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Growth rate of Fucales on the Murman Coast, the Barents Sea

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Abstract. Fucales are among the key algae on the coast of the Northern Hemisphere and are being actively studied, although minor attention is paid for the age structure, since there are no reliable signs for determining the age of the algae. Direct observations on the thallus growth on the coast evidence on a variation of this trait under different conditions. We assess the rate of linear growth and the number of formed dichotomous branching per year in *Fucus vesiculosus* and Fucus distichus on the Murman Coast of the Barents Sea. These parameters differ in plants sampled from different biotopes. The annual growth of *F. vesiculosus* is two times higher and more dichotomous branches are formed per year in the environment characterized by low water movement intensity and pronounced salinity fluctuations than in plants growing on a weakly protected area of the coast. In the Barents Sea, the branching rate and the annual growth in *F. distichus* and *F. vesiculosus* depend on the intensity of water movement and the salinity regime of a particular biotope. The number of formed branches depends also on the number of already formed dichotomies, i.e., on the physiological age of thallus. It is necessary to modify the equation for calculating the age of these species using the correction factors for salinity, the intensity of water movement, and the number of dichotomies.

1 Introduction

In the Barents Sea, and throughout the Russian Arctic, the largest stock of Fucales is concentrated along the Murman Coast. The biomass of these brown algae may reach up to 20 kg/m2, and the total stock in the Barents Sea are estimated as almost 100 thousand tons of wet weight (Malavenda, 2018). On the one hand, Fucales are commercial species, on the other, it is a key component of coastal ecosystems, supplying a huge amount of organic matter as primary producer, serving as a substrate that increases the bottom surface area several times, and being the bioremediating species. The Fucales communities attract much scientific interest since the very beginning of their studying.

All physiological, population, and partly ecological studies take into account the age of Fucales. It is generally accepted that two dichotomous branches are formed per year in *Fucus vesiculosus* L. and *F. distichus* L. on average, regardless of the characteristics of a particular biotope [2, 3, 4]. However, these data have been obtained for the White Sea populatons, and their application to the Barents Sea populations is still questionable. In addition, the formation of branches and of the air bubbles in F. *vesiculosus* at the coast of the Barents Sea depends on abiotic environmental factors (illumination, littoral level, etc.) [5]. This conclusion has been made on the basis of observations of these plants during the first two years of life. In the population of *F. distichus subsp. evanescens*, inhabiting the Russian Far East, up to six branches can form in the first year of life, then the branching rate and linear growth of plants is significantly reduced [6]. Therefore, this issue may be considered controversial, and so it requires targeted study.

The study aims to search for the effect of the degree of protection of the biotope and its salinity regime on the rate of formation of dichotomous branching and on the linear growth in the populations of *Fucus vesiculosus* and *F. distichus* inhabiting the Murman Coast of the Barents Sea. We have tested the hypotheses if two branches are formed per year and if the growth rate may be considered constant.

2 Materials and methods

2.1 Study area

The growth rate of Fucales was studied mainly in vicinity of the Dalnie Zelentsy Biological Station of the Murmansk Marine Biological Institute, in particular, in Yarnyshnaya, Zelenetskaya, and Shelpinskaya bays (figure 1). This area is the most accessible as one of the pristine biotopes of the Murman Coast of the Barents Sea and is the most studied. The studies have been also performed in the Pechenga Bay of the western Murman Coast to check if the obtained data may be used for extrapolation to the entire Murman Coast (figure 1). The study has been carried out from 2008 to 2014.

