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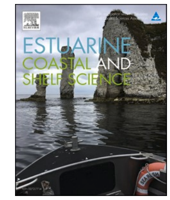

Community science approach reveals temporal and eutrophication-related spatial patterns in bladderwrack-associated invertebrate fauna

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ABSTRACT

Coastal zones are affected by a variety of anthropogenic drivers. While scientific assessments of the large-scale impacts are often insufficient due to limited resources, community science approaches (i.e. engaging voluntary participation by the general public in scientific research) may allow studying processes on larger geographic and/or temporal scales. In this study, a community science campaign was launched to assess geographic and temporal patterns in subtidal bladderwrack (*Fucus vesiculosus*) -associated invertebrate fauna along the coastal eutrophication gradient of the Finnish Baltic Sea coast in 2020–2021. The data collected by the community scientists were quality-controlled and generally similar to scientist-collected data. However, most taxa had somewhat lower abundances than data collected with another, more established sampling method. The community composition of fauna differed between areas with varying eutrophication status, and the total abundances of fauna were highest in the areas with the lowest eutrophication impacts. The data also revealed spatial and temporal patterns of individual taxa. For example, the abundance of blue mussel (*Mytilus edulis*) was highest in less eutrophied areas, while the abundance of non-indigenous Harris mud crab (*Rhithropanopeus harrisii*) was highest in the areas with moderate eutrophication impacts. A two-fold increase in the abundance of isopods that graze on bladderwrack was observed between the study years, indicating a sizeable temporal variation in bladderwrack grazing pressure. The study provides novel information on bladderwrack-associated invertebrate fauna and the applicability of using community science in marine subtidal research. The results suggest that community science is an effective approach to assessing subtidal community-level patterns, and its continued use is recommended to complement data collection across large spatial and temporal scales in marine key habitats.

1. Introduction

Eutrophication and other anthropogenic drivers affect coastal ecosystems globally (Smith et al., 2006). Eutrophication may, for example, increase the growth of microalgae and ephemeral macroalgae (Smith et al., 2006), decrease perennial macrophyte cover (Bonsdorff et al., 1997), modify predator-prey interactions (Ortega et al., 2020) and cause hypoxic dead zones (Diaz and Rosenberg, 2008). Monitoring the impacts of such extensive effects on biota is challenging, especially as these may vary spatially and temporally (Salo and Salovius-Laurén, 2022).

While the accumulation of human activities in the coastal regions has led to many negative ecological impacts, the large number of people in coastal areas may simultaneously act as a resource for research. Public participation in scientific research, i.e., community science, has become increasingly common in recent decades (Dickinson et al., 2010; Garcia-Soto et al., 2021). The possibilities of application are vast (for example Dickinson et al., 2010; Wiggins and Crowston, 2011; Garcia-Soto et al., 2021), and the benefits of community science in ecological research lie in understanding processes on larger geographic and temporal scales, which is difficult and expensive to achieve with traditional research methods. While community science approaches have become more common, research on marine environments remains underrepresented in community science publications (Sandahl and Tøttrup, 2020). Globally, in the marine environment, volunteers have helped in research related to, for example, shorebirds, marine mammals, fish, molluscs, mangroves, corals, seagrasses, and marine litter (Thiel et al., 2014; Sandahl and Tøttrup, 2020).

Bladderwrack (*Fucus vesiculosus*) is a key species providing various ecosystem functions and services on the rocky, non-tidal shores of the Baltic Sea. In the Baltic Sea, bladderwrack occurs subtidally, mainly in

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<3 m depths. As a large and perennial macroalgae, it forms habitats for many invertebrate and fish species, providing food and refuge from predators and waves (Kautsky et al., 1992; Wikström and Kautsky, 2007; Henseler et al., 2019). Bladderwrack-associated invertebrate communities comprise amphipods, isopods, bivalves, gastropods, and insect larvae (Henseler et al., 2019; Rinne et al., 2022). These invertebrates form a crucial link between lower and higher trophic levels in coastal ecosystems by transferring energy from primary producers to secondary consumers. The geographic distribution of bladderwrack in the Northern Baltic Sea is limited by the low salinity (to salinities above approximately 3; Schagerström, 2013). However, in 1980's bladderwrack decreased drastically within its distribution area due to eutrophication (Kangas et al., 1982; Rönnberg et al., 1985). Although bladderwrack has returned to many places, reduced water transparency caused by eutrophication still restricts its depth distribution (Snickars et al., 2014; Rinne and Salovius-Laurén, 2020). While the effects of eutrophication on bladderwrack occurrence are well known (Snickars et al., 2014; Rinne and Salovius-Laurén, 2020), information on geographic and temporal variation of bladderwrack-associated fauna is far from complete (but see Rinne et al., 2022; Salo et al., 2023 for spatial data).

