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Analysis of spatio-temporal changes in Arctic Ocean ecosystem using machine learning and its impact on marine transportation system

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Abstract

Arctic Ocean is large and important ecosystem. Growth of human impact in last decades of XXI century leads to significant changes in different environmental variables. Main goal of this research was analysis of spatio-temporal structure of Arctic Ocean ecosystem to find main causes of its changing and impact on Arctic transportation system. For analysis of Arctic Ocean ecosystem structure, we used Bayesian network, while for spatio-temporal analysis – k-means clustering. This analysis was produced for 3 timestamps – 2007, 2012 and 2017. Main drivers of this ecosystem structure changes generally occur from human activity in this region – shipping and other marine operations. In last years, level of anthropogenic impact significantly increased, large number of territories was turned into agricultural lands, this leads to increase in number of biogenic substances falls into Arctic waters. Spatio-temporal analysis shows very significant changes in last 10 years. Despite the fact, that spatially areas of different zones in Arctic Ocean doesn't change, qualitative changes here look major. The same as ecosystem structure, the main cause of spatio-temporal changes mainly caused by marine shipping impact.

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Keywords: Arctic Ocean; machine learning; Bayesian networks; spatio-temporal analysis; k-means clustering, marine transport.

1. Introduction

Arctic Ocean supports lifecycle of habitat areas for many different marine organisms and also plays a key role in forming of global climatic system. Arctic marine ecosystems have many significant differences from other

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ecosystems, including even Antarctic's. Species that are live in this ecosystem have high level of adaptation for different environmental conditions, sometimes very harsh (Petrov and Bobkov, 2017). Despite the fact, that in last 10 thousand years Earth's climate characterized by stability, anthropogenic impact slowly changed environment, especially in Arctic region (Matishov, et al., 2018). Increase in amount of carbon dioxide concentration in atmosphere due to interactions with hydrosphere leads to acidification of water environment. Mainly it's shows in increase of pH value, changing chemical characteristics of marine waters (Suo, et al., 2016). Increase in amount of waterflows from agricultural lands and higher speed of sea ice melting, caused by climate changing leads to increase of fresh water amount leads to thermohaline circulation changes.

Thus, the main goal of this paper was analysis of spatio-temporal structure of Arctic Ocean ecosystem to find main causes of its changing (Krivoguz, 2020; Krivoguz and Borovskaya, 2020).

2. Materials and methods

For analyzing spatio-temporal changes in Arctic ecosystem we used Bayesian networks and k-means clustering.

Bayesian network represents casual relationship connections between random variables and their conditional probabilities (Kisi, et al., 2020). It consists of 2 main parts – oriented acyclic graph and set of conditional probabilities, where oriented acyclic graph is a set of random variables, represented by nodes (Bendtsen, 2017). If there's any casual relationship between two random variables, these variables will be connected with directed edge, that will be directed from node A to node B and indicate, that random variable A is the cause of the random variable B. While using Bayesian networks our main goal is to calculate a posterior probability of any unseen causes or $P\{Cause|Envidence\}$ (Scutari, 2010). Conception of Bayesian networks based on Bayesian theorem, which helps us to represents conditional dependency distribution of causes according to observable evidences using reverse conditional probability:

$$P\{Cause|Evidence\} = P\{Evidence|Cause\} \cdot \frac{P\{Cause\}}{P\{Evidence\}}$$

Important part of the Bayesian network is a table of conditional probabilities, which calculates separately for every node and used for calculation and specification of relations between nodes.

For spatial zoning of territory, we used k-means clustering. It's one of the machine learning algorithms, which helps to find similar groups between random variables distribution in a complex space (Krivoguz, 2020). In this research we used data normalization using minimax method:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

Then we tried to find predisposition of analyzed data for clustering using Hopkins statistics (Campello, et al., 2019). When $H_{ind} > 0{,}5$, it's corresponds to null hypothesis, that q_i and w_i are equal and their values has random and even distribution. If $H_{ind} < 0{,}25$, dataset has tendency for clustering.

$$H_{ind} = \frac{\sum_n w_i}{\sum_n q_i + \sum_n w_i}$$

In our case, Hopkins statistics was equal 0,19 which corresponds to good clustering tendency for our dataset.

Optimal number of clusters was calculated using elbow method and optimal number of clusters or environmental zones in Arctic Ocean was 3.

