stunning beauty is, however, overshadowed by the sight of rusty, deserted ships, which can be seen here and there above water level. The Kola Bay has unfortunately turned into a graveyard for battle, transport and fishing ships. This in turn is a sad reminder of the fact that the bay has been identified as one of the 42 environmental hot spots in the Russian Barents region. /15/

According to estimations by Russian specialists nearly 200 ships and several boats are abandoned in the coastal zone or sunk in the waters of the Kola Bay hindering navigation and causing a huge environmental problem. Most of the deserted ships contain asbestos and heavy metals like lead, mercury, zinc and copper, which leak into the surrounding environment. /15/

Abandoned and sunken maritime vessels have been a problem in the Kola Gulf for years. Ecological monitoring of the seabed at dumping grounds has shown that, in these areas, pollution levels are dozens of times higher than in other areas of the gulf. /15/

The dumping grounds also threaten navigational safety. At present the Kola Gulf is over-saturated with vessels serving trading or fishing ports, ship-repair yards, Northern Fleet bases and other facilities in the Murmansk Region. In the immediate future the Gulf will be served by even more transport vessels, as the volume of oil and oil-product transfers increases. /15/

Oil and oil products are the mass pollutants of the Kola Bay. Residual oil products and other environmentally dangerous substances are often discovered on abandoned or sunken boats.

But the most irresponsible owners are the military. Military transport boats, once taken out of service, are not decommissioned due to a lack of money, and environmental control bodies in the Murmansk Region do not have enough high-level leverage mechanisms to affect military departments.

The Kola Bay is the most polluted place in the Barents Sea. There are, at least, four ways of the polluting substances downing into the Kola Bay:

- Falling from the atmosphere;
- Coming with the river flowing;
- Faults of municipal and industrial sewage from the coastal sources;
- Polluted water and solid waste faults from the ships.

It was shown that the concentration of sulphureous gas (SO_2) in the atmosphere over the Kola Bay depends on the wind direction, because the industrial enterprises which are situated to the south from Murmansk (mainly the “SeveroNikel” at Monchegorsk - 140,000t and the “PechengaNickel” - 260,000t annually) bring the big contribution to this process. /16/

Nitric oxides (NOx) enter the atmosphere mainly from the local sources (transport, heat power-stations), so, wind direction does not influence greatly to their concentration.

The mixture of all polluting substances, ending up in the Kola Bay reflects predominating contribution of municipal sector, transport and food enterprises. Suspended solids coming from the local enterprise “Vodokanal” predominate in the faults. Among separate enterprises is Murmansk fishing port, plant “Sevmorput”, “Sudoverf”, the technical base of “Atomfleet” and ship repairing plant “Nerpa”. Nearly 85% of the whole volume of the wastes is formed at the ship repairing enterprises. /16/

4 METHODS

4.1 Material collecting

The research was carried out within the littoral area of the Kola Bay and the Barents Sea Eastern coast in 1999 and 2007. During that time first samples were collected from three villages: Abram-Mys, Belokamenka and Dalnie Zelency in the Eastern Murman (***Figure 2***). The second set of samples was collected in 2007 from two villages Abram-Mys and Belokamenka to be studied.

Figure 2: The map of samplings areas: Abram-Mys, Belokamenka and Dalnie Zelency

Source: http://www.murman.ru/ecology/comitet/report97/vod_more.htm

The littoral zone in Dalnie Zelency is separated from the sea by a chain of islands and it is connected to the sea through narrow straits. It is an open sea coastal area and it does not seam to be anthropogenic polluted (***Figure 3***). At side of sampling the littoral area was rocky, gently slopping and weakly protected from the straight waves.

Figure 3: The littoral zone of the Barents Sea in Dalnie Zelency
Source: The picture was taken by Elena Shoshina, 1999

The village Belokamenka is situated in a lightly polluted area (***Figure 4*** and **Figure 5**) and the shoe is clear, smooth and sandy with some stones. *Fucus serratus* and *Ascophyllum nodosum* dominate close to water, in the centre – *Ascophyllum nodosum*, upper *Fucus vesiculosus* and *Ascophyllum nodosum*.

Figure 4: The littoral zone of the Kola Bay in Belokamenka in 1999

Source: The picture was taken by Elena Shoshina, 1999

Figure 5: The littoral zone of the Kola Bay in Belokamenka in 2007

Source: The picture was taken by Aleksandr Stryuchkov, 2007

There are some industrial enterprises situated along the Kola Bay which refuse their waste into the water. The majority of the pollutants come from the fishing and commercial ports, military bases and municipal centers. Abram-Mys is situated in the central part of the Kola Bay and it is subjected to heavier anthropogenic pollution. The ***Figure 6*** and **Figure 7** describe the conditions in the mentioned area.

Figure 6: The littoral zone of the Kola Bay in Abram-Mys in 1999

Source: The picture was taken by Elena Shoshina, 1999

Figure 7: The littoral zone of the Kola Bay in Abram-Mys in 2007

Source: The picture was taken by Aleksandr Stryuchkov, 2007

The work was done in the laboratory of the Biological department of Murmansk State Technical University and in the laboratory of algology of Murmansk Marine Biological Institute in the village Dalnie Zelency.

From Abram-Mys and Belokamenka 5 samples were taken from the littoral region of the Kola Bay whereas in Dalnie Zelency 5 samples were taken from along the littoral of the Barents Sea. Dalnie Zelency is situated in the coastal area of the Barents Sea and this place was chosen as a control one because it is not so much polluted yet (during the low tide the frame was throwing and all plants that got in were cut). In **Figure 8** one can see a wooden square frame 0.5 m on the side (0.5 x 0.5 m^2) that was used at the gathering algae.

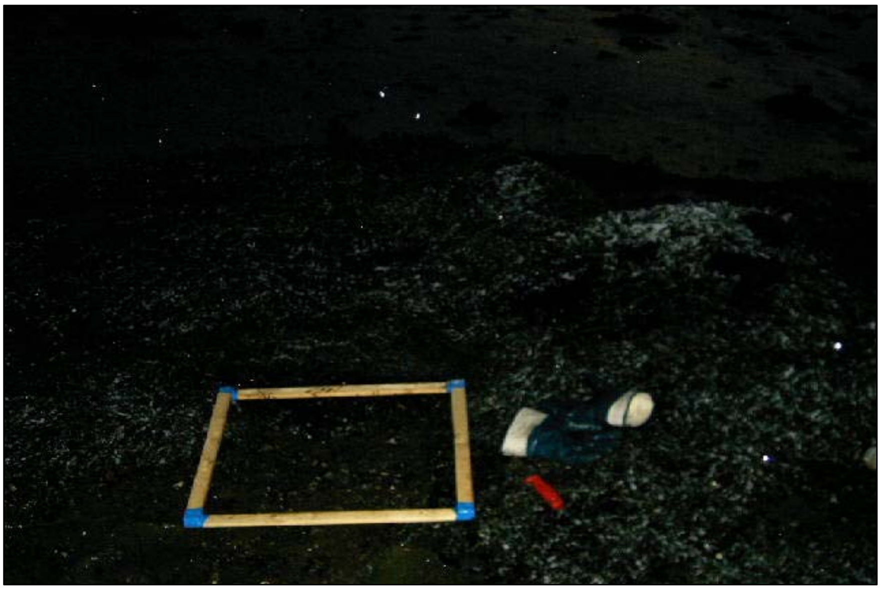


Figure 8: A wooden square frame 0.5 m on side (0.5 x 0.5 m^2)
Source: The picture was taken by Aleksandr Stryuchkov, 2007

The population from each sample was divided into the age groups. The total biomass and the number of the plants in each age group were measured. Then, 3-5 plants from each age group were taken and their mass and length were measured (**Figure 9**).

Figure 9: Studying algae

Source: The picture was taken by Irina Panteleeva, 2007

The results were pretended in Excel and graphs and diagrams were designed to show the age-dimensional characteristics of the populations of brown algae *Fucus vesiculosus*.

4.2 Age determination

There are not many researches about physiological functions of the thallus and its age mostly because there are not enough simple and handy methods for determining the age of algae.

For the majority of *Fucus* algae the age can be defined according to the amount of their dichotomic bifurcations. During the first year of the life *F. vesiculosus* does not ramify. The thallus of such young algae is dark brown and thick.

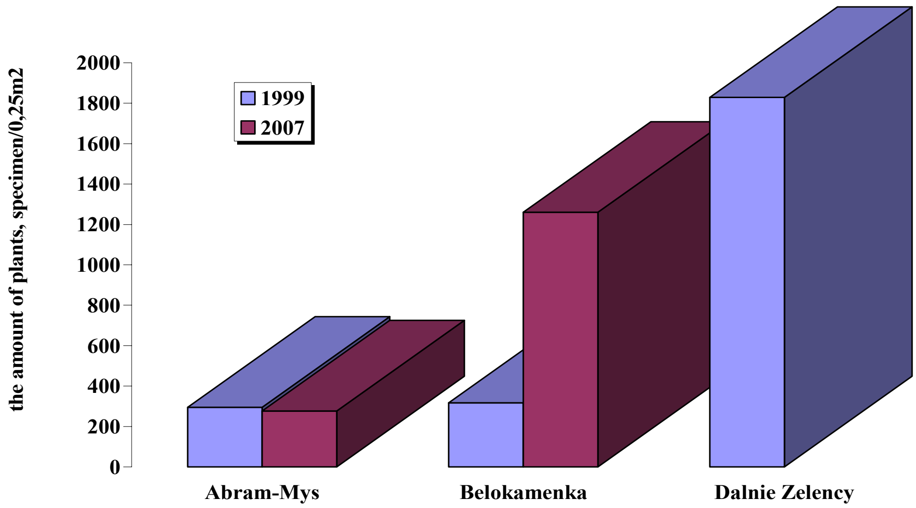
Some scientists suggest to define the age of Fucus algae according to the amount of rows of the air vesicles. But this method is not reliable because there are different opinions about how often vesicles are formed.

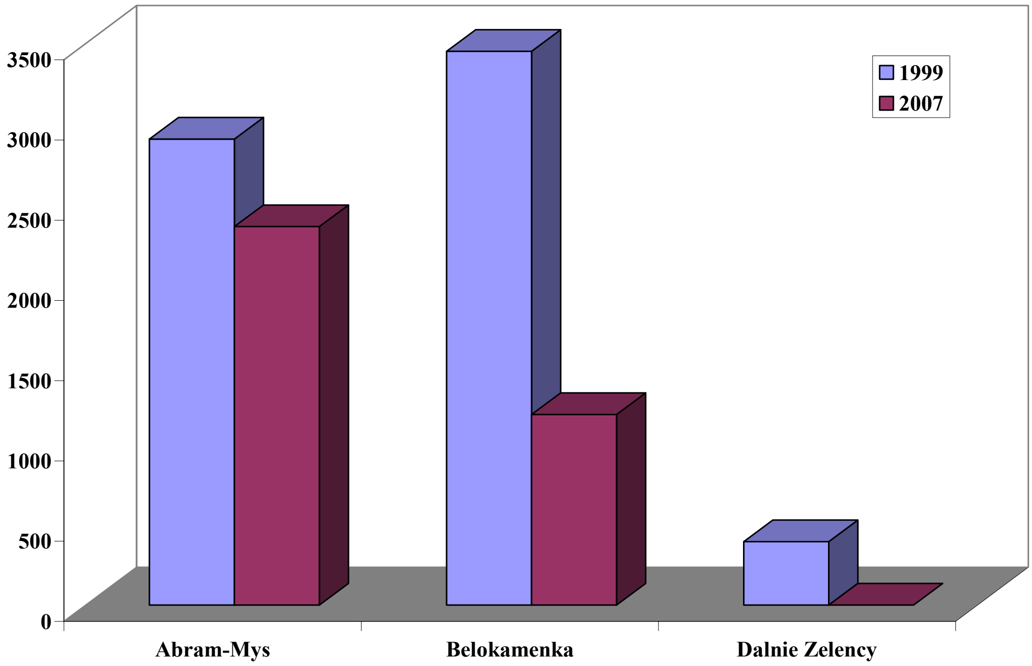
For this research it was considered that F. vesiculosus has two dichotomic branches in a year on the tallus that is older than one year; as it was mentioned during the first year of life the alga does not ramify or there can be only one ramification (Кузнецов, 1960). /11/

5 RESULTS

In Graph 1 bellow one can see the total amount of fucoids (specimen/0,25 m^2) collected in the different places of the Murmansk' coast. The biggest quantity of plants was collected on the littoral zone of the Barents Sea near the village Dalnie Zelency and nearly the same sum of fucoids was collected at Abram-Mys and Belokamenka in 1999. However in 2007 the number of plants collected in Belokamenka' region was four times bigger than in 1999 that show increased production most lightly due to the influence of the population. Observation is also supported by Tolstikova (1980) who reports that the amount of plants at the coastal area of the Barents Sea can reach 10000 specimens per cubic meter. /12/ /13/

Graph 1: The amount of fucoids in 0,25 m^2 area collected in the different parts of the Kola Bay and the Barents Sea.

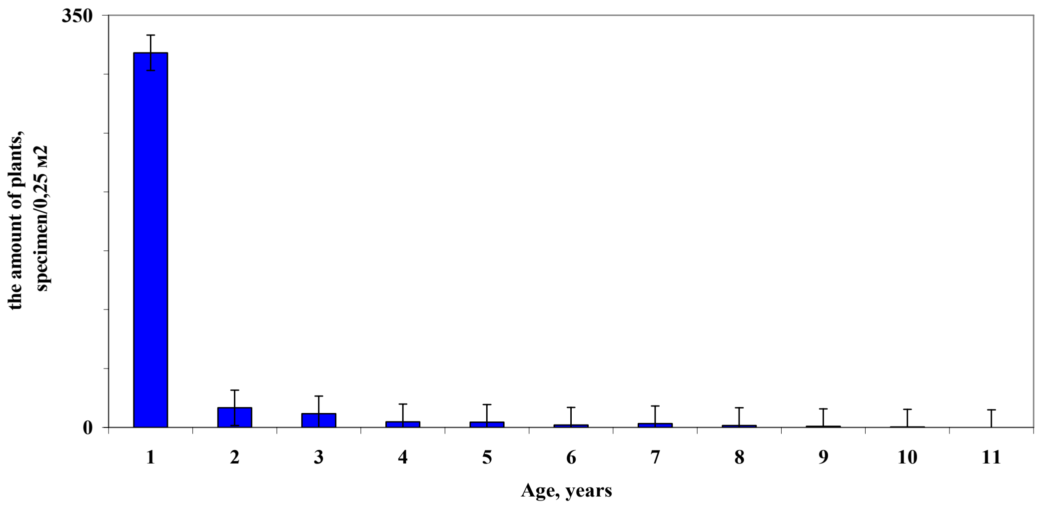




Graph 2: Biomass of fucoids in 0,25 m^2 area collected in the different parts of the Kola Bay and the Barents Sea.

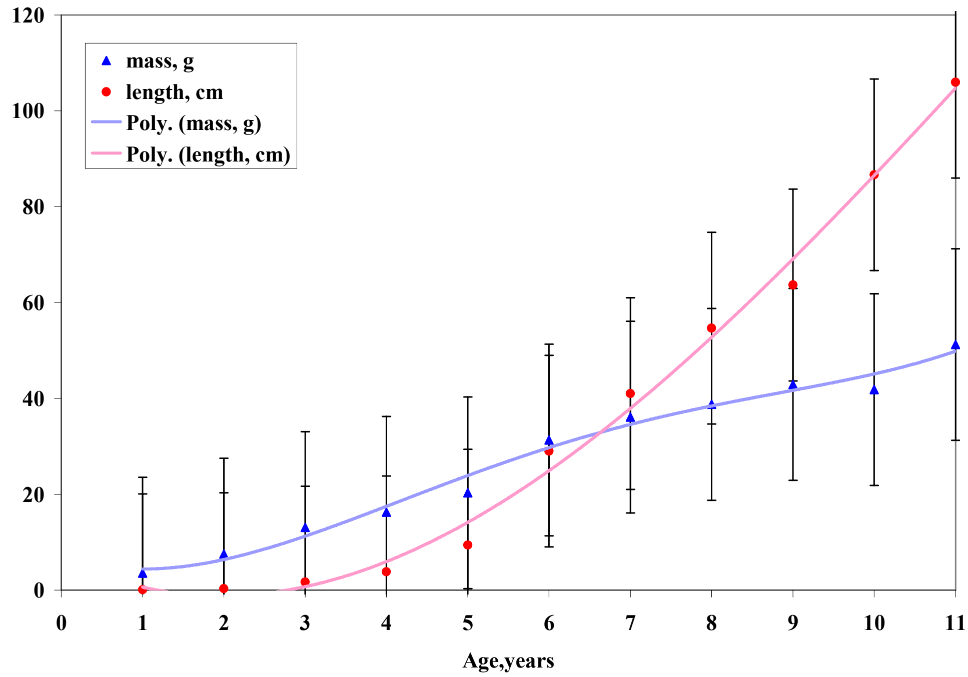
Graph 2 shows total biomass of all samples collected in littoral areas of Aram-Mys, Belokamenka and Dalnie Zelency. In 1999 biomass was larger because in 2007 young algae were dominating whereas in 1999 the dominant was observed in the middle-ages plants.

Graph 3 and Graph 4 show age-dimensional structure of the population of F. vesiculosus collected on the littoral area of the Barents Sea Eastern coast where Dalnie Zelency is situated in 1999.



Graph 3: Age structure of the population of *Fucus vesiculosus* on the littoral of the Barents Sea (Dalnie Zelency) in 1999.

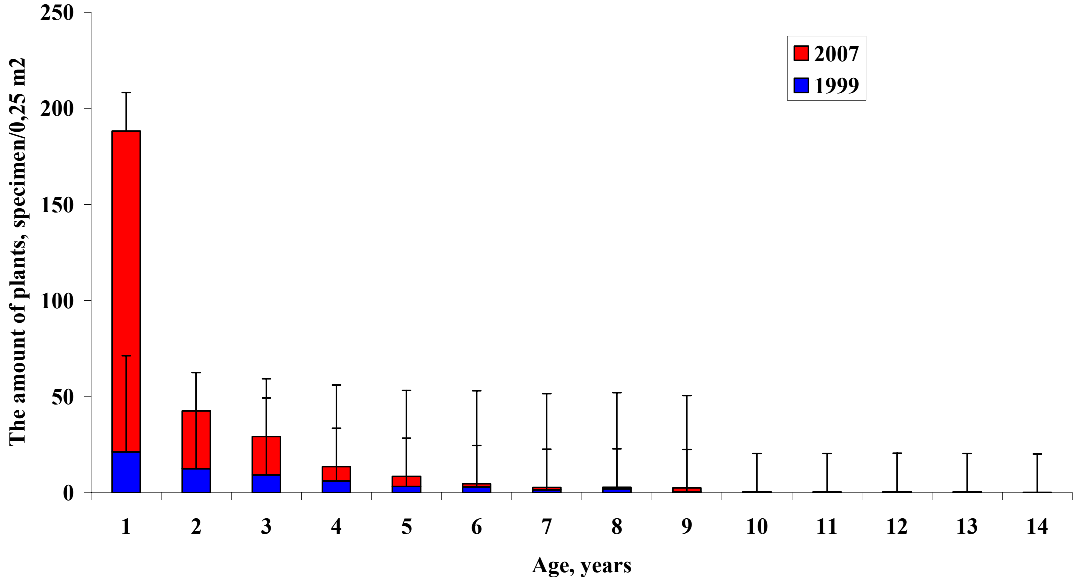
There is a quite long age series for the population of F. vesiculosus collected in that section. Plants shown in graph 3 represent all the ages (1 – 11 years); maximum age of plants is 11 years.



Graph 4: Dimensional structure of the population of *Fucus vesiculosus* on the littoral of the Barents Sea (Dalnie Zelency) in 1999

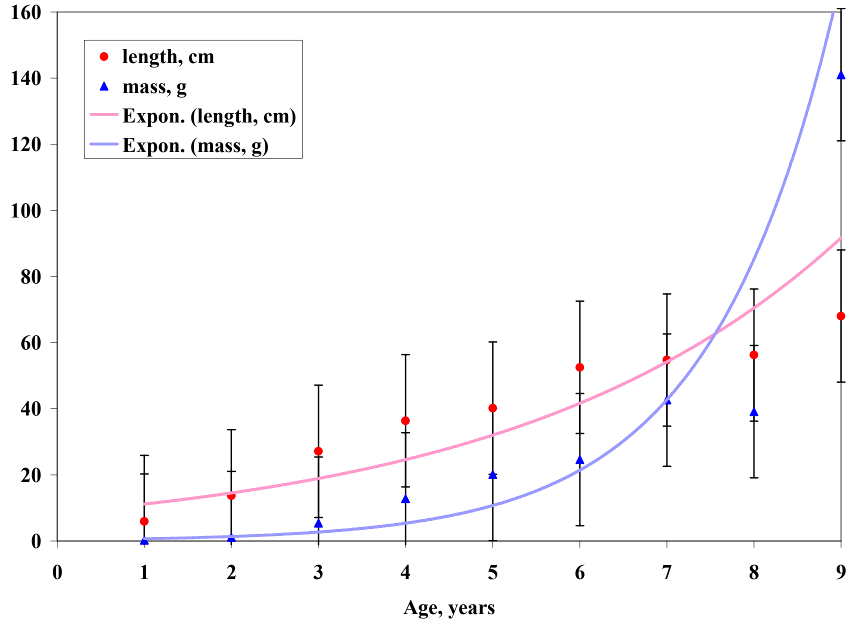
The length and mass of the plants are changing polynomial; although values of length and mass are not high (maximum length is around 110 cm, mass – 40 g).

Graph 5, Graph 6 and Graph 7 show age-dimensional structure of the population of F. vesiculosus collected on the littoral area of the Kola Bay where Belokamenka is situated in 1999 and 2007 accordingly.



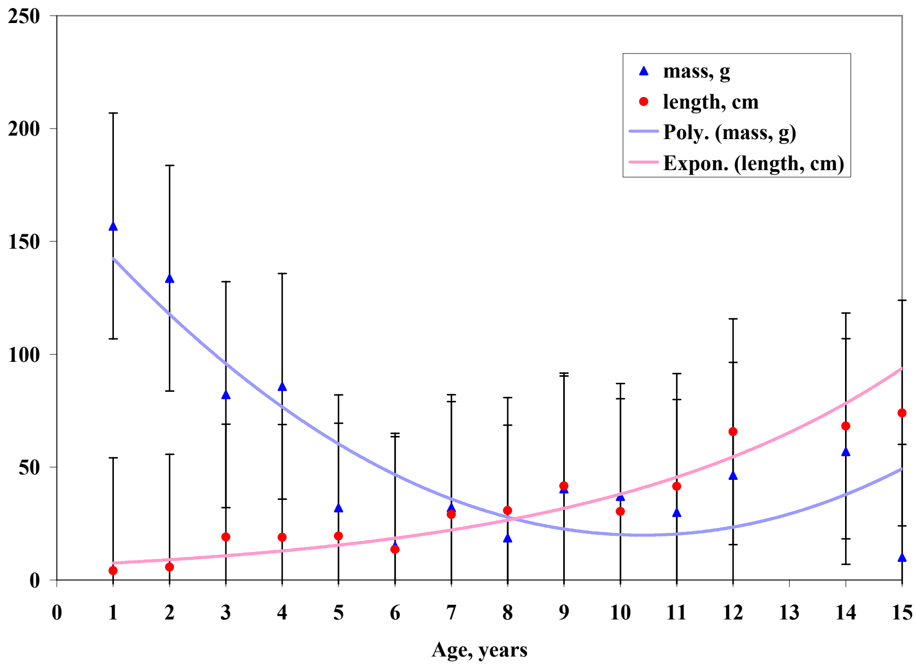
Graph 5: Age structure of the population of *Fucus vesiculosus* on the littoral of the Kola Bay (Belokamenka) in 1999 and 2007

There are also long age series for the population of F. vesiculosus in Belokamenka: in 1999 maximum age of the plants was 9 and in 2007 – 14 years old. There are quite many young plants dominated there in 2007.



Graph 6: Dimensional structure of the population of *Fucus vesiculosus* on the littoral of the Kola Bay (Belokamenka) in 1999

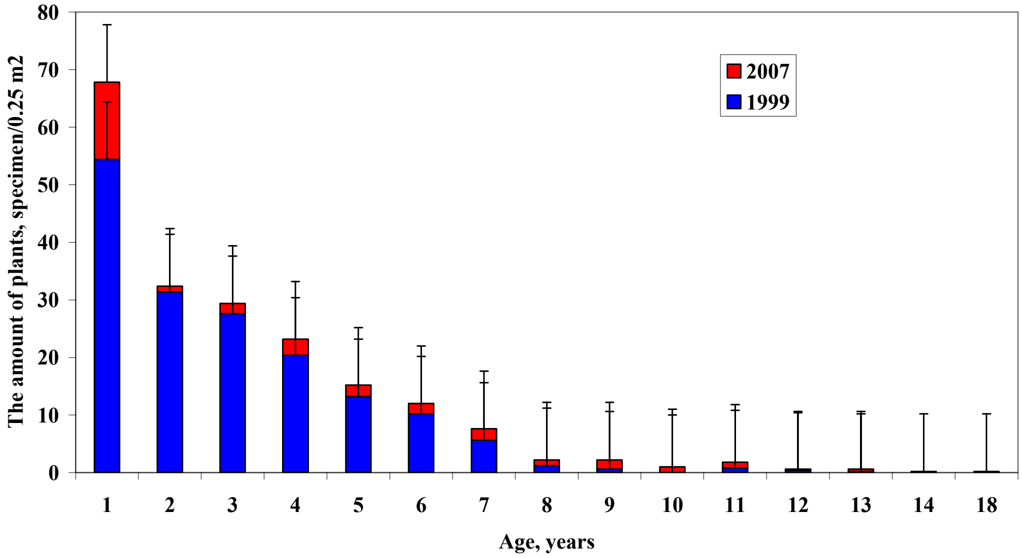
Species collected in that area in 1999 had a good structure, quite large (maximum mass – 140 g, length – 60 cm); the length of plants is changing exponentially and it is constant for middle-age plants; mass is slightly increasing.



Graph 7: Dimensional structure of the population of *Fucus vesiculosus* on the littoral of the Kola Bay (Belokamenka) in 2007

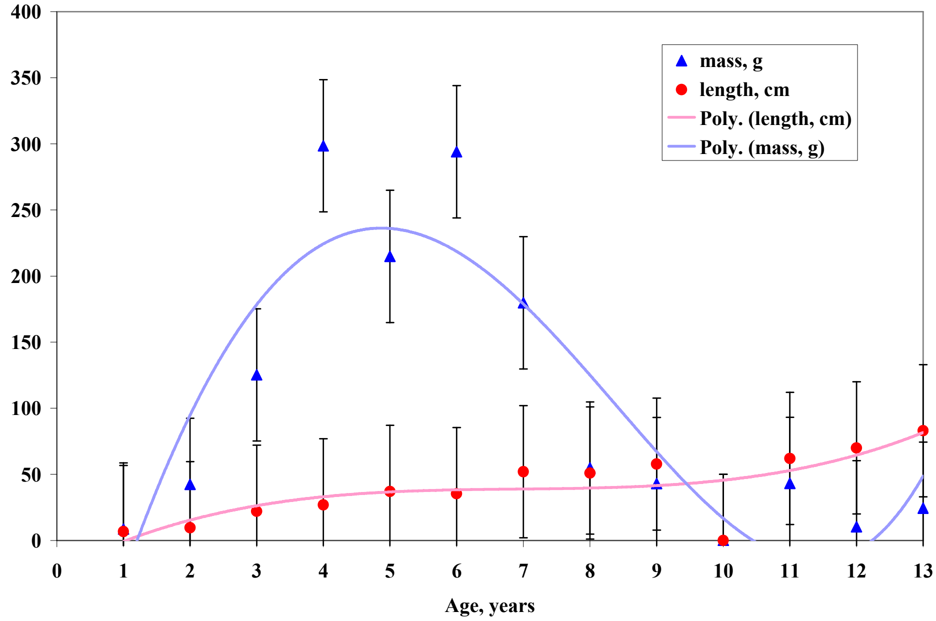
In 2007 the situation is rather different with dimensional structure: young plants were dominating and mass is changing polynomial; length changes in the same way as in 1999 – exponentially.

In Graph 8, Graph 9 and Graph 10 there is age-dimensional structure of the population of *F. vesiculosus* collected in the littoral region of Abram-Mys in 1999 and 2007. Maximum plant life in 1999 was 13 years, in 2007 there was an alga found of 18 years old.

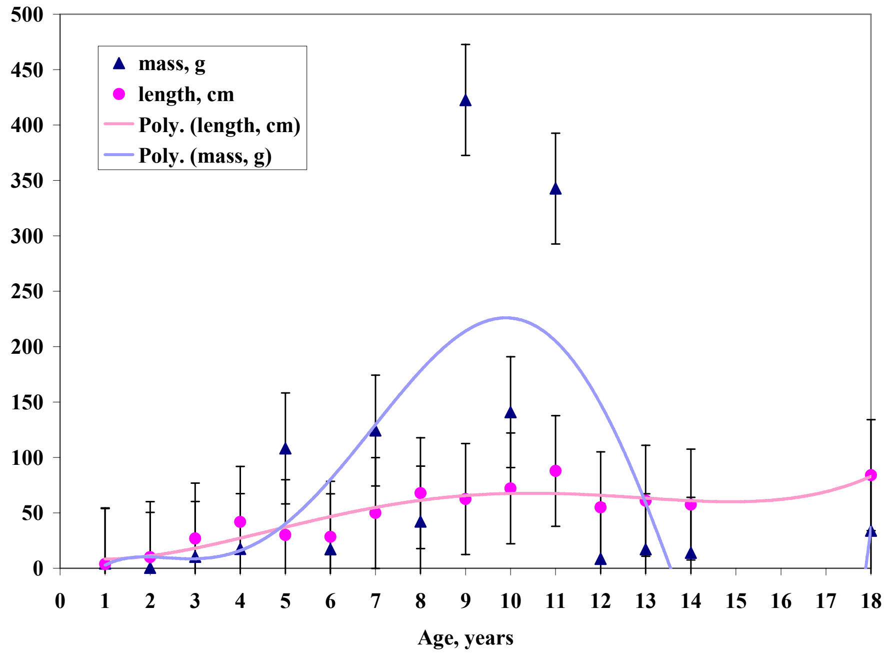


Graph 8: Age structure of the population of *Fucus vesiculosus* on the littoral of the Kola Bay (Abram-Mys) in 1999 and 2007

Graph 9 and Graph 10 show how older algae dominant in mass and length (they change polynomial), but young are dominating in age (Graph 8).



Graph 9: Dimensional structure of the population of *Fucus vesiculosus* on the littoral of the Kola Bay (Abram-Mys) in 1999



Graph 10: Dimensional structure of the population of *Fucus vesiculosus* on the littoral of the Kola Bay (Abram-Mys) in 2007

Fucus needs to have plenty of germs in order to grow in bush for surviving in the cold waters of the Barents Sea. Adult plants and their common base are often surrounding by "brush" of germs.

6 Discussions

"It was once prettily said by a lady who cultivated flowers, that she had 'buried many a care in her garden'; and the sea-weed collector can often say the same of his garden – the shore; as many a loving disciple could testify, who, having taken up the pursuit originally as a resource against weariness, or a light possible occupation during hours of sickness, has ended by an enthusiastic love, which throws a charm over every sea-place on the cost…" (Mrs. Gatty, British Seaweeds, 1872). /1/

During this work the following conclusions were made:

- The duration of life of Fucus vesiculosus at the Murmansk coast in general is from 9 to 13 years (it can reach 20). There are always plants from 1 to 8 years old in the bushes. The length of the thallus didn't exceed 120 cm, mass – 450 g. Studied populations of F. vesiculosus are the populations of a normal type: they have a long age rank; there are plants of all ages and young species dominate. Such kind of populations is typical for the nature and they are rather stable.
- In all places where the samples were collected the age-dimensional structure of the population of F. vesiculosus has the similar view. It tells about high adaptability of this specie to different conditions of the environment.
- Populations from the polluted regions are rejuvenated: young plants dominate in amount; adult plants have just several specimens in each age group.
- Maximum age was found out in the littoral zone of the Kola Bay (Abram-Mys): in 1999 it was 13, in 2007 – 18 years old. Big parameters of the plants were marked in the littoral area of the Kola Bay as well. Therefore, this specie can survive in the conditions of different level of pollution.

As it was mentioned *F. vesiculosus* can live till the age of 13 in the Barents Sea and sometimes can reach even 20 years old. The average age of the same algae at the coastal area of the USA (Maine State) is about 2-4 years.

For studied species dominant on the littoral zone of the Murmansk coast it is typical to have a long age range, high percentage of young plants and rather many of fertile plants. It has been noticed that the population of *F. vesiculosus* gradually decreasing in amount of plants with age. F. vesiculosus grow in bushes, having many specimens of different ages and making thick settlements of about 1700 specimen/m^2.

In that way, age-dimensional structure of algae in the Barents Sea and the Kola Bay is very changeable, depends on biological characteristics of specie and environmental conditions. Dominant species of brown algae have long life cycle, they grow fast and they are macro, all those factors help to survive. Algae respond rapidly to changes in ecosystem conditions and they are generally more sensitive to environmental change than other aquatic organisms. /10/

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