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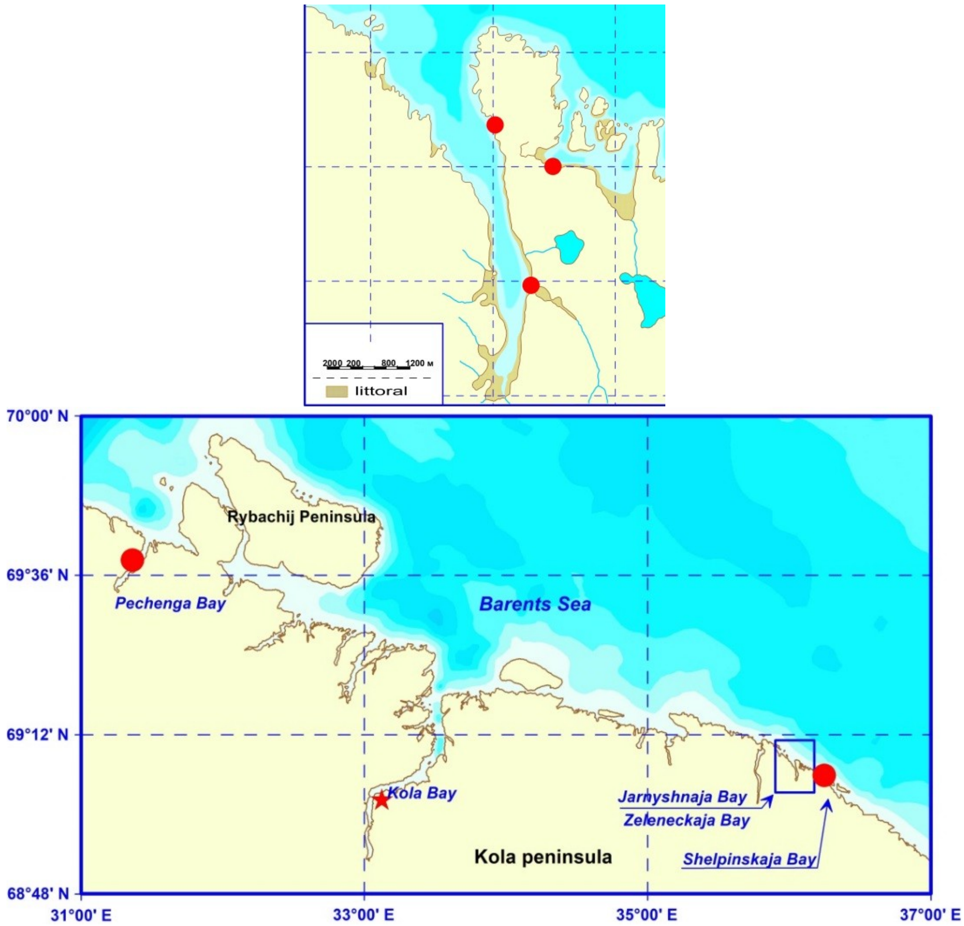


Fig. 1. Study area.

2.2 Hydrological observations

The intensity of water movement in algae thickets was estimated by the method of plaster balls [7, 8]. At each test site, at least twenty 30-g plaster balls with a diameter of 40 mm were exposed during the day at syzygy and quadrature tides. The water salinity was measured using a portable refractometer with an accuracy of 1‰. At each test site, several salinity measurements were carried out during syzygy and quadrature tides (both at high tide and low tide) in summer.

2.3 Labeling

Adult *Fucus vesiculosus* and *F. distichus* were labeled in the littoral zone in the first decade of August each study year. The label was a 2 × 2 cm cardboard with a number, pasted over with adhesive tape and tied with a cotton thread to the base of the thallus, more precisely to the first cylindrical elements. This method of labeling was tested by us earlier and provided a greater safety of the material in comparison with other methods. Labels were placed in the littoral areas with known values of the intensity of water movement and salinity fluctuations (table 1). In order to take into account, the effect of illumination, plants were labeled at the same levels of the littoral zone: *F. distichus*, at –0.6 m, *F. vesiculosus*, at 1.3 m. There were 3 to 10 dichotomous branches on the main branch of plant, i.e., these specimens were mature and able to reproduce; since the number of apexes was less than the number of receptacles in such algae, their growth potential was still high [9]. The length of the main plant axis and the number of branches were determined, and the apical parts of the plant were additionally labeled to determine their growth rate. In total, about 1 000 plants were tagged.

Starting from 2009, the labeled thalli were sampled and measured each year in the first decade of August. However, in all studied biotopes, not all of the noted thalli were found: *F. distichus* was found at all experimental sites, but *F. vesiculosus* was found only in the littoral zone of the Yarnishnaya Bay. In total, over the entire period of the experiment, after a year of life, we have found 399 labeled thalli. High rate of loss of materal due to breakage of thallus parts is a serious methodological obstacle to the widespread use of this method for determining the growth rate and the branching rate.

2.4 Statistics

The average number of formed branches and the average length increase were estimated for *F. vesiculosus* and *F. distichus* at each site. Variation of the trait was assessed by standard deviation. The role of physiological age and the influence of hydrological parameters were assessed using one-way ANOVA for each factor separately using PAST 3.0 software package. The calculations were performed in Excel (primary data) and in the PAST 3.0 software package (analysis of variance) [10, 11].