3. Results

3.1. Arctic ocean ecosystem structure analysis in 2007, 2012 and 2017

Since functionality of Arctic Ocean ecosystem mainly depends from sea ice regime, thus the main driver here is sea surface temperature (SST). Its level highly impact on amount of dissolved oxygen in Arctic waters (Figure 1A), according to its structure in 2007. Mainly, it can be linked with sea ice regime and with the fact, that besides phytoplankton synthesis, main source of oxygen in water environment is water aeration, due to atmosphere and hydrosphere interaction. Level of net primary production, according to modelling results, depends on impact form sea surface temperature and dissolved oxygen. Here, water temperature plays role of variable, that define conditions for photosynthesis organisms living, while oxygen defines their activity, as far as number of phytoplankton, that situated lower in this scheme. Sea water salinity (SSS) is an indicator of different chemical elements amount in water environment - Cl, Na, Mg, S, Ca, Si, N and other. Usually it has seasonal fluctuations, that's defines its dependency from SST of water environment. Concentrations in water of NO_3 and PO_4 usually represents human activity, due to the main sources of this compounds in water are flush from the agricultural lands. Most clearly their connections can be seen with net primary production and dissolved oxygen, because NO_3 and PO_4 are factors, that have high impact on phytoplankton growth, and consequently on oxygen amount, which is produced by them. Zooplankton in this scheme (Fig. 1A) is a key node, due to the highest position in this scheme. Its biomass depends from the number of phytoplankton and its location defines by temperature and salinity. Generally, ecosystem structure in Arctic Ocean in 2007 presented in figure 1A is usual to most of the water objects. Different ecological variables described in strong hierarchical consequence, when environmental variables come first and are basis of ecosystem structure, while biogenic and anthropogenic variables come next. Under them are producers and consumers of the 1-st order.

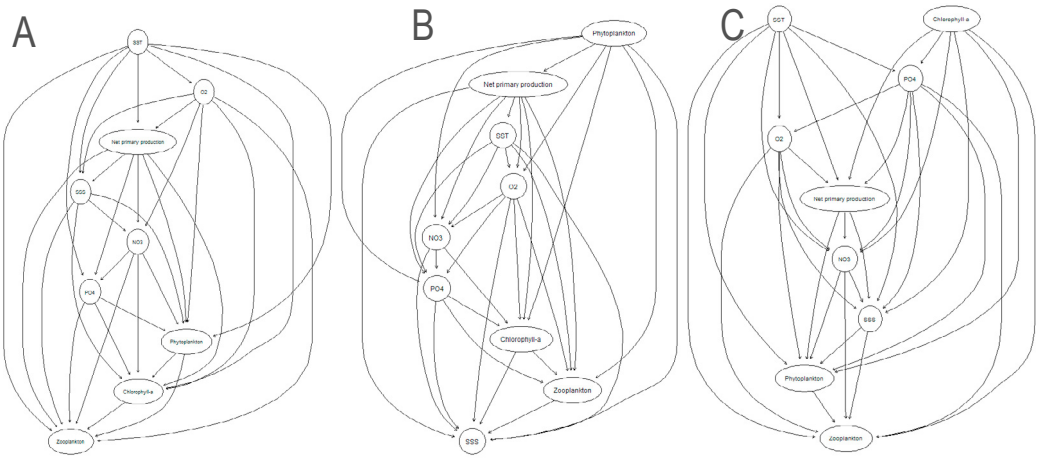

Fig. 1. A – Arctic Ocean ecosystem in 2007, B – Arctic Ocean ecosystem in 2012, C – Arctic Ocean ecosystem in 2017.

Generally, ecosystem evolution in 2007-2012 looks very significant (Figure 1B). Core variable, on which structure is being built is phytoplankton biomass. Such location of this variable in ecosystem structure tells us about absence of any significant impact on phytoplankton biomass, which most likely is evidence of its active growth in 2007-2012. Usually, stimulus of such active growth can be large number of phosphates and nitrates in ecosystem from agricultural lands as the result of human activity. Nevertheless, there's a direct connection between phytoplankton and zooplankton, that tells about good conditions lowest level of trophic chains in Arctic Ocean.

Period of Arctic Ocean from 2012 to 2017 can be characterize by relative normalization of ecosystem structure (Figure 2C). Highest levels in its structure represented by relationship of phytoplankton and zooplankton. Also, we can see seasonal increasing of phosphates in ecosystem, which is unusual for past periods. Based on relationship between phosphates and SST we can say, that income of PO_4 is most likely seasonal and is a result of human activity intensification.

3.2. Arctic ocean spatial zonation in 2007, 2012 and 2017

Year 2007 (Figure 2A) can be characterized by 3 different zones. First – near European coast, from Norway and Iceland to France coast. These are open from ice water, with higher level of temperature and salinity. Central zone located from Novaya Zemlya and Murmansk, from Spitsbergen and Greenland to east coast of Canada and USA. This zone characterizes by colder and less saltier waters, with periodical presence of ice cover, which has a seasonal tendency. Third zone located near northern coast of Russian Federation, coasts of Canada and USA, and also northern part of Greenland. This zone characterized by permanent ice cover. The level of sea surface temperature there is lowest from all of the Arctic Ocean area, as far as salinity level.

