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Environmental justice in a very green city: Spatial inequality in exposure to urban nature, air pollution and heat in Oslo, Norway

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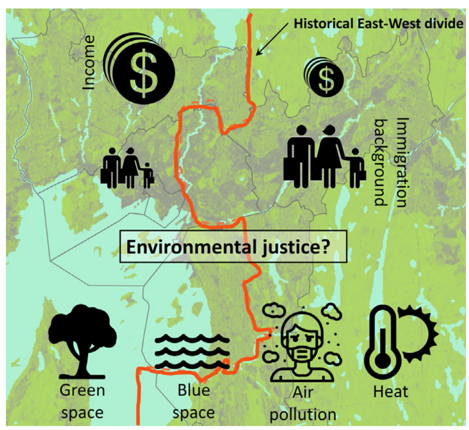
HIGHLIGHTS

- We expected to find environmental justice in Oslo given its reputation for sustainability and abundance of nature
- Yet we found spatial inequality in the availability of blue-green space
- Poorer citizens are surrounded by less urban nature and are more exposed to air pollution and heat
- Our findings illustrate how social sustainability is often overlooked in urban densification agendas

GRAPHICAL ABSTRACT



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ABSTRACT

Poorer citizens are often more exposed to environmental hazards due to spatial inequalities in the distribution of urban blue-green space. Few cities have managed to prevent spatial and social inequality despite sustainable development strategies like compact city planning. We explore whether environmental injustice exists in a city where one would least expect to find it: a city with abundant nature, an affluent population governed by a left leaning social democratic city council, and an aggressive densification strategy; Oslo, Norway. Green space was measured with a satellite-derived vegetation index which captures the combined availability of gardens, street trees, parks and forest. Blue space was defined by the proximity of residential areas to the closest lake, river or fjord. We found that poorer city districts, often with greater immigrant populations, have less available blue-green spaces and are disproportionately exposed to hazardous air pollution levels, but not extreme heat compared to wealthier city districts. Citizens living within 100 m of a water body are likely to earn US$ 20,000 more per year than citizens living 500 m away from water, and a US$ 3000 increase in annual income corresponds to a 10 % increase in green space availability. Hazardous air pollution concentrations in the poorest city districts were above levels recommended by the WHO and Oslo municipality. Historical trends showed that districts undergoing population densification coincide with the lowest availability of blue-green space, suggesting that environmental justice has been overlooked in compact city planning policy. Despite Oslo's affluence and egalitarian ideals, the patterns of inequality we observed mirror the city's historical east-west class divide and point to spatial concentration of wealth as a core factor to consider in studies of green segregation. Urban greening initiatives in Oslo and other cities should not take spatial equality for granted, and instead consider socio-economic geographies in their planning process.

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1. Introduction

The three pillars of sustainable development – social, economic and environmental – are often difficult to maintain simultaneously, especially in urban areas. In urban planning, an intrusive antagonism exists between the legitimate political goals of pursuing environmental sustainability and ensuring socio-environmental justice. This is particularly evident in cities where all development is confined within strict boundaries. The antagonism manifests in the spatial distribution of wealth, blue-green spaces, and environmental hazards within and around cities. Identifying and understanding these spatial patterns are key to overcome friction between goals that are both environmentally and socially sustainable.

Blue-green spaces in cities, often referred to as 'urban nature' or 'blue-green infrastructure', are the multifunctional, predominantly unbuilt spaces that supports both social and ecological landscape settings and processes (Pauleit et al., 2011). Operationalized as parks, forests, street trees, gardens, playgrounds, rivers, lakes and oceans, blue-green spaces provide a range of services to society, not least of which include the mitigation of exposure to environmental hazards such as air pollution and extreme temperatures (Bratman et al., 2019). There is a wealth of evidence for the link between beneficial public health outcomes (mental and physical) and exposure to blue (Britton et al., 2020; White et al., 2020) and green spaces (Kondo et al., 2018; Shuvo et al., 2020). Based on the scientific evidence, the World Health Organization has recommended that urban residents have access to at least 0.5-1 ha of public green space within 300 m of their home (WHO, 2017). In addition, the Global United Nations Sustainable Development Goal (SDG) 11.7 focuses on the provision of green spaces in a universal, safe, inclusive and accessible manner.