In this study, a community science approach was used to collect data with extensive spatial and temporal coverage on bladderwrack-associated invertebrate communities. Bladderwrack is a well-known species among people who spend time on the coast. As its disappearance has been one of the symbols of eutrophication development in Finland, many people also recognise it as an indicator species that provides information on the ecological changes and the state of the Baltic Sea (pers. obs.). This, together with the wide distribution of bladderwrack and the need for large-scale data on invertebrates it hosts, makes the species a suitable organism for a community science study. The main aims of the study were (1) to test the applicability of community science in subtidal marine ecological research and (2) to assess temporal and eutrophication-related spatial variation in bladderwrack-associated invertebrate communities along the Finnish Baltic Sea coast.

2. Material and methods

2.1. The study area

The distribution of bladderwrack covers a large part of the Finnish Baltic Sea coast from the northern Bothnian Sea (Kvarken) to the Archipelago Sea, the Åland Islands, and the Gulf of Finland (Finnish Inventory Programme for the Underwater Marine Diversity, Fig. 1). The community science campaign covered all these areas. Still, most advertising efforts occurred in the southwestern archipelago areas, where participation was highest. Therefore, the control data (see below) were also collected mainly in this area (Fig. 1). It is noteworthy that almost half of the Finnish population lives within 20 km of the Baltic Sea, and the coast and archipelagos are important recreational areas. For example, recreational boating is popular, and the coastal region has a high density of summer houses.

2.2. The community science approach

The community science campaign was launched in June 2020 and ended in October 2021. In 2019, a simple method was developed to assess the number of invertebrates within a bladderwrack thallus. A small group (approximately ten people) of non-scientists from different age groups and educational backgrounds were asked to give feedback, for example, on the workflow, the provided support material, and the time used. The equipment needed for participation consisted of items commonly found at home, summer houses, or recreational boats. The final workflow consisted of (1) collecting a single bladderwrack thallus, (2) loosening the invertebrates hiding in the thallus by shaking it over an

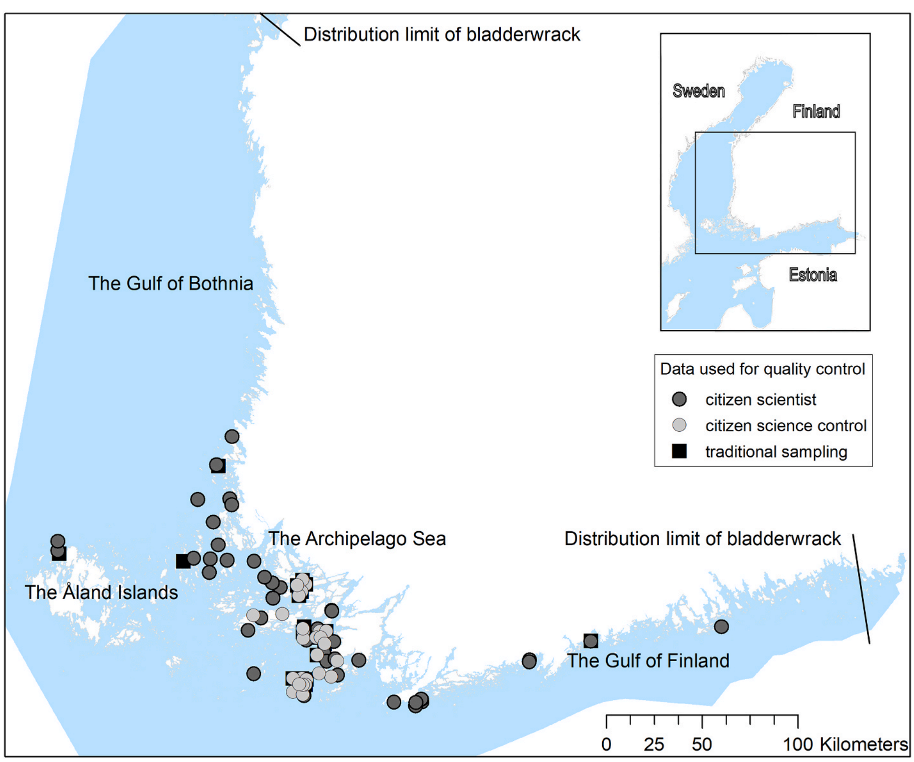

Fig. 1. Map indicating the samples used in comparisons for the sampler identity (community scientists [dark grey circles] *vs* scientists using the community science method [light grey circles]) and method (community science sampling method [all circles] *vs* "traditional" sampling method" [black squares]). Only community science data originating from the same or nearby area than the black squares were included in the analysis comparing methods. All data are from 2020. The black lines indicate the northern and eastern distribution limits of bladderwrack in the Baltic Sea. The smaller map illustrates the location of the study area in the Northern Baltic Sea.

empty bucket or container, (3) identifying all invertebrates and counting the number of individuals within each identified taxa, and (4) measuring the length of the bladderwrack individual or taking a picture of it next to an everyday object with known size (for example a matchbox or a soda can). The participants were asked to report the abundances of all observed invertebrate taxa, the bladderwrack length, the sampling date, and the exact location. The reporting was done through either e-mail, SMS, or WhatsApp. Species identification material was provided on the project website in local languages. When requested, the participants also received assistance with the identification through the above-mentioned reporting channels. Due to the European Union General Data Protection Regulation (GDPR), no background data on the participants were collected.

