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# Fucoid seaweeds on the Russian Arctic coast: using traditions and ecological monitoring

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**Abstract**. In recent years, harvest and cultivation of marine biological resources, including commercial seaweeds, has increased significantly. The task of this research was the ecological monitoring of commercial fucoid seaweeds beds in coastal waters of the Barents and White Seas. Data of seasonal supervision at stationary biological station and materials of expedition works on Murmansk coast were analyzed. The species, age, generative and spatial structures of fucoid populations in different biotopes of the littoral were studied. It was found that species composition of phytocenoses and quantitative parameters of commercial fucoids varied significantly in open and closed bays, as well as in algae living in the lower and upper littoral. The average biomass of fucoids in semi-closed inlets varied from 2.8±0.6 to 17.7±2.9 kg/m2, depending on dominant species in community, the structure of substrate and impact of waves. The results indicate that phytocenoses of fucoid algae under the influence of changing environmental factors largely ensure the integrity of littoral ecosystem. For rational harvest and cultivation of commercial fucoids, as well as the restoration of disturbed phytocenoses after the removal of some algae, it is recommended to use the technology of synchronization of harvesting with life cycles of seaweeds.

## 1 Introduction

Since the fifteen centuries, monks of the Solovetsky monastery have been gathering and using as food the benthic seaweeds, including the brown algae, collected from the coastal zone of the White Sea. In later years, the Monks started extracting iodine, bromine and soda from the collected seaweeds. During the First World War iodine extracted from White Sea seaweeds was utilized. In 1930's, The Algal Institute (Arkhangelsk) developed technologies for extraction of agar from red seaweed and extraction of mannitol and alginate from brown seaweeds. In the White Sea there are commercial quantities of brown algae – two species of Laminaria and three Fucus species plus Ascophyllum nodosum and one red alga species – *Ahnfeltia plicata*. In 1990's, in the Barents Sea, the commercial harvest of *Laminaria saccharina* and *Fucus vesicilosus* was initiated. Currently industrial processing of seaweeds is carried out at Arkhangelsk algal plant which is producing a wide assortment of medical, food, cosmetic and technical production.

Brown, red and green seaweeds play a leading role in formation of littoral biocenoses of the Barents Sea which are characterized by high species biodiversity and biomass of benthic hydrobionts. Due to their long-life cycles fucoid seaweeds are edificators-species in littoral phytocenoses and form the structure of the benthic community. These fucoid seaweeds function as the main primary producers in these communities while also acting as determinants for the rest of the biotic community and in many respects helping to determine the state of coastal ecosystem [1, 2, 3].

In the littoral zone brown seaweeds create multilevel phytocenoses, in which the spatial complexity increases with depth resulting from increasing species diversity due to the numerous accompanying species and epibionts which use the algal thallus as a substratum. Seaweeds are also the important in the food chain as numerous invertebrates are phytophages eating adult plants or, more often juveniles, which plays a role in regulating species diversity and in the formation of spatial structure within the phytocenoses [4]. Benthic seaweeds create the habit environment and serve as a refuge for numerous larvae of invertebrates and fishes.

Coastal seaweeds are known to play an important role in the biological clearing processes, of coastal seawaters from oil and toxic heavy metal pollutants. Seaweed along with others hydrobionts are widely used in reconstruction of damaged biocenoses by construction of artificial reefs for biomediation in coastal ecosystems [5, 6, 7]. Benthic seaweeds have become extremely important trade products for their valuable mineral and organic contents [8, 9]. Development of new or perfection of existing cultivation techniques for seaweed

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is becoming increasingly important in the field of ocean aquaculture [10, 11].

In the coastal zone of the Barents Sea brown seaweeds are the dominant species in the littoral zone benthic community. The top littoral horizon is occupied by *Fucus vesiculosus* and *Ascophyllum nodosum,* middle – by *F. distichus,* and *F. serratus* prefers low littoral horizon. Various other seaweeds are cohabitants with the fucoids, however their biomass are on an order of 1-3 times less, than *Fucus sp*. In the low littoral zone the commercial laminarean seaweeds *Saccharina latissima, Laminaria digitata, Alaria esculenta* are grown. In addition here the red alga *Palmaria palmata,* species of genus *Porphyra* and green alga *Ulvaria obscura* are growing which are also used by man. The red alga – agarophyte, *Ahnfeltia plicata* is the dominant species found forming the extensive fields of alga found in the bays of the White Sea.