3 Results and Discussion

3.1 Hydrological regime

During the observation period, it was possible to identify the main features of the hydrological regime of the study sites. The data obtained formed the basis for factor analysis of the growth rate of Fucales (Table 1).

Table 1. Intensity of the water movement (IWM) and water salinity in summer at the study sites.

Study site	IWM, 10^{-3} $mgCaSO_4/g*h$	Salinity, ‰	
		High tide	Low tide
Bobrovaya Inlet, Yarnyshnaya Bay	7	30	5
Devkina Zavod' Inlet, Pechenga Bay	8	34	25
Oskara Inlet, Zelenetskaya Bay	10	34	25
Shel'pinskaya Bay (central part)	14	34	30
Cape Krasnaya Skala, Yarnyshnaya Bay	20	34	30

The hydrological regime at the study sites did not differ from that observed in 2004–2007 [12]. According to literature data, there was a slight increase in water temperature in the coastal regions of the Kola Peninsula [13]. In 1983–1984, the water temperature in the 0–15-m layer in January could drop below –1.5°C, in June-July, it was stably below 7°C and reached 9°C only at the end of August–September. In 2002–2012, the average surface water temperature was 3.8°C, in July–September, it exceeds 7°C in average, while in winter it did not fall below 0.7°C [13].

It is important that salinity and intensity of water movement correlate in the study area. A large stream flows to the apex of the Yarnyshnaya Bay, and a river flows to the Pechenga Bay, which causes a decrease in salinity from the mouth to the apex. The Zelenetskaya Bay is distinguished by its wide mouth, blocked off by a group of islands.

3.2 Branching

Our observations evidence that from three to four branches of the thallus are formed per year on average, but this parameter varies. There is a relationship between the number of newly formed dichotomies and the number of already existing dichotomies at the time of labeling (Figure 2). The maximum growth rate has been observed for *F. distichus* thalli carrying six already formed dichotomies: in average, 4 branches per year were formed; the plants with 3–5 existing branches formed somewhat less (3, less often 4) branches; the oldest thalli with 9–10 branches formed two new ones.

Fig. 2. Average number of branches formed per year in *F. distichus* in regard to the age (total sample).

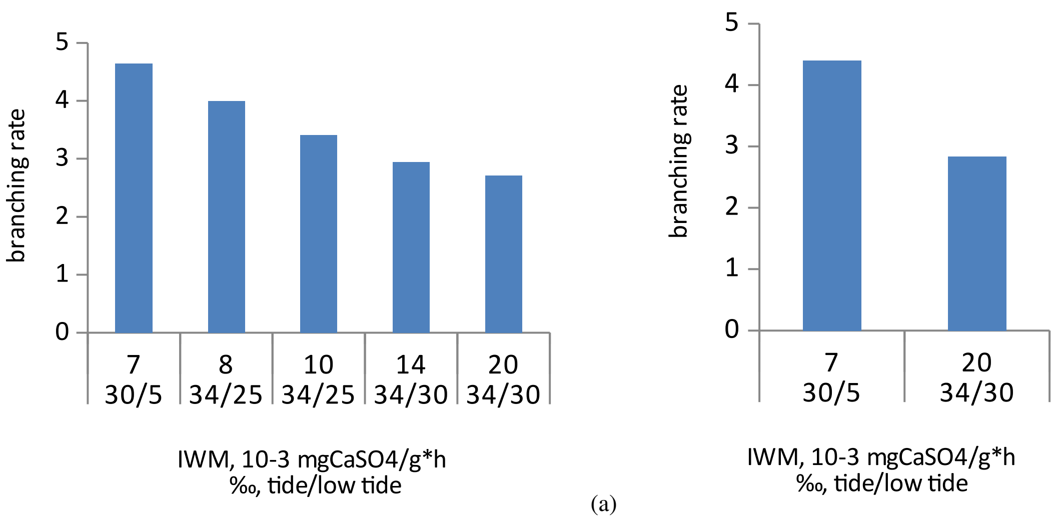
The branching rates differ in plants from different biotopes (Figure 3). *F. distichus* forms 4–5 branches per year in the close bays, but only 2–3, in a biotope with high intensity of water movement; in *F. vesiculosus*, from 3 to 6 branches formed in the well-protected part of the coast, and from 1 to 4, in the weakly protected areas (Figure 3). Therefore, on average, twice as many dichotomies were formed in thalli of both species in the well-protected area of the littoral zone comparing to the weakly protected area, but the variation of this parameter was higher in *F. vesiculosus*.