People were encouraged to participate in the campaign by spreading information about the project through media, social media posts with images and videos, posters in the archipelago, science pop-up events, and virtual and on-site primary school visits. Also, a short documentary film was made and shown during visits to raise interest in fauna occurring within bladderwrack belts. Various outreach methods were selected to target audiences of different ages and socioeconomic groups. In the on-site events, hand-outs with species identification material and a data collection sheet, where the needed parameters could easily be noted, were given to people. The COVID-19 pandemic limited the planned engagement of the public to some extent; for example, the on-site school visits were limited during the spring of 2020. Most of these outreach activities were conducted as a part of larger educational projects that targeted increasing Baltic Sea knowledge among people of all ages. Thus, the primary purpose of many activities (for example school visits and pop-up events) was not to increase data collection but to provoke interest in bladderwrack and other important Baltic Sea habitats.

2.3. The effectiveness of the community science approach

To assess the quality of the data collected by the community scientists, data were collected by scientists using the same sampling method. This data ($n = 32$) was collected in the Archipelago Sea area and the southern Gulf of Bothnia in July 2020 (Fig. 1). This data was then compared to the data collected by community scientists ($n = 59$) during the campaign in June–August 2020 (Fig. 1). These datasets had somewhat different geographic spread, with the community scientist data covering a larger area (Fig. 1).

To evaluate the potential differences in fauna collected with the community science method and a traditional sampling method, the community science data and data collected by Rinne et al. (2022) were compared. The samples collected by Rinne et al. (2022) were collected by placing a mesh bag over the thallus when the algae was still attached, closing the bag tightly around the holdfast and cutting the thallus loose from the substrate. The fauna was then detached and analysed in the laboratory (for a more detailed description of the method, see Rinne et al., 2022). To decrease variation unrelated to the sampling method, only data with samples from the same or nearby locations (<5.6 km distance) with both methods were included. This resulted in a data set with 21 community science data points collected between June 21 – August 27, 2020, and 22 data points collected with the traditional sampling method collected during July 2020. Most of the data originated from the Archipelago Sea area, but also data points from the Åland Islands, the Gulf of Finland and the southern Gulf of Bothnia were included (Fig. 1).

2.4. Eutrophication-related spatial variation

The Baltic Sea-wide eutrophication influences the study area. Eutrophication effects (nitrogen and phosphorous concentrations and turbidity) increase towards the mainland and are high especially near the river discharge areas (for example Bonsdorff et al., 1997; Carstensen et al., 2020; Salo and Salovius-Laurén, 2022). To assess how the spatial eutrophication gradient relates to the variation in bladderwrack-associated fauna, the study area was divided into three eutrophication status classes: good, moderate, and poor. The division was based on a Secchi depth model developed within the Finnish Inventory Programme for Underwater Marine Diversity (Lappalainen et al., 2019). The model is based on MERIS satellite sensor data (300 m resolution) and presents June–August averages from 2003 to 2011. The class boundaries were set based on status class threshold values defined for the EU Water Framework Directive (WFD) related assessments: <2.9 m for poor, 2.9–4.6m for moderate, and >4.6 m for good status. As the study area covers several WFD assessment areas geographically, each with slightly different status class threshold values, the average of class boundaries from six WFD areas was used to define the class boundaries for this study.

2.5. Data analyses

As some community scientists identified the taxa at a higher taxonomic level than others (for example taxa identified as gastropods instead of a specific gastropod species), all faunal data was grouped into higher taxonomic groups for the community analyses. This simultaneously decreased the risk of misidentification at the species or family level. The following taxonomic groupings were used: prawns and shrimps, Harris mud crab (*Rhithropanopeus harrisii*, i.e., the only abundant crab species in the study area), amphipods, isopods, gastropods, bivalves, insects, and balanoids. The abundances of a common and easily identified species, the blue mussel (*Mytilus edulis*, bivalve), were also analysed separately in univariate analyses. The abundance of invertebrate individuals is known to vary with the thallus size of the algae (Schagerström et al., 2014). Thus, to compare the abundances in different-sized algae, the size-to-wet weight (WW) ratio of bladderwrack was calculated using linear regression on bladderwrack thallus length and wet weight data from 404 individual thallus (data from Rinne et al., 2022 and unpublished data). The WW of a thallus was estimated to be 5.939x-44.53, where x is the length (cm) of that specific thallus ($R^2 = 0.3$, $p > 0.0001$, Fig. S1).