During the last few decades commercial fucoid seaweeds have received the attention of researchers who have studied their anatomy, morphology, physiology, systematics and biochemistry. Currently further research into the biology and ecology of seaweeds, including their life cycles and growth rate of thallus, the analysis of age and generative structures of populations is needed. In addition, the role of ecological factors in determining the distribution of different biotopes needs further work to determine the role these biotopes play in coastal ecosystem integrity. With increasing use of marine biological resources seaweeds are enter into our life more persistently as food products. Marine aquafarm development in the coastal zones of the Barents and White Seas assures for the fuller utilization of the natural seaweed resources.

Through our research our goal is to facilitate more effective study of our natural seaweed resources. The purpose of our work is hoped to lead to a more rational use of the commercial seaweeds found in the coastal zone of the northern seas. In this research we have monitored the conditions of the fucoid seaweed beds found on the Murmansk coast of the Barents Sea.

## 2 Materials and methods

Long-term seasonal monitoring of seaweeds data collected at the biological station of Murmansk Marine Biological Institute of the Russian Academy of Sciences (in region of Dalnie Zelentsy) and seaweeds data collected from expeditions on the Murman coast of the Barents Sea and on coast of the Kandalaksha and Onega gulfs of the White Sea were analyzed. Methods of gathering and the materials examined were presented in our publications [1, 7]. The methods used to gather seaweeds data utilized sample plots in typical habit sites of seaweeds in the intertidal zone along transects oriented perpendicular to the coast line. Sampling in fucoid phytocenoses was carried out using a frame of 0,5 x 0,5 m2 (3–5 replicates). Collected seaweeds in each sample were divided into species, then wet weight of each species was measured and summed to determine the total wet weight of seaweeds (B) in communities. The average biomass and the error of average (B ± mB) were calculated. In the population study of fucoids, all plants from samples (n = 3–5) were divided into age groups. Age group determinations were established by the number of dichotomous branches on the thallus (t = d/2). Total number of fucoid plants (Nf), number of plants in each age group (Nt) and wet biomass of each age group (Wt) were determined. In each age group, 5–10 typical thallus was selected, and length (L), weight (W) of plants were measured, then average and standard deviations (σ) were calculated. Statistical processing of the received data was by means of the software package «Microsoft Office Excel».

## 3 Results and discussion

Fucoids are common and abundant seaweeds in the intertidal zone throughout the coastlines of both the Barents and the White Seas. Fucoids in these areas form complicated perennial phytocenoses. The composition of species comprising the phytocenoses (dominating and accompanying species) show variability depending upon location; open to closed parts of inlets and from upper to low littoral horizons. Over time, the quantitative parameters of phytocenoses and populations of dominating species show a wide corridor of variations.

The high biodiversity found in fucoid phytocenoses of the littoral zone of the Murman coast results many accompanying species of seaweeds, on which the thallus and within the thallus were numerous invertebrates living and clinging to prevent outflow. The spatial structure of phytocenoses is multidimensional. The base level is occupied by the fucoid species as edificators, under their beds and on their thallus litophytes and epiphytes are found growing. The number of seaweed species living in association with the fucoids increase from the upper to the lower portions of the fucoid beds (from 1–7 up to 20–30 species). Similarly, this increasing biodiversity is seen spatially from the closed to the open portions of inlets (from 15–22 up to 20–30 species). For most of the long-lived brown fucoid seaweeds found dominating the research areas, biodiversity was highest in the spring and summer and decreased in the autumn and winter.

The seaweed's biomass was seen to increase with depth from the upper to middle and lower littoral horizons. This being said, even in the upper littoral zone the fucoid's biomass can be quite large. At all sites within the inlet from open to closed portions significant variations in biomass values were seen being dependent upon the conditions of biotope and sampling sites (Table 1).

