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SHORT COMMUNICATIONS

Impact of Biotic and Abiotic Factors on Epibiotic Communities of the Barents Sea Red King Crab

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Abstract—Based on a long-term dataset of species composition and infestation levels of associated organisms on the invasive Barents Sea red king crab, a multivariate analysis was conducted to determine the contributions of biotic and abiotic factors to the fouling community structure. Results indicate that host size and exoskeleton age were the most significant factors for diversity indices and infestation intensity. Abiotic factors played a lesser role in the formation of fouling communities. Temperature conditions during the mass molting periods were found to have significant effects, apparently acting as a trigger for the primary settlement of crab shells by benthic organisms. Our data not only provide new insights into the formation of fouling communities of decapod crustaceans, but also provide valuable information for further studies on the adaptation process of the red crab to the conditions of the Barents Sea.

Keywords: red king crab, Barents Sea, epibionts, multifactor analysis

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INTRODUCTION

The introduction of non-native species into new habitats is considered one of the most significant threats to the biological diversity of recipient ecosystems because such introductions often lead to serious disruptions in established interspecific relationships, which can trigger cascading changes resulting in ecosystem degradation (Alimov and Bogutskaya, 2004). In addition to uncontrolled distributions of invading species, deliberate introductions of commercially important species also occur with the aim of achieving economic objectives. One example is the transoceanic transplantation of the red king crab into the Barents Sea, which resulted in the establishment of a new self-sustaining population, contributing to stable landings (Kuzmin and Gudimova, 2002). Catch rates for the crab are steadily increasing, approaching levels observed in its native range in the Sea of Okhotsk (Dvoretsky, V.G. and Dvoretsky, A.G., 2022).

The assessment of the ecological consequences of the red king crab introduction remains a prominent concern in modern scientific research. As this species occupies a top position in the local benthic food web, its feeding activity is presumed to directly affect benthic community structure. Some previous studies have confirmed this hypothesis, documenting decreased species diversity and simplification of benthic communities following the introduction (Pavlova, 2008, 2011; Pavlova and Dvoretsky, 2022). However, a time-series analysis has demonstrated that the population dynamics and abundance of traditional fishery species, including both fish and shellfish, were not linked to this introduction. This provides evidence that the overall ecosystem productivity remained unaffected (Dvoretsky, A.G. and Dvoretsky, V.G., 2015a, 2015b).

In addition to trophic interactions, non-native organisms can form symbiotic relationships with indigenous host species. Investigating this phenomenon can provide valuable insights into the adaptation processes occurring between introduced and local fauna. Moreover, studies of epibiotic interactions involving decapod hosts may reveal new information on biodiversity and its dynamics in marine ecosystems (Williams and McDermott, 2004; Dvoretsky, V.G. and Dvoretsky, A.G., 2021). Over the past two decades, many aspects of the symbiotic relationships between red king crabs and native benthic organisms have been extensively studied, including the species composition and infestation rates (Dvoretsky, A.G. and Dvoretsky, V.G., 2009a, 2009b, 2011, 2013a; Dvoretsky, V.G. and Dvoretsky, A.G., 2024). However, the role of environmental drivers, especially abiotic factors affecting the colonization of red king crabs by their symbionts, remains less understood and warrants further research.

The aim of this study is to evaluate the contribution of environmental factors to the biodiversity of epibiotic communities on red king crabs and the infestation rates of common symbionts.

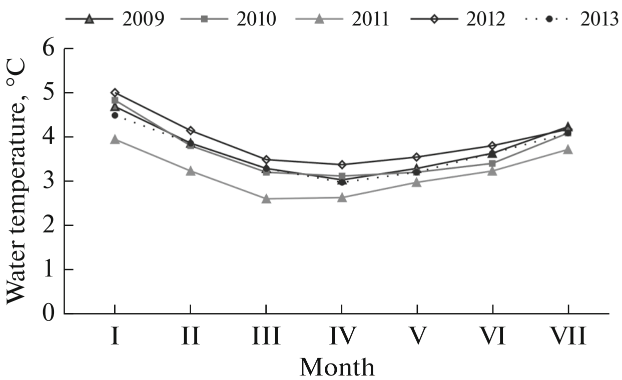

Fig. 1. Water temperature of the coastal branch of the Murmansk Current in January–July 2009–2013 (Karsakov et al., 2022).