All statistical analyses were conducted in PRIMER 6. The univariate and multivariate permutational analyses (total abundances and abundance of individual taxa) were conducted using PERMANOVA. Nonmetric multidimensional scaling plots (nMDS) and similarity percentage analysis (SIMPER) were used to illustrate and analyse potential differences in community composition. The resemblance matrixes were based on Bray-Curtis similarities on square root transformed data, and 9999 permutations were run. Dispersion of the data was inspected visually using nMDS plots and running PERMDISP analyses. The potential differences between samples from scientists and community scientists were estimated in a model with the sampler (community scientist or scientist) as a fixed factor. The sampling methods were compared in a model with the method (community science method or traditional method) as a fixed factor. Finally, to assess the spatial and temporal variation of bladderwrack-associated invertebrate fauna, analyses were run with the eutrophication status (good, moderate, or poor) and year (2020 or 2021) as fixed factors. Both factors and their interaction were included in the univariate analyses, while multivariate analyses were run separately for each factor.

3. Results

3.1. The effectiveness of the community science approach

The community science campaign reached people well. In total, 5016 unique visitors visited the campaign web pages during the campaign. 93.5 % of the visitors visited the websites during June–August, with the highest visitor peaks (max. 323 per day) taking place after media coverage. Most visitors (73.8%) followed a social media link to the page, while a substantial part of the visitors (22.7%) used the website address or a search engine to locate the site. The average session duration was 6 min 20 sec. 76% of the visits were done by using a mobile phone.

In total, the community scientists reported data from 151 bladderwrack-associated fauna communities. Thirty-five observations were from good, 84 from moderate, and 47 from poor eutrophication status class areas (Fig. 2). 15 (9.9%) failed to report some of the required information and were disqualified from further analyses. The remaining data consisted of 61 observations from 2020 to 75 from 2021. The geographic coverage was highest in samples from intermediate and poor eutrophication status classes and lowest in the good eutrophication status class (Fig. 2).

Whether scientists or community scientists had collected the data had no impact on the community compositions of fauna when the same sampling method was used (Pseudo-$F_{1,89} = 0.34$, $p = 0.88$, Fig. 3a). This suggests that the community scientists succeeded in the sampling and taxa identification at the higher taxonomic level well. The data was thus estimated to fulfil the requirements to assess temporal and eutrophication-related spatial patterns.

However, the community composition differed between the samples collected with the community science sampling method and the traditional sampling method (Pseudo-$F_{1,41} = 6.34$, $p < 0.001$, Fig. 3b). The differences depended on lower abundances of especially amphipods, gastropods, bivalves, and isopods in the samples collected with the community science sampling method compared to the traditional sampling method (SIMPER). Interestingly, Harris mud crab was more abundant in the samples collected with the community science method (Fig. 3b).

3.2. *Temporal and eutrophication-related spatial variation in invertebrate communities*

Community composition of fauna collected with the community science method differed between the areas with different eutrophication status (Pseudo-$F_{2,160} = 6.68$, $p < 0.001$, Fig. 4). However, the multivariate data dispersion for eutrophication status differed (PERMDISP $p = 0.015$), with lowest dispersion in the good status areas. This heterogeneous data dispersion may have contributed to the observed difference in community compositions. The composition did not differ between the study years (Pseudo-$F_{1,160} = 1.50$, $p = 0.19$), and the interaction between year and area was non-significant (Pseudo-$F_{2,160} = 0.92$, $p = 0.53$). The average dissimilarity between communities in different eutrophication status areas (good, moderate, and poor) was highest (62.2) between communities in areas with poor and moderate status and lowest (59.4) between communities in areas with moderate and good eutrophication status. The dissimilarity between communities in areas with good and poor eutrophication status was 60.6. Abundances of amphipods, gastropods, isopods, and bivalves contributed most to the observed differences.

The total abundance of fauna differed between the eutrophication status areas (Table 1). Pairwise comparisons revealed that this was due to differences between the fauna in good vs poor and moderate status classes ($t = 2.44$, $p = 0.016$ and $t = 2.32$, $p = 0.011$, respectively, Fig. 5a). The total abundances did not differ between the study years, and the interaction between year and area was non-significant (Table 1).

Abundances of isopods were similar across eutrophication status areas but differed between years (Table 1, Fig. 5b), with approximately two-fold higher abundances in the latter study year. However, the data dispersion was not homogenous across the two years, which might contribute to the observed differences. Abundances of amphipods differed across eutrophication status areas (Table 1) and were higher in moderate status compared to poor status areas ($t = 2.35$, $p = 0.023$, Fig. 5c). Similarly, the abundances of Harris mud crabs also differed between eutrophication status areas (Table 1), with the highest abundances in the moderate status areas compared to good and poor areas ($t = 2.50$, $p = 0.008$ and $t = 2.12$, $p = 0.035$, respectively, Fig. 5d). However, the data dispersion was not homogenous across status areas, which may contribute to the observed differences. The abundance of amphipods and Harris mud crabs did not differ between years (Table 1). Shrimps and prawns had similar abundances across eutrophication status areas and years (Table 1, Fig. 5e). Gastropod abundances differed between eutrophication status areas (Table 1). Abundances were higher in the moderate status areas compared to good and poor status areas ($t = 7.03$, $p = 0.001$ and 2.04, $p = 0.039$, respectively) and higher in the