Greater than 90 % of the phytocenosis biomass was composed of fucoid seaweeds *Ascophyllum nodosum, Fucus vesiculosus, F. distichus, F. serratus*. These species dominate in semi-protected inlets (Table 1) with an average fucoid community biomass of from 2.8±0.6 to 17.7±2.9 kg/m$^2$. Variables which determined biomass include: the species composition present, the granulometric structure of substratum on which seaweeds were growing and the level of force from the surf. In fucoid phytocenoses the biomass of seaweeds increased since spring to the maximumal values seen in the summer and then decreased during the autumn–winter period. The most significant seasonal changes were observed in association of *A. nodosum* +*F. vesiculosus* in the central part of the inlet with a threefold biomass increase (4–12 kg/m$^2$).

**Table 1.** Average biomass variation (kg/m2) in fucoid phytocenoses in inlets of semi-protected and exposed types.

| Intertidal | Semi-protected inlet | | | Exposed inlet |
|---|---|---|---|---|
| | closed→ | middle→ | →open part | |
| upper | 2.6 | 2.3–12.0 | | 1.5–5.1 |
| middle | 3.0–17.7 | 2.8–6.9 | 2.7–14.4 | 3.2–6.4 |
| low | 0.5–1.1 | 0.2–0.5 | – | 9.5 |

In the protected type of inlets, the maximum average biomass was observed in settlements of *F. vesiculosus* in open portions (3.7 kg/m$^2$) with a gradual decrease in biomass being seen in closed portions where the minimum values (1.8 kg/m$^2$) were noted. Analysis of the fucoid population found that as measured by biomass middle aged plants dominated the open and middle portions of inlet, but in the closed areas young individuals dominated due to their high population numbers (Figure 1).

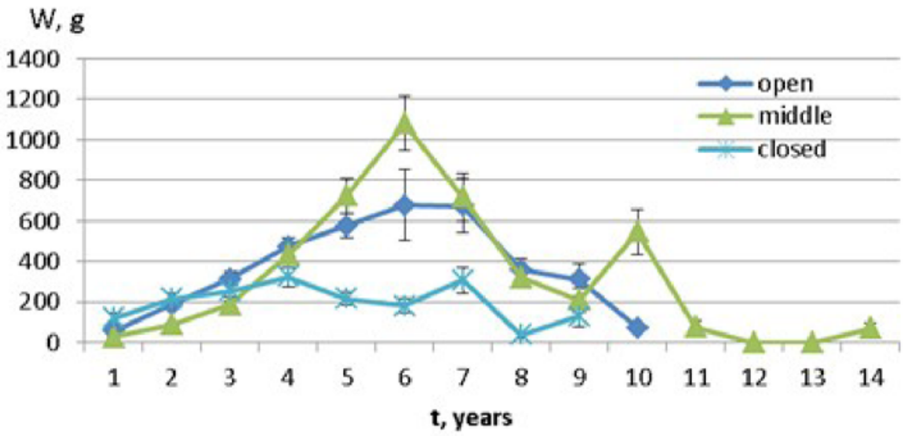


**Fig. 1.** Total weight of Fucus vesiculosus age groups (Wt, g) in different sites of protected inlet, *n* = 510.

In the littoral zones of the Murmansk coastline, the age structure of fucoid seaweeds was dominated by young plants but all generations from young to old (fertile plants) were present. In the upper littoral horizon seaweeds *A. nodosum* and *F. vesiculosus* were growing in populations with mixed age structure with densities ranging from 750 to 1700 plants/m². While in populations of F. distichus and *F. serratus*, occupying the middle and low portions of the littoral zone, seaweeds were found in groups of similar aged plants in which 4–6 years plants were dominated, with density ranging from 120 to 170 plants/m².