MATERIALS AND METHODS

For this study, we used a dataset containing the species composition and infestation indices of epibionts on red king crabs collected during coastal expeditions by the MMBI RAS on the Eastern Murman coast over a five-year period from 2009 to 2013 (Dvoretsky, A.G. and Dvoretsky, V.G., 2013b, 2013c, 2016, 2018, 2019).

For each crab, we calculated standard infestation indices: prevalence of infestation (the proportion of crabs colonized by a symbiotic species, %) and intensity of infestation (the number of associated specimens per colonized host). The latter index was not determined for colonial animal and algal species.

Biodiversity indices included species richness (SR, number of species) and the Shannon index (Magurran, 1988). In order to approximate expected species richness based on the observed data, we calculated the Chao1 and Chao2 indices (Chao, 1984, 1987; Colwell and Coddington, 1994).

Among the factors that may potentially shape the epibiotic communities of red king crabs (independent variables), we took into account crab size (CL, carapace length in mm), exoskeleton age (EA, assessed visually per the scale proposed by Kuzmin and Gudimova (2002) for molting stages), sex (SM—males, SF—females), sampling depth (H, m), injury rate (IR, number of injured legs that were either missing or regenerating), water temperature at sampling (T0, °C), water temperature of the coastal branch of the Murmansk Current at 50–200 m depth from January to July of the corresponding year (T1–T7, °C), and annual water temperature (TA, °C) obtained from the monograph by Karsakov et al. (2022).

To assess the relative importance of environmental factors influencing the composition of epibiotic communities, we used redundancy analysis (RDA) with two matrices containing dependent variables. One matrix encompassed the mean intensity of infestation for non-colonial species (log-transformed data), while the other included biodiversity indices calculated for the entire dataset. We conducted a Monte Carlo permutation test to elucidate the explanatory variables that contributed the most to the total variation and to ascertain their significance. These statistical analyses were performed using the software packages NCSS PASS 2004, PAST 4.11, and CANOCO 4.5. Mean values are presented with standard errors.

RESULTS AND DISCUSSION

In total, 388 red king crabs were examined during the study period (62, 133, 77, 58, and 58 individuals in 2009 to 2013, respectively). The carapace length ranged from 23.3 to 171.5 mm. There was a decreasing trend in the number of small-sized crabs, with mean crab size tending to increase from 79.7 mm in 2009 to 119.4 mm in 2013. The proportion of crabs with older exoskeletons also increased. Females dominated the total catch at a 2 : 1 ratio, reflecting the general migratory behavior patterns of the different sexes (Kuzmin and Gudimova, 2002). The local red king crab population demonstrated a trend toward aging, aligning with overall patterns across the entire Barents Sea population during the replacement of one generation by another (Bizikov et al., 2018).

In terms of annual temperature, the minimum occurred in 2011 while the maximum was in 2012, reflecting variations in the heat content of water masses in the inshore zone of the Barents Sea (Karsakov et al., 2022).

Over the study period, infestation indices of common symbiotic and epibiotic groups showed an increasing pattern on their crab hosts (Table 1). The greatest infestation prevalence was found for amphipods, whereas the highest infestation intensity was registered for copepods. Earlier studies have shown that amphipods of the genus *Ischyrocrus* are abundant on the mouthparts of red king crabs (Dvoretsky, A.G. and Dvoretsky, V.G., 2009b) and can reproduce on the crab body, forming close symbiotic relationships (Dvoretsky and Dvoretsky, 2009a, 2011).

Copepods tend to colonize the gills of red king crabs in high numbers and are often preyed upon by larger symbionts (Dvoretsky, A.G. and Dvoretsky, V.G., 2013a). The mean intensity levels were also found to be high for sedentary polychaetes, which have been previously registered as epibionts of other decapod species (Williams and McDermott, 2004).

The total number of species per colonized host ranged from 1 to 23, averaging 4.8 ± 0.2. The Chao1 index ranged from 1 to 51, averaging 7.0 ± 0.6 species. The total observed number of species was 90, while the expected number based on the Chao2 index was 106 ± 9 species. Thus, our data appear to adequately reflect the actual species richness of the epibiotic communities on red king crabs. During the course of the research, there was a noticeable increase in the number of new species observed on red king crabs, result-

Table 1. Dynamics of infestation indices on red king crabs from the Eastern Murman coast during the summer periods of 2009–2013