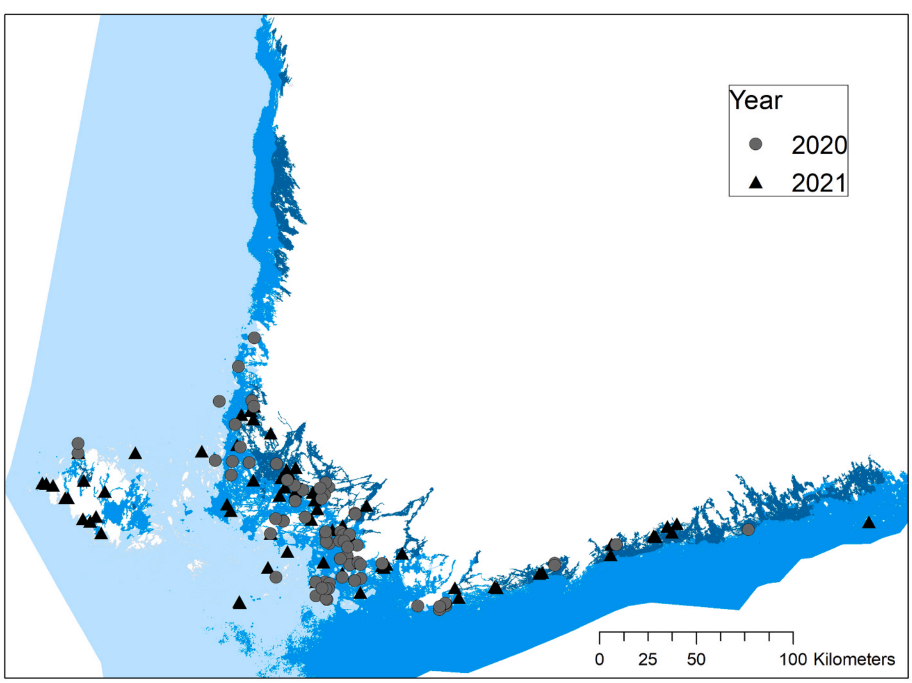

Fig. 2. Map indicating the geographical spread of the community science data in 2020 (grey circles) and 2021 (black triangles). The light, mid, and dark blue colours indicate areas with good, moderate, and poor eutrophication status classes, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

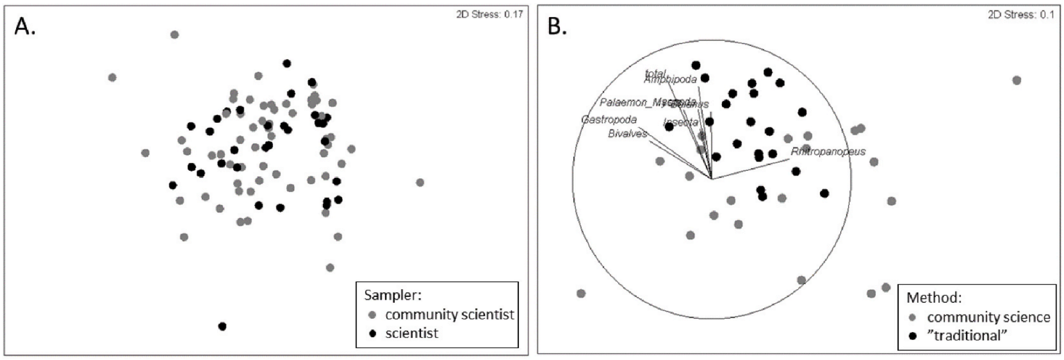

Fig. 3. nMDS based on community composition of bladderwrack-associated invertebrates for A. data quality control and B. method comparison. Data in A. is collected by community scientists (grey symbols) and scientists (black symbols) using the same method. Data in B. is collected using the community science method (grey symbols) and the "traditional" fauna sampling method (black symbols). The vector overlay indicates how different taxa (correlation >0.2) relate to the samples. Data are square root transformed.