Despite the SDG goals, portions of the global population that are urbanizing rapidly lack adequate access to blue-green spaces and the benefits for human wellbeing that they provide. In Europe, approximately 75 % of the population now reside in urban areas (United Nations, 2019). Although the drivers behind this development are complex, it aligns with contemporary political sustainability agendas. Since 1990 the Compact City ideal has become the leading paradigm within international agencies, governments and local planning authorities (Burgess, 2002; EC Commission, 1990; European Union, 2011). One central feature of compact city policies is densification of urban dwellings. It is broadly acknowledged that urban densification reduces car dependency, household energy consumption and not least land consumption, with the overarching aim of minimizing the environmental impact from population growth and hence a growth in the building stock (Ahlfeldt et al., 2018).

Urbanization is, however, often accompanied by rising socio-economic inequality (Glaeser et al., 2009; Tammaru et al., 2014). In cities inequality often manifests spatially through the ability of wealthy residents to outcompete less wealthy residents for locations (predominantly via the housing market) that provide better access to goods and services and other social infrastructure including education and employment opportunities (Soja, 2009). This often occurs at the periphery of cities which coincide with industrial areas that concentrate poorer, working-class citizens. Therefore, concentration of poverty over space may result in disparate exposures to environmental hazards among poorer city residents – the central issue concerning the environmental justice movement (Brulle and Pellow, 2006). The preoccupation with environmental justice, and also the coining of the term, can be traced to the struggle for racial equity in the 1980's in the United States where racial minorities were disproportionately exposed to toxic wastes and pollutants. However, since then climate change has resulted in an evolution of the environmental justice discourse to include aspects of climate justice (Barrett, 2013; Schlosberg and Collins, 2014). Climate justice concerns socio-economic inequalities in the exposure to climate hazards such as extreme heat, acid rain or flood risk (Chakraborty et al., 2019; Sarricolea et al., 2022; Sovacool, 2013).

The disproportionate exposure to environmental and climatic hazards is mediated by the unequal distribution of blue and green space and can have negative consequences for public mental and physical health (Jennings et al., 2012; Wolch et al., 2014). Comprehensive reviews of the literature on the distribution of green space in cities shows that inequality is prevalent across both the Global South (Rigolon et al., 2018) and the Global North (Rigolon, 2016; Schüle et al., 2019). Extremes of spatial inequality are more evident in developing nations (e.g. South Africa; Venter et al., 2020b) where there are also more extreme baseline population exposures to environmental hazards and consequent public health burdens (e.g. extreme air pollution levels in India; Achakulwisut et al., 2019). However, rapidly urbanizing cities in Europe mirror some of the environmental justice extremes found in the Global South (e.g. Paris, France; Liotta et al., 2020).

Despite the mounting evidence for the near-universal pattern of spatial inequality in access to urban blue-green space, there are several gaps in our current knowledge on the topic. Firstly, there is a notable lack of consensus on whether these inequalities inevitably are reinforced by urban densification or if goals of social sustainability and urban greening can be achieved within the compact city paradigm (Cavicchia, 2021; Haaland and van den Bosch, 2015; Madureira and Monteiro, 2021; Næss et al., 2020). Secondly, few studies address blue and green spaces combined (Haeffner et al., 2017; Nghiem et al., 2021; Wüstemann et al., 2017). Blue spaces are important to consider given that they provide a range of ecosystem services that are qualitatively as important as those provided by green spaces (Britton et al., 2020; MacKerron and Mourato, 2013). Thirdly, although there is abundant literature on the link between blue-green space equity and public health, there are few studies that explore the intersection with exposure to environmental hazards such as air pollution and extreme heat (Rigolon et al., 2021). This is particularly important in Europe, which is becoming more racially and ethnically diverse due to in-migration and refugee resettlement (OECD, 2015), and is experiencing accelerated rates of climate warming (Bastin et al., 2019).

In this context, Oslo, Norway is an intriguing case study to explore the question of environmental justice because it exists at the extreme of several relevant social, economic and political gradients. Oslo is ranked among the world's greenest cities, both in terms of the availability of green space (Huang et al., 2021; Kuang et al., 2021) and in terms of energy consumption, climate mitigation, carbon neutrality and other measures of sustainability (see Schroders European Sustainable Cities Index). In 2019 it was even awarded the title of "European Green Capital" by the European Commission, thanks to a climate strategy that includes "green solutions" to everything from transport to business and the organization of large music festivals. Oslo is the capital and by far the largest city in a country which has consistently ranked near the top of the list for a range of social, economic and political global indexes including the United Nations' Human Development Index, the Organisation for Economic Co-operation and Development's Better Life Index, and the Association for Development and Advancement's Democracy Index.