Analysis of variance evidenced on a high dependence of the number of formed branches on the intensity of water movement and salinity (Table 2). Water salinity had a greater effect on the number of branches than the intensity of water movement did.

Table 2. ANOVA results.

The intensity of water movement (IWM)					
	Sum of squares	*df*	Mean square	*F*	*p*(same)
Between groups	361.79	39	9.27	6.33	3.101E-17
Total	658.99	199			
Omega²	**0.44**				
Levene's test for homogeneity of variance, based on means: *p*(same) = 1.127E-08					
Based on medians: *p* (same) = 0.05053					
Salinity					
	Sum of squares	*df*	Mean square	*F*	*p*(same)
Between groups	2968.37	39	76.11	44.88	1.057E-66
Total	658.99	199			
Omega²	**0.88**				
Levene's test for homogeneity of variance, based on means: *p*(same) = 1.088E-05					
Based on medians: *p*(same) = 0.5452					

Previously, it has been experimentally proven that constant fluctuations in salinity increased the rate of photosynthesis and enhanced the linear growth of Fucales in the Barents Sea. Periodic decrease in salinity to threshold values (5 ‰) contributes to an increase in the overall productivity of Fucales [14]. Such adaptations are key for Fucales. The intensity of water movement does not affect the salinity tolerance range of *F. vesiculosus* and *F. distichus*, but increases the time of survival in unfavorable conditions and contributes to the development of adaptive changes [15].



(a) (b)

Fig. 3. Branching rate, levels per year, in *F. distichus* (a) and *F. vesiculosus* (b) in the gradient of intensity of the water movement (IWM) and salinity (‰).

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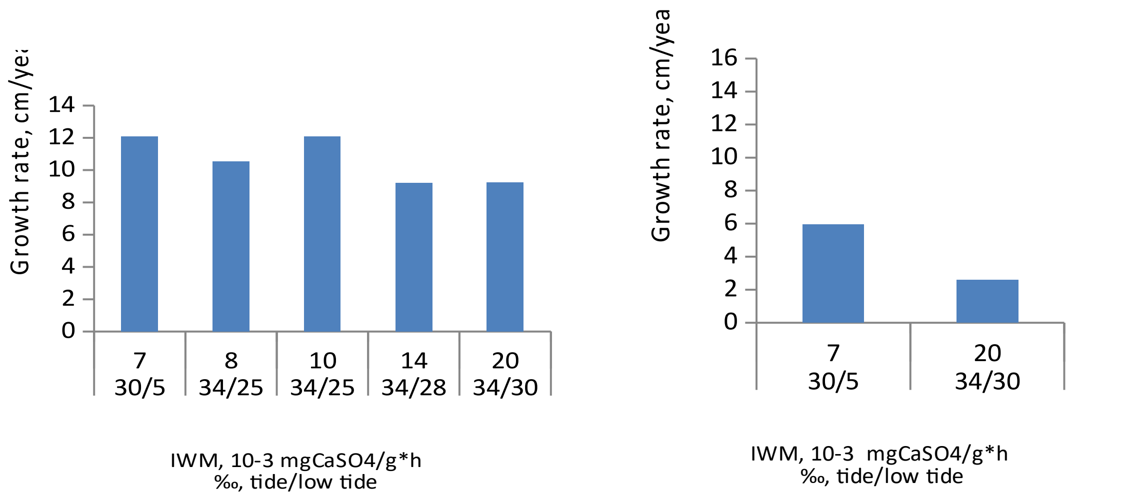

(a) (b)

Fig. 4. Linear growth rate (cm/year) in *F. distichus* (a) and *F. vesiculosus* (b) in the gradient of intensity of the water movement (IWM) and salinity (‰).