In Figure 2, the age structure of *F. vesiculosus* settlements in the protected (from surf) portions of the inlet is shown. In the near shore locations, the age structure was dominated by young plants with high density (1290 plants/m$^2$). In the middle part of the inlet, plant ages varied from young to old (up to 14 years) with densities sharply decreasing (809 plants/m$^2$) as compared to the other parts of the inlet. In the open portions there was settlement with high density (1350 plants/m$^2$) again, characterized by plants of a wide range of ages. The *Fucus* population age structure in the protected inlet consisted of plants from young to Middle Ages to old plants. The heterogeneous age structure of this population provides evidence that effective management strategies are allowing for renewal of the population.

Fucoid seaweeds are characterized by having long life cycles. In the Barents Sea the maximum age for *F. vesiculosus* plants ranges from 11 to 14 years while longevity for *F. distichus* plants can reach up to 8-9 years, with *F. serratus* living up to 14 years and finally *A. nodosum* has longevity estimates ranging from 19 to 25 years [1].

Fucoids have an unusual type of sexual reproduction for macroalgae. In the diploid phase in life cycle the reproduction bodies act as receptacles where the gametes are formed. Male and female gametes can be formed in the same plant or in different plants, gamete release is synchronized by circadian, lunar and seasonal internal clocks. Species *A. nodosum, F. vesiculosus, F. serratus* – dioecious plants with individuals being either male and female plants; *F. distichus* – a monoecious species. In *Fucus* species the receptacles are formed on top of the branches. These reproductive branches stop growing after reproduction. In *Ascophyllum* receptacles are formed on small stalks on edge of branches. The reproductive receptacles are dumped after reproduction. Following reproduction these shed receptacles can be so numerous, that the coast is covered by them. Fertilization occurs in the water column where the newly formed zygote immediately settles to the bottom and attaches to a substratum. This stage of development is the most critical in life cycle.

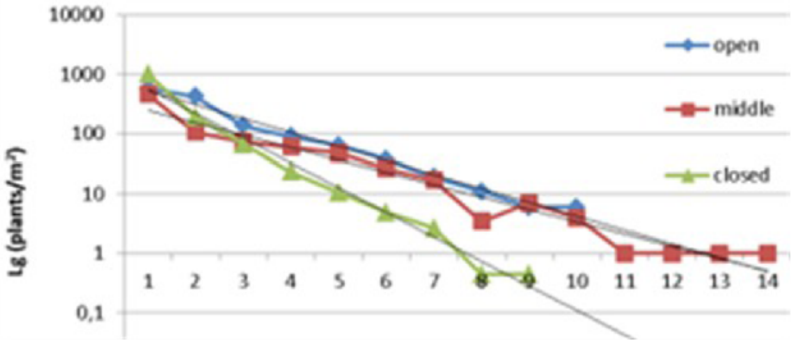


**Fig. 2.** Age structure of Fucus vesiculosus population in different sides of protected inlet (*n* = 3450).

Murman fucoid seaweeds start to reproduce in their second to fourth year. This non-reproductive period is considerably longer than is seen in other long-lived seaweeds. Another characteristic feature of fucoids is the long developmental period for receptacle formation which requires from 5 to 12 months. In the White and Barents Seas in *F. vesiculosus, F. distichus, A. nodosum* the receptacles form in the autumn, slowly developing in winter; with the release of numerous gametes in first half of summer of the next year. The quantity of fertile plants in the populations of the different fucoid species depends on ecological factors. The percentage of fertile plants vary from 20-30 % in *F. vesiculosus* and *F. serratus* and up to 50 % in *F. distichus* and *A. nodosum*. The population age group primarily responsible for reproduction is the seaweeds of 4–7 years of age.

In inlet of protected type, the first receptacles in *F. vesiculosus* develops in two-year-old plants. With aging the relative number of fertile plants increases with the majority of adult plants having receptacles. The total percent of fertile plants average from 25-34 %. The ratio of female to male plants found in the central parts of the settlement was estimated as 1:3 female to male while on the edge of the settlement the ratio was found to be approximately 1:1 (Figure 3).