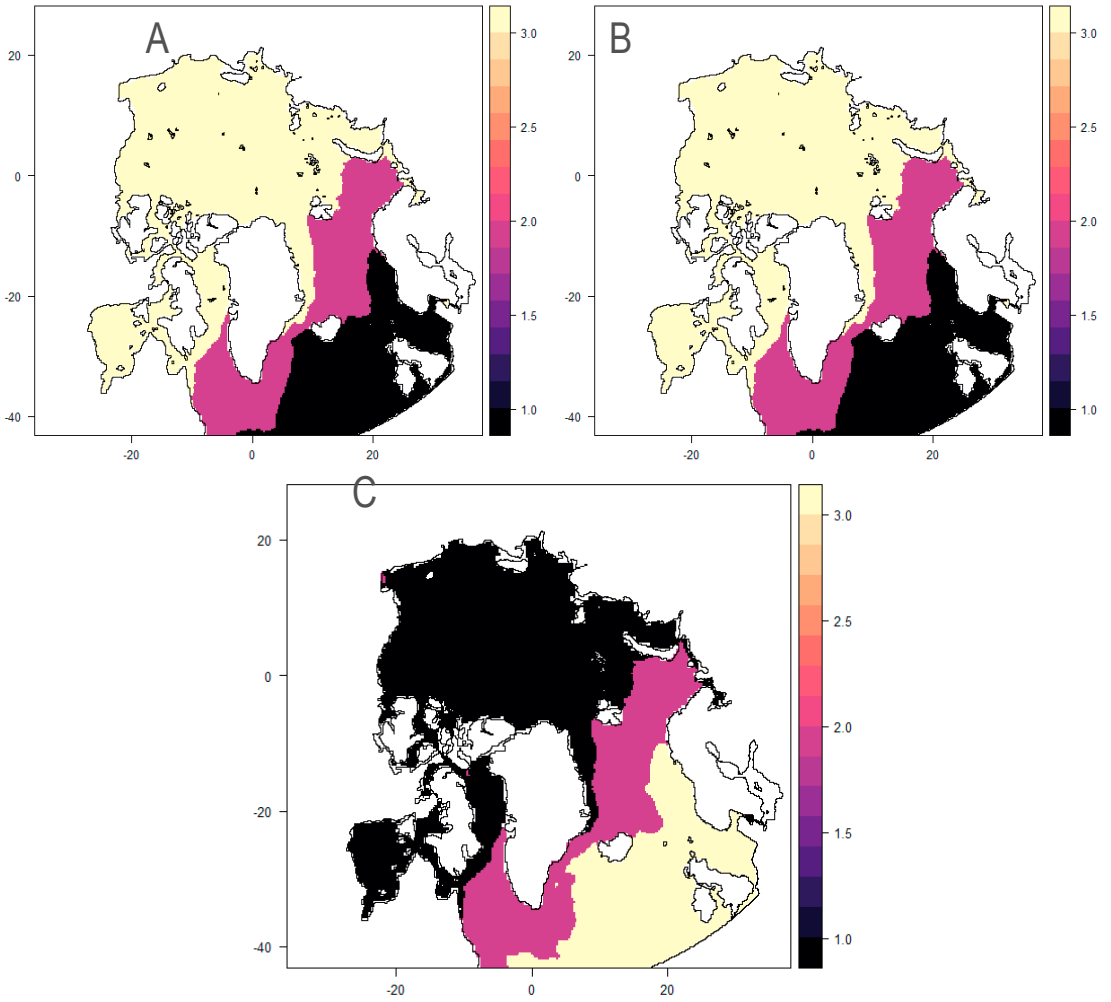

Fig. 2. Spatial zonation of Arctic Ocean in 2007 (A), 2012 (B) and 2017 (C).

In 2007-2012 period (Figure 2B) there weren't any significant changes. Mainly, impact from different environmental variables was the same as in previous years. Small fluctuations in zones areas weren't big and likely explained by climatic variations.

In 2012-2017 period we can see significant changes in ecosystem of Arctic Ocean. This traced in changing of different environmental variables impact level in 1-st and 3-rd zones, because of what they're changing places. Since analysis of multiyear changings of temperature, salinity and se ice cover doesn't shows any significant changes

(Figure 1C), thus we think that the main drivers of this process are environmental variables, such as increasing level of phosphates and nitrates, phytoplankton and zooplankton biomass and level of net primary production. Due to the fact, that sources of this factors are intensification of human impact, we this that the main cause of Arctic Ocean ecosystem changes in last years was human impact.

4. Conclusion

Thus, this approach shows good results in analyzing Arctic Ocean ecosystem structure. Bayesian networks helps to understand temporal changes in ecosystem structure and main drivers of this changes. Main drivers of this changes generally occur from human activity in this region. In last years, level of anthropogenic impact significantly increased, large number of territories was turned into agricultural lands, this leads to increase in number of biogenic substances falls into Arctic waters.

Spatio-temporal analysis shows very significant changes in last 10 years. Despite the fact, that spatially areas of different zones in Arctic Ocean doesn't change, qualitative changes here look major. The same as ecosystem structure, the main cause of spatio-temporal changes mainly caused by human impact.

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