Taxa group	Prevalence, %					Mean intensity, ind. per crab				
	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
Algae $n = 4$	–	–	–	–	13.8	–	–	–	–	–
Hydrozoa $n = 8$	8.1	11.3	7.8	12.1	25.9	–	–	–	–	–
Nemertea $n = 2$	9.7	4.5	6.5	8.6	10.3	8.5	4.5	1.8	4.2	2.2
Polychaeta (Sedentaria) $n = 7$	8.1	3.8	5.2	5.2	15.5	9.6	1.0	7.0	55.3	64.8
Polychaeta (Errantia) $n = 5$	6.5	9.0	7.8	19.0	29.3	1.3	1.1	1.2	1.9	3.4
Hirudinea $n = 3$	6.5	14.3	36.4	24.1	13.8	1.3	1.5	2.3	2.1	1.4
Gastropoda $n = 4$	3.2	2.3	7.8	6.9	15.5	1.0	1.0	1.0	1.3	2.0
Bivalvia $n = 5$	12.9	14.3	2.6	8.6	43.1	2.8	2.4	1.0	10.4	4.1
Copepoda $n = 23$	33.9	38.3	84.4	75.9	82.8	225.3	26.2	37.0	103.0	257.6
Amphipoda $n = 7$	58.1	72.9	87.0	84.5	81.0	51.7	44.2	70.3	70.4	87.7
Cirripedia $n = 3$	3.2	27.8	16.9	1.7	20.7	1.5	3.9	6.9	1.0	3.3
Echinodermata $n = 3$	–	1.5	1.3	1.7	1.7	–	1.0	1.0	1.0	1.0
Bryozoa $n = 8$	12.9	9.0	3.9	10.3	15.5	–	–	–	–	–
Others $n = 8$	–	–	7.8	3.4	8.6	–	–	1.0	1.0	1.0

n—number of species in each group.

ing in elevated biodiversity indices for these communities (Fig. 2).

In particular, algal species were first registered as epibionts in 2013. Notably, algae usually colonize herbivorous crab species (Kuznetsov, 1964; Firstater et al., 2009); their presence on the large predatory red king crabs was likely facilitated by favorable settlement conditions during periods of significant influxes of warm Atlantic waters.

For infestation intensity, the test of canonical axes indicated a significant model explaining 66.9% of total variation ($F = 75.65$, $p = 0.001$). The first ordination axis showed the strongest negative correlation with crab size, while the second axis was most closely associated with exoskeleton age and June water temperature (Fig. 3a). The first and second axes explained 63.1 and 2.5% of the total variation, respectively.

For infestation indices, the RDA model was also significant, explaining 55.9% of the total variation ($F = 47.72$, $p = 0.001$). The first axis accounted for 55.6% of the total variance and had positive correlations with both size and exoskeleton age data (Fig. 3b), while the same factors also demonstrated strong correlations with the second axis.

A Monte Carlo permutation test revealed five factors that significantly explained the observed variations in the mean intensity of red king crab epibionts. Specifically, crab size made the largest contribution to the model (59%) followed by exoskeleton age (3%), and temperatures in January (3%), June (1%), and February (0.5%). For biodiversity indices, a total of eight significant factors were identified, with crab size (35%), exoskeleton age (13%), and water temperature in March (3%) being the biggest contributors, while crab sex and temperatures in January, July, annual

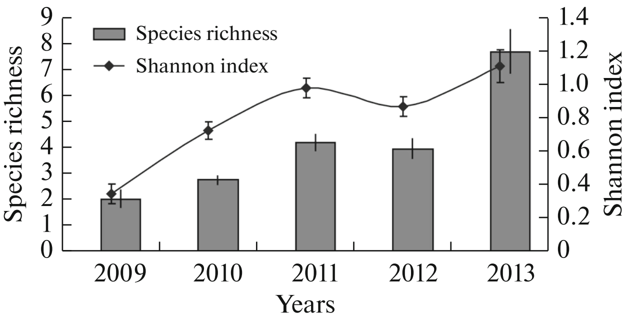

Fig. 2. Dynamics of biodiversity indices of red king crab epibiotic communities on the Eastern Murman coast during the summers of 2009–2013. Mean values calculated per infested host are presented with standard errors.

water temperature, and water temperature at sampling each contributed 1%.

Regarding biotic factors, we obtained the expected results: crab size had a direct effect on both infestation indices and biodiversity of epibiotic communities, with older shells resulting in more diverse communities. A direct relationship between crab size and infestation intensity has been reported for most symbiotic associations worldwide (Williams and McDermott, 2004; Fernandez-Leborans, 2010). Molting frequency is also known to directly affect the number of epibionts, with older exoskeletons potentially carrying multiple generations of epibiotic species. This process may be facilitated by the crabs' active migrations to different habitats, increasing their chances of being colonized by local species (Talberg, 2005).