To all appearances Oslo is a city where one might expect to find high relative equity on many levels, also in the distribution of blue-green space and the burden of environmental hazards. At present the city faces severe growing pains, however. In the European context, the strongest urban densification over the last three decades has taken place in the Nordic countries, and Oslo has been in front with a particularly high increase in population density (Næss, 2022). A long-existing legal-administrative separation between built-up areas and a large protected forest belt and natural boundaries created by the Oslo fjord, combined with an ambitious compact city policy over the last three decades, seem to have stimulated a monocentric densification pattern (Næss, 2022; Næss and Moberg, 2021; Tiitu et al., 2021). From 2000 to 2020 the number of residents in the inner areas of the city increased with as much as 50 % (Næss, 2022). In fact, a recent study of green space and mortality in European cities estimated that approximately 55–76 % of the Oslo population (depending on how green space provision is operationalized) now live in areas that do not satisfy the WHO targets for exposure to green space (Barboza et al., 2021). In addition to this, a comparison of five Northwestern European capitals showed that, although income differences are relatively low (but growing) at the macro-scale, Oslo stands out as a city with a particularly strong and persistent pattern of affluence segregation, that is spatial concentration of wealth (Haandrikman et al., 2021; Wessel, 2015).

Our study takes place in this complex landscape of diverging tendencies: On the one hand, Oslo is located in one of the wealthiest and most egalitarian countries in the world. It has an abundance of water and forests within its geographical boundaries (Jørgensen and Thorén, 2016). On the other hand, Oslo is characterized by rapid urbanization, geographical segregation of wealth (Næss et al., 2020), and there are some indications that a considerable share of its residents are not sufficiently exposed to nature in their daily lives (Suárez et al., 2020).

The aim of this study is to explore environmental justice in Oslo: To what extent does spatial inequality in blue-green space availability exist in a city so well-equipped to avoid it? If there are patterns of blue-green space inequality, to what degree do they map to those of exposure to air pollution and heat? On a more general note, what lessons can we learn about the dynamics of urban environmental justice from a city with abundant blue-green resources that also pursues a strong compact city policy? To answer these questions we perform a spatial analysis of city sub-district level variations in blue-green space, air pollution and heat, and their associations with income, immigration background and densification trends. Exposure to urban nature is operationalized by the measurement of the availability and not accessibility or quality of blue-green space.

To our knowledge, this study is the first to map the socio-spatial distribution of urban nature in Oslo – or any other Norwegian city. As such, the article addresses an important research gap in the Norwegian context. The combination of Oslo's overall affluence, ample natural resources and densification pace moreover makes it an intriguing case to explore an understudied issue in the literature on urban environmental justice; that of compact urbanization as a potential driver of injustice (Haarstad et al., 2022) in terms of unfair spatial distribution of environmental burdens and goods between social groups.

2. Methods

2.1. Study area

In 2021 82.4 % of the Norwegian population lived in urban areas, defined as settlements, towns and cities with >200 inhabitants (Statistics Norway, 2021). Oslo municipality (59′55 N, 10′45E) had a population of 699,827 in 2021, accounting for 13 % of the country's population. In 1946, just after WWII, the population in the area that constitutes today's city borders amounted to circa 400,000. From 1990, after a period of degrowth, population growth rate has been high, and in 2021 Oslo was ranked as the fourth fastest growing city in Europe and the second fastest growing capital (Ghosh, 2021). The recent rapid population growth coincides with a time of increased focus on protecting Oslo's surrounding forests from development (Syse, 2016). This peri-urban forest zone is called "Marka" (altogether 1700 km^2) and has been protected from urban development by law since 2009, and de facto even longer. Dominated by boreal spruce and interspersed with freshwater lakes (Fig. 1), the forest covers 63 % of the Oslo municipality and provides an all-year range of opportunities for outdoor recreation (Gundersen et al., 2015; Suárez et al., 2020). Apart from the surrounding forest, Oslo's built-up zone is punctuated with green spaces and riverine corridors (Fig. 1). Oslo is also located on the Oslofjord, with beaches and a 140 km terrestrial coastal zone which provide a range of recreational opportunities. However, the inner Oslofjord has the least amount of publicly accessible coastline in Norway due to private properties. <30 % is accessible for the public (Statistics Norway, 2018).