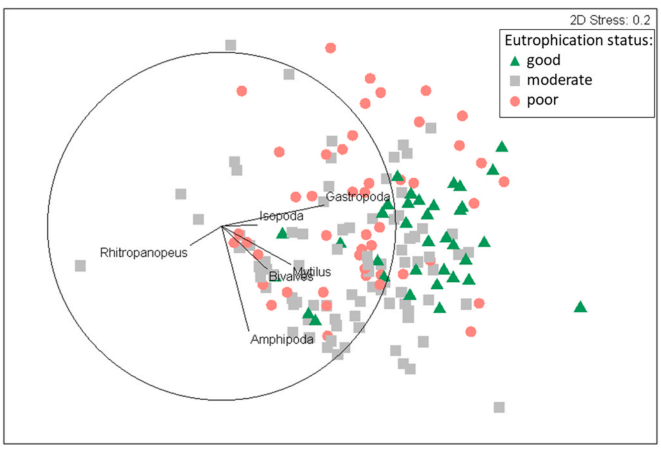

Fig. 4. nMDS based on community composition of bladderwrack-associated invertebrates originating from different eutrophication status areas (green triangles indicate good, grey squares indicate moderate and red circles indicate poor eutrophication status) and collected with the community science method. Data are square root transformed. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

good status compared to the poor status area ($t = 3.41$, $p = 0.003$, Fig. 5f). The data dispersion was however heterogeneous for status areas, potentially contributing to the significance. While bivalves had similar abundances across eutrophication status areas and time (Table 1, Fig. 5g), the abundances of one bivalve species, blue mussel, differed between eutrophication status areas (Table 1). Specifically, the abundances of blue mussels were higher in the good status areas compared to moderate and poor status areas ($t = 1.76$, $p = 0.08$ and $t = 2.32$, $p = 0.016$, respectively, Fig. 5h). The blue mussel abundances were similar across the years.

4. Discussion

Anthropogenic drivers extensively modify coastal ecosystems. As the impacts may affect all the ecosystem components to different degrees, assessing the multitude of effects through regular monitoring activities is challenging. Within the Baltic Sea region, community science has been used, for example, in the evaluation of coastal fish stocks (Stottrup et al., 2018) or to complement the knowledge of distribution patterns in a non-indigenous species (Lehtiniemi et al., 2020), but generally, the use of community science as a method in Baltic Sea research is still rare. Here, the community science approach was tested to assess the spatial and temporal variation in subtidal bladderwrack-associated faunal communities. The resulting data were of high quality and had a better spatial spread than the data collected by scientists. Despite the lower taxonomic resolution compared to the traditional sampling method, the data revealed water-quality related patterns in faunal community composition and abundance of different taxa, as well as novel temporal changes in isopod abundances across large spatial scales. The results illustrate the applicability of the community science approach to assess

Table 1
Results from the PERMANOVA for the spatial (eutrophication status) and temporal (year) differences for the total abundance of invertebrate fauna and the abundance of different taxa. Significant results are bolded.

Source	df	MS	Pseudo-F	P (perm)
Total abundance				
eutroph.status	2	2002.90	3.304	**0.024**
year	1	45.56	0.075	0.943
ES x Y	2	85.73	0.141	0.967
residual	160	606.14		
Isopods				
eutroph.status	2	3.11	0.329	0.767
year	1	42.78	4.527	**0.027**
ES x Y	2	2.41	0.255	0.816
residual	160	9.45		
Amphipods				
eutroph.status	2	216.70	3.153	**0.042**
year	1	8.36	0.122	0.775
ES x Y	2	25.83	0.376	0.700
residual	160	68.74		
Harris mud crab				
eutroph.status	2	0.41	4.985	**0.011**
year	1	0.23	2.818	0.120
ES x Y	2	0.03	0.356	0.743
residual	160	0.08		
Shrimps and prawns				
eutroph.status	2	0.39	0.807	0.469
year	1	0.14	0.291	0.606
ES x Y	2	0.62	1.274	0.279
residual	160	0.49		
Gastropods				
eutroph.status	2	702.16	20.858	**0.0001**
year	1	40.61	1.206	0.274
ES x Y	2	36.92	1.097	0.343
residual	160	33.66		
Bivalves				
eutroph.status	2	7.57	0.234	0.910
year	1	6.29	0.195	0.696
ES x Y	2	32.20	0.997	0.383
residual	160	32.28		
Blue mussel				
eutroph.status	2	11.04	3.259	**0.036**
year	1	0.04	0.013	0.922
ES x Y	2	2.30	0.680	0.527
residual	160	3.39		