3.3 Linear growth rate

In the plants from the weakly protected part of the bay, the average length of the element was on average twice as long comparing to the plants from the closed inlets (Figure 4). The annual increase in the thallus length of *F. distichus* in the Bobrovaya Inlet exceeds that in plants inhabiting the area nearby the Cape Krasnaya Skala. The length of one element and the number of elements seem to balance each other, and larger, branched thalli are formed. The significance and mechanism of this adaptation in *F. vesiculosus* have been described earlier [16]. The length of the elements of whole thalli of *F. distichus* also varies in different orders of branching and may vary significantly under different conditions of water exchange [17]. The average length of the thallus elements of *F. distichus* in the weakly protected area decreases from the basal to the apical part of the thallus, i.e., from parts that perform a supporting function to the parts that perform a photosynthetic function. In the protected inlets, the length of the elements is somewhat higher in the apical part of the plant, but it is practically the same in the basal and middle parts. This pattern is due to the increased relationship of particular thallus elements under conditions of reduced water exchange; s, called determinism.

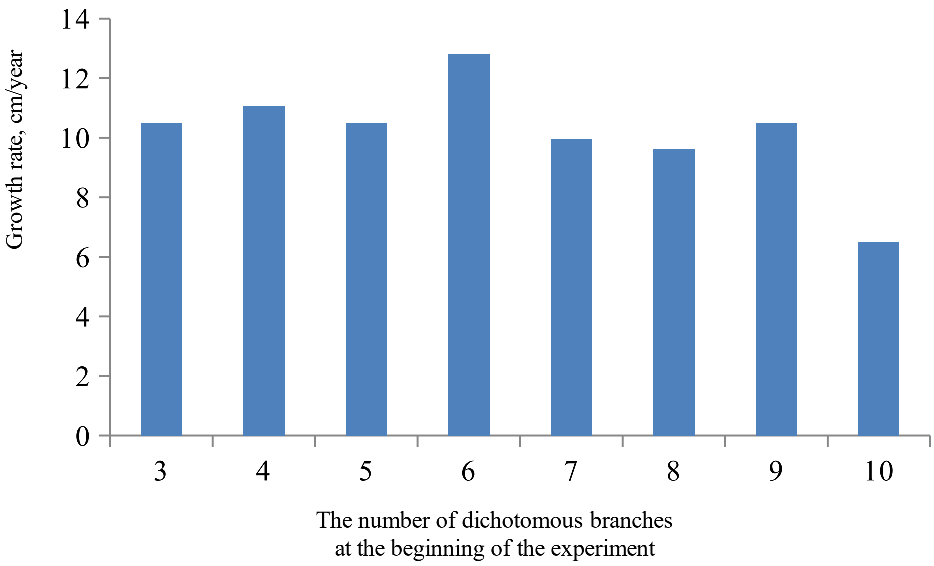

Fig. 5. Linear growth rate in *F. distichus* in regard to the age (total sample).

It was believed that the rate of linear growth in Fucales weakly depended on the number of branching and averaged 5 cm per year [3, 4]. However, the results of our experiment evidenced that the annual growth was from 7 to 13 cm per year, although this indicator was highly variable (Figure 5), depending on the biotope conditions as described above. As well as the branching rate, the maximum growth rate was observed in *F.*

distichus plants carrying six branches, then it decreased with age and reached a minimum in plants with ten dichotomies (7 cm per year).

The dichotomic branching rate in *F. distichus* depends on the age of the thallus; these results are in good agreement with the concept of the physiologically optimal age of this species. It has been found that the highest rate of photosynthesis is a characteristic of thalli with 8–9 branching; in addition, the loss of parts of thalli begins to prevail over their growth as the alga reaches this age [17].

Our data evidence that *F. distichus* and *F. vesiculosus* grow intensively during the first two years of life, when they form two or three dichotomies on average; in the third year, they are the peak of their growth rate, reaching maximum biomass, when 4 branches are formed (in total, there are 9 to 10 branches are formed on average). In the fourth year of life, both growth rate and branching rate slow down, as well as photosynthesis does, about two branches are formed, very few thalli reach the fifth year of life, and aging processes prevail. These simple calculations force us to look completely differently at the age structure of the population and the lifespan of Fucales.

The annual growth of *F. vesiculosus* is two times higher and more dichotomous branches are formed per year in the environment characterized by low water movement intensity and pronounced salinity fluctuations than in plants growing on a weakly protected area of the coast.

4 Conclusion

Therefore, in the Barents Sea, the branching rate and the annual growth in *Fucus distichus* and *F. vesiculosus* depends on the intensity of water movement and the salinity regime of a particular biotope. It is necessary to modify the equation for calculating the age of these species using the correction factors for salinity, the intensity of water movement, and the number of dichotomies.

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