Oslo is divided into five broad administrative areas (outlined in black in Fig. 1) constituting 99 sub-districts (outlined in white in Fig. 1). The districts to the east of Oslo generally rank low on a range of socio-economic metrics compared to those in the west (Statistics Norway, 2021). Historians trace the origin of the east-west divide (Fig. 1) in Oslo back to the second half of the nineteenth century (Kjeldstadli and Myhre, 1995). Until then, the city's bourgeoisie elite had mostly inhabited the centre. But as the city grew, the centre became noisy, crowded, and stained with bad smells. As a consequence, the upper classes started to move westward, out of the centre, to areas closer to nature in which many already owned private properties and country houses. In the same period, a rapid development of manufacturing industries took place along the small but powerful rivers Akerselva and Alna on the east of the city (Fig. 1). This led to a concentration of poor, working class citizens in areas close to the factories on Oslo's East End. Recent studies have shown that the historical east-west class segregation pattern in Oslo has remained remarkably stable up until today (Ljunggren and Andersen, 2014). One important exception to this east-west divide is the Nordstrand plateau on the eastern bank of the fjord. Often referred to as the "Eastern West End", the area has exceptional views, excellent lighting conditions, and a good distance to industry. Economically and socially it is similar to Oslo's West End.

2.2. Socio-economic data

Socio-economic data reported by Statistics Norway and disseminated through the Oslo municipality statistic bank (https://statistikkbanken.oslo.kommune.no/) were used in our analysis. Statistics are reported at the "delbydel" administrative level which we translate to "sub-district" in this paper. There are 99 sub-districts in Oslo municipality which were included in our analysis (Fig. 1). The spatial data format were vector data outlining the geometries of the 99 sub-districts. We extracted average gross annual income for the years 2008 to 2019 which includes wage income, business income, pensions and capital income for the population 17 years and older. For each sub-district, we calculated the mean income by averaging over the yearly values. In addition, we calculated the trends in annual income using the slope of a linear regression line fitted to the annual gross income values per sub-district. Population counts, stratified by immigration background, for the years 2000 to 2021 were used to derive population growth rates (slope of the linear regression line through annual counts) and the percentage of Norwegian natives per city sub-district. The immigrant population was defined as people who have moved to Norway within their lifetime and their children. Income and population averages per city sub-district were calculated over the available annual time series.

2.3. Blue-green space and environmental hazard data

All blue-green space and environmental hazard data described below were collected as gridded datasets at different spatial resolutions (Table 1), but aggregated to city sub-district level by calculating the mean values within sub-district polygons. This was done in order to align with the spatial resolution of the socio-economic data provided by Oslo municipality. Before spatial aggregation, sub-district polygons were first buffered by 1000 m in order to account for the reality that residents walk to access blue and green space that is not necessarily within their city sub-district. A buffer size of 1000 m is a well-established distance used in blue-green space epidemiology (Labib et al., 2020).

The availability of green space was derived from satellite remote sensing using the Google Earth Engine cloud-computing platform (Gorelick et al., 2017). We used imagery from the Sentinel-2 Multispectral Instrument surface reflectance product (10 m resolution) to calculate the median normalized difference vegetation index (NDVI, Tucker, 1979) during 2020, after filtering for images with a cloud cover of <5 %. NDVI is a good proxy for vegetation cover and productivity and has been used throughout the epidemiology literature to quantify exposure to green space (Gascon et al., 2016; van den Berg et al., 2015). In the urban environment NDVI gives an all-encompassing measure of green space, as it integrates across small (e.g. street trees, gardens) to very large (e.g. parks, forests) green space elements. While NDVI is generally expressed on a scale between 0 and 1, we multiply it by 100 to express it as a percentage score for ease of interpretation.

To quantify availability of blue space, we calculated residential proximity to the closest blue space (lake, river or fjord) >1 ha in surface area. Water bodies were defined by a national land cover dataset produced by the Norwegian Institute of Bioeconomy Research called AR5, rasterized to a 2.5 m grid. We chose the area threshold of 1 ha to exclude very small blue spaces like city fountains and private swimming pools which only