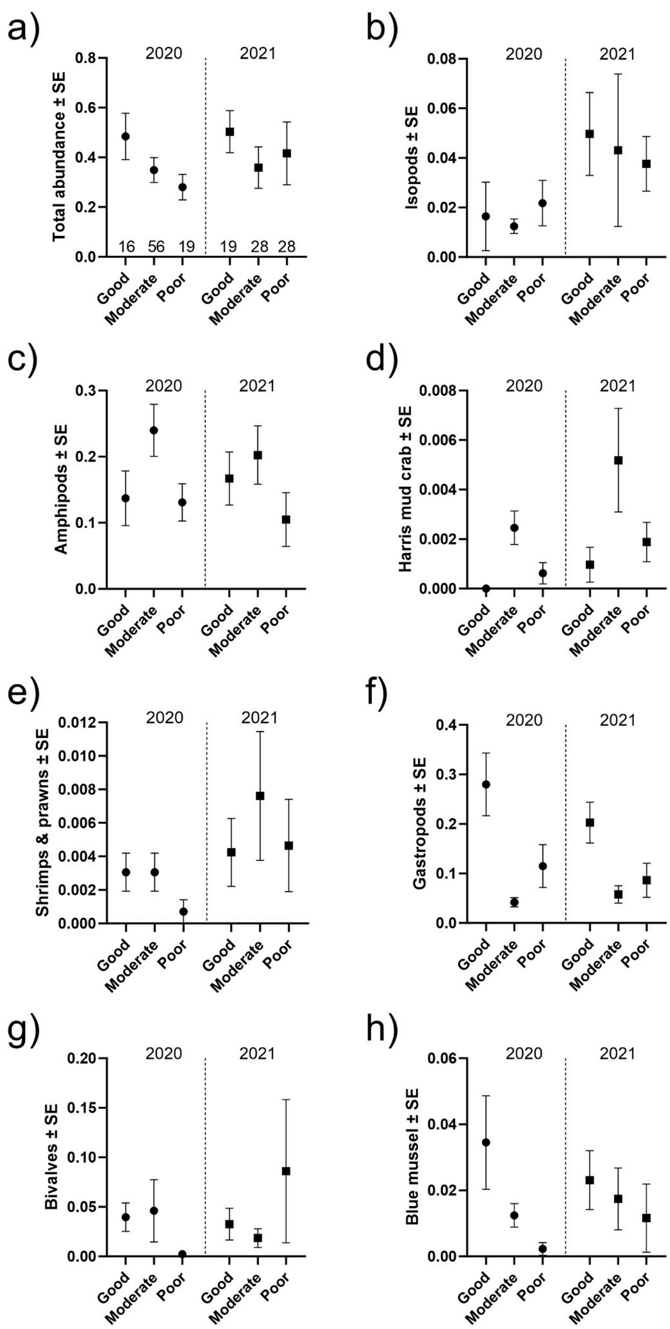

Fig. 5. Average ± SE abundances for a) all fauna, b) isopods, c) amphipods, d) Harris mud crab, e) shrimps and prawns, f) gastropods, g) bivalves, and h) blue mussels as individuals per g estimated wet weight of bladderwrack in good, moderate, and poor water qualities in 2020 (left columns) and 2021 (right columns). The numbers in a) indicate the number of samples for all variables in respective water quality class and year. Data were collected using the community science method.

novel community information across large spatial and temporal scales. The community science approach is a valuable tool to complement, for example, long-term monitoring efforts in subtidal habitats.

4.1. The effectiveness of the community science approach

Community science approaches usually include educational aspects, with community scientists gaining, for example, new knowledge and increased awareness (Garcia-Soto et al., 2021). Similarly, educational elements were also important in this project. The selected outreach activities reached many people from different age groups. While only approximately 3% of the unique website visits led to people reporting research observations, many of the community scientists, on their initiative, indicated that they had conducted the sampling together with one or more persons - often with their child/children, other family, friends, or colleagues (data not shown). Asking community scientists to indicate the number of people who participated in the sampling, their background, or some other additional information as part of the data reporting would allow more detailed analyses of the effectiveness of the campaign. However, finding the balance in the amount of information requested is tricky in community science - too many requests may reduce general participation, as indicated by the community scientists who helped to modify the sampling protocol in this study. Overall, the outreach activities reached thousands of people who got more familiar with the important bladderwrack habitats, the associated fauna, and the ecosystem services they provide.

Aside from the educational aspects, community science often aims to collect data that fulfils the quality requirements for scientific use. However, the data quality can vary to a great extent due to the differing skill sets and backgrounds of the community scientists. Although the proportion of observations that fulfil the quality requirements may vary, 95% of data usage may be reached in community science (Delaney et al., 2008). In the current study, the data quality was high as >90% of the data included all necessary information, and the community composition was similar to that of the control data (i.e., data collected by scientists using the same method). This was likely due to the lower taxonomic resolution than is commonly used in similar assessments (Rinne et al., 2022). Using higher taxonomic resolution would likely have increased the risk of misidentification of taxa, especially among the participants with lower pre-existing knowledge, despite the species identification material provided to all community scientists.

The method comparisons illustrated that the community science method catches partly different communities than “traditional” sampling. For example, some invertebrate individuals could potentially be lost during the sampling. In addition, counting and identifying small gastropods, bivalves and especially small, rapidly swimming taxa, such as amphipods and isopods, is more difficult in the field than in the laboratory. The community science approach may thus be especially suitable for collecting larger, slower-moving and easily identifiable taxa. However, the higher abundance of the non-indigenous Harris mud crab in the community science data suggests that the observed differences between the methods could also be due to partly different taxa compositions between the sampling locations. While the samples for these comparisons were always from nearby places, community scientists may have still sampled areas with somewhat higher anthropogenic impact than scientists. For example, shipping and recreational boating are likely vectors for non-indigenous species in the study area (Gagnon et al., 2022). Thus, the potentially non-random site selection of community scientists may contribute to the observed differences. Further, community scientists collected data from areas that do not allow sampling by scientists due to land use (private shores) or due to logistic challenges (more outspread sampling instead of sampling specific focus areas), which are also the known advantages of the approach (Dickinson et al., 2010).

4.2. Temporal and eutrophication-related spatial variation in invertebrate communities

The community science data illustrated changes in faunal communities with decreasing water quality, observed as a decrease in the total abundance of invertebrates and altered community composition along the coastal eutrophication gradient. The observed pattern was relatively similar but somewhat less distinct compared to the only existing large-scale study from the region (Rinne et al., 2022). The received data in the current study also shared other similar features to the scientist-collected data by Rinne et al. (2022): the variation in faunal communities was larger in the moderate and poor eutrophication status areas (i.e., in inner and mid archipelago) compared to the good status areas. This could indicate either that the strength of the eutrophication effects differs between regions and/or that some additional drivers are shaping the species and community composition distinctively in different areas.

While not all observed taxa patterns could be compared with earlier studies due to the lower data resolution in this study (i.e., the grouping of taxa at higher taxonomic level), the patterns of, for example, blue mussel and Harris mud crab abundances follow the patterns observed by Rinne et al. (2022) in the same region. Both studies observed blue mussel abundances declining with water quality and the highest abundances of Harris mud crabs in areas with moderate water quality (Rinne et al., 2022, this study). Such changes in community composition across large geographic scales may greatly impact the local and regional food webs. For example, blue mussels are an important food source for waterfowl, and the decreased blue mussel abundance has been suspected to contribute to lower clutch sizes of Baltic common eider (*Somateria mollissima*) in eutrophied areas (Hermansson et al., 2023). Further, the non-native Harris mud crab has been suspected to have drastically modified local invertebrate communities as it predates on, for example, isopods (Jormalainen et al., 2016; Rinne et al., 2022). Isopods, in turn, control the annual filamentous algae by grazing and reduce the negative impacts of filamentous algae on bladderwrack, such as competition for space and light (Jormalainen et al., 2016). The fact that an increase in one predator or decrease in one common prey species may result in large, potentially cascading effects emphasises the importance of invertebrate community data across large areas.

The community science data clearly illustrated yearly variation in isopods, with almost two-fold higher abundances in the second year of the study. Due to the need for more data on temporal variation in bladderwrack-associated fauna in the study region, it is unknown how much the isopod populations vary annually within and between areas. The isopod *Idotea balthica* is the primary grazer of bladderwrack in the area (Forslund et al., 2012; Leidenberger et al., 2012), and a mass occurrence of isopods and isopod grazing has been suggested as one of the potential reasons contributing to bladderwrack decline (Kangas et al., 1982; Rönnberg et al., 1985). When isopods are abundant, they may graze down the whole bladderwrack stand (Kangas et al., 1982; Enqvist et al., 2000; Nilsson et al., 2004), but on the other hand, they also benefit bladderwrack in interspecific competition (see above; Jormalainen et al., 2016). Although smaller-scale data on herbivore abundances exists (for example Korpinen et al., 2010), the lack of consistent large-scale data on invertebrate grazers along the coast makes it currently impossible to estimate how much invertebrate grazing contributes to the abundance and cover of bladderwrack in the Baltic Sea. While more temporal information is needed to establish the interaction between bladderwrack and isopod population sizes (including predation effects), the between-year variation in isopod abundances observed in this study indicates that the grazing pressure may be at least doubled between years.

5. Conclusions

This study assessed eutrophication-related and temporal patterns in coastal bladderwrack invertebrate fauna using a community science approach. Data was received from a broad geographic area over two years. While the taxa resolution and animal abundances were often lower compared to traditional field sampling efforts conducted by scientists, the data still illustrated spatial and temporal patterns in fauna. While the educational and societal impacts of the campaign were not quantified, thousands of people became more familiar with this important underwater ecosystem, and hundreds of children and adults gained hands-on experience in marine life and science by participating in the research. The observed decrease in faunal abundances and changes in community composition with decreased eutrophication status implicate a strong human impact on the coastal faunal communities and their functioning. The observed temporal variation in isopod abundance especially calls for longer-term studies. The large-scale information on spatial and temporal variation in habitat-forming species, such as bladderwrack, is still relatively scarce in the study region. Based on the findings, it is recommended that community science approaches should be continued and further developed to complement traditional monitoring efforts.

CRediT authorship contribution statement

Tiina Salo: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Anniina Nieminen:** Methodology, Writing - original draft, Validation, Investigation, Data curation. **Sonja Salovius-Laurén:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Henna Rinne:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data are available from Zenodo: DOI 10.5281/zenodo.11482089 (Salo, 2024).

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Appendix A. Supplementary data

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