For the first time, we documented the role of temperature conditions in establishing red king crab epibiosis. Temperatures in January and March were found to be the most important factors shaping epibiotic communities. This aligns with the periods of mass molting occurring in January for large male crabs and March for females (Kuzmin and Gudimova, 2002). Water temperature can play a key role for organisms reproducing via planktonic larvae, as their survival directly depends on the heat content of water masses. This influences both current velocities (Matishov et al., 2009) and distributions of pelagic larvae (Bhaud et al., 1995; Dvoretsky, V.G. and Dvoretsky, A.G., 2022). The close relationship between water temperature and infestation intensity of species with planktonic larvae is well illustrated by the proximity of corresponding vectors in the ordination plot (Fig. 3a).

In conclusion, the epibiotic communities of the red king crab comprise a dynamic system shaped not only by host characteristics but also by temperature conditions. This allows their use as environmental indicators and a means of tracking crab adaptation and expansion within the Barents Sea ecosystem (Dvoretsky, V.G. and Dvoretsky, A.G., 2021).

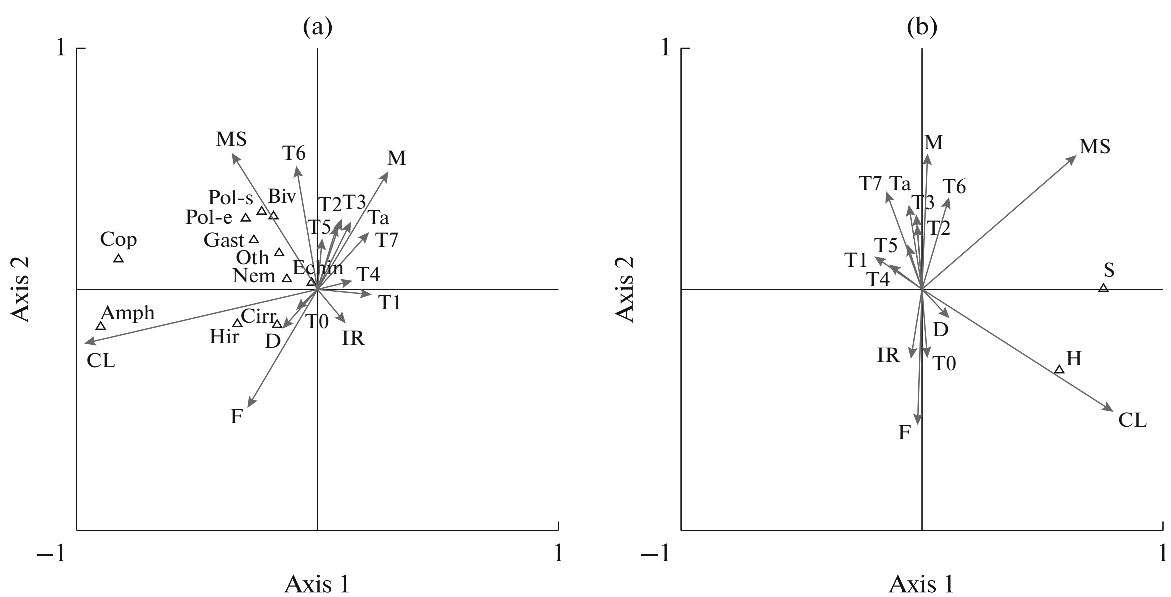

Fig. 3. Ordination plots, showing relationships between environmental factors and mean infestation intensities of red king crabs (a) and biodiversity indices of epibiotic communities (b). Independent variables: CL—carapace length, MS—molting stage (exoskeleton age), M—males, F—females, D—sampling depth, IR—leg injury rate, T0—temperature at sampling, T1–T7—water temperature of the coastal branch of the Murmansk current in the 50–200 m layer from January to July, Ta—annual water temperature. Dependent variables (infestation intensities): Nem—Nemertea, Pol-s—Polychaeta (Sedentaria), Pol-e—Polychaeta (Errantia), Hir—Hirudinea, Gast—Gastropoda, Biv—Bivalvia, Cop—Copepoda, Amph—Amphipoda, Cirr—Cirripedia, Echin—Echinodermata, Oth—Others. S—number of species, H—Shannon index.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All applicable international and Russian institutional principles for the use of animals were followed (MMBI Act 188-1252/14, December 19, 2023).

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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