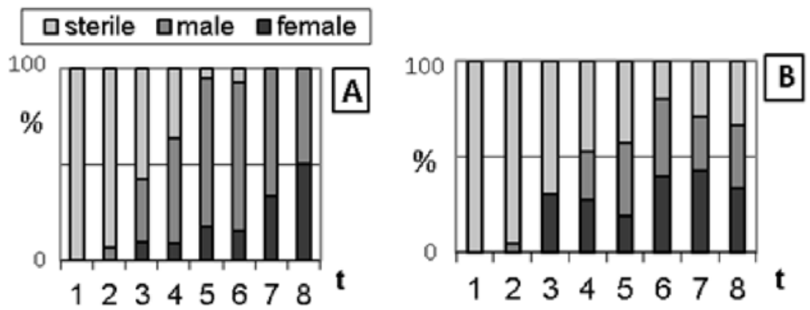


**Fig. 3.** Generative structure of *Fucus vesic*ulosus population in middle (A) and closed (B) sites of protected inlet; t – age, years; n = 426.

In populations of dioecious species in the partially protected regions in dense beds of *A. nodosum* and *F. vesiculosus* the ratio of female to male plants was 1 to 1,5. In populations of *F. serratus* which usually occupies the lower littoral horizon the ratio of female to male plants was 1 to 1. The general it was observed that in stressed habitats the of females to males increased.

Fucoid growth is through the activity of the apical meristem and by dichotomic branching of the thallus, which occurs throughout the entire plant life. It is expected in this case that the growth curve as measured by biomass in a normal population should be exponential in character (Figure 4). The weight of thallus rises almost exponentially up to years 7–10. In later ages the growth of the thallus is not observed. This observation might be due to damage from storm energy by breaking of the thallus as well as by stoppage of branch growth with riped receptacles. However, more often we see that the curve takes the form of an S-curve in more protected areas (Figure 5) where biomass growth data are presented. The shown data were based upon raw thallus weight of plants in protected type inlets. The maximum values of thallus biomass were observed in different age groups in various parts of the inlet of different types.

The first quantitative estimations of commercial seaweed stocks in the White Sea were carried out by employees of the State Oceanographic institute under the leadership of professor Meyer K. I. in 1931. Beginning in the 1950s, the estimation of seaweed stocks was carried out regularly. In recent years mapping of seaweed stocks in the Barents and White Seas was performed through the use of aerial photography, by use of cameras on ships and by underwater observations through the use of diving equipment [12, 13]. Stocks of fucoid seaweeds on the Murmansk coast of the Barents Sea were estimated as 180 thousand tons according to data of PINRO and VNIRO; the regions with the greatest potential for commercial harvest were found in Rybachyi peninsula, Kildin Island, Drozdovskaya and Ivanovskaya Bays [13, 14].

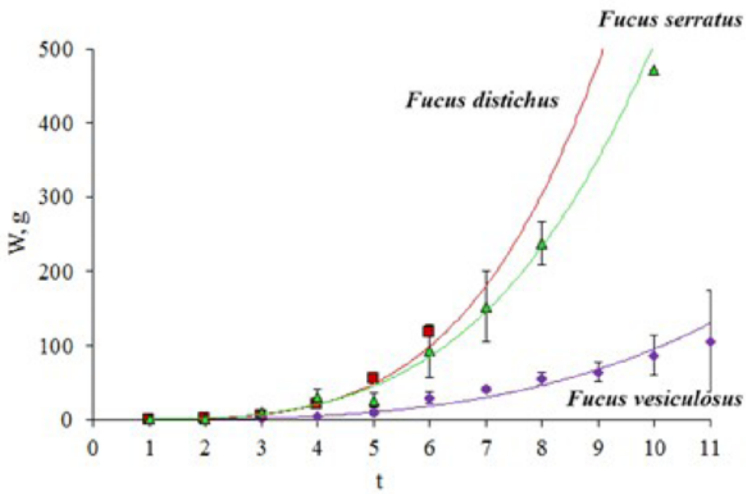


**Fig. 4.** Weight of thallus (W, g) in ontogenity of *Fucus vesiculosus* (n = 59), *F. disthus* (n = 49*), F. serratus* (n = 40) in semi-protected inlet, the y-axis – t, age, years.

The stock estimation of commercial seaweeds in each location is based on determination of seaweed biomass according to the formula: Q = (B * PC * S)/100 %, where B – an average biomass in a site, kg/m$^2$; PC – a projective covering (the area occupied with seaweeds), is defined visually, in %; S – the site area, m$^2$.

Intervention in natural ecological processes which is inevitable with the harvest and trade of seaweeds, can lead to negative consequences, both for the ecosystem and for the environment. Therefore, to minimize the negative ecological consequences of seaweed harvest comprehensive investigations are necessary. The principle of rational wildlife management of stocks of seaweed is based on the estimation of seaweed stocks and on the results of research on the biological communities and specific biology of the commercial seaweed species.

Estimates of seaweed biomass is the primary parameter used for regulation of seaweed harvest. Estimates of seaweed stocks and allocation of quotas for harvest is based on the idea that the algal resources are relatively static. However, seaweed biomass is the result of the habitat conditions under which the seaweeds are growing which can be quite variable, especially on the Arctic coast. The biomass varies considerably with the most important factors being the granular structure of the substrate along with the hydrodynamic conditions (surf conditions, frequency and magnitude of storms, tidal currents, motion of ice, and water outflows). Intensity of water exchange is the most important indicator in determining the makeup of the specific seaweed communities found in the bays and open water zones of the sea, as well morphological and functional structure of dominating species. Seasonal cycle of growth of littoral seaweeds is strongly connected with temperature and photoperiod [1]. The biomass of seaweed has considerable seasonal and inter-annual dynamics, especially in the long-lived fucoid seaweeds, with their highly variability population age structure which is directly dependent upon environmental conditions.

Despite the many advantages which would result from seaweed culture as compared to harvesting from nature, cultivation of seaweeds in the northern Russian seas remains practically undeveloped. There is potential for development of seaweed plantations which could grow seaweeds for raw biomass for direct use or for the processing and extraction of biologically active substances from the seaweeds. Other benefits which could result from the creation of seaweed plantations include use of seaweed as natural biofilters for water treatment in aquafarms when growing invertebrates and fishes or for use in cleaning of sewage dumped at sea. Seaweed as a primary producers can be used as food in aquaculture in the joint cultivation of mussels and

*Laminaria*. Fucoid seaweed substrates which float at the sea surface because of their air-filled vesicles can be used for cleaning of oil spills in the sea [6]. Cultivation of *Laminaria* on an experimental trial plantation on the Murmansk coast and on an industrial plantation around Solovetsky islands has shown that seaweed farming can be profitable in the north.

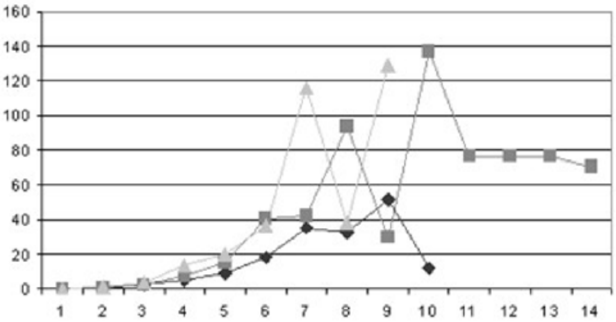


**Fig. 5.** Weight of thallus (W, g) in ontogenity of *Fucus vesiculosus* (n = 59), *F. disthus* (n = 49*), F. serratus* (n = 40) in semi-protected inlet, the y-axis – t, age, years.

## 4 Conclusion

The studies of thallus growth dynamics and species, age, and generative structure of fucoid populations can serve as a basis for assessing stocks and justifying quotas for the harvestl of commercial seaweeds from natural phytocenoses and aquaculture plantations in the coastal zone of the Barents and White Seas. The research results allow us to make the recommendations for the rational use of seaweeds and the restoration of phytocenoses disturbed during harvesting, as well as to develop and use a technology for synchronizing the process of harvesting of commercial object with the life cycle of algae, which will provide scientifically based quotas for production and restoration of seaweeds stocks in the littoral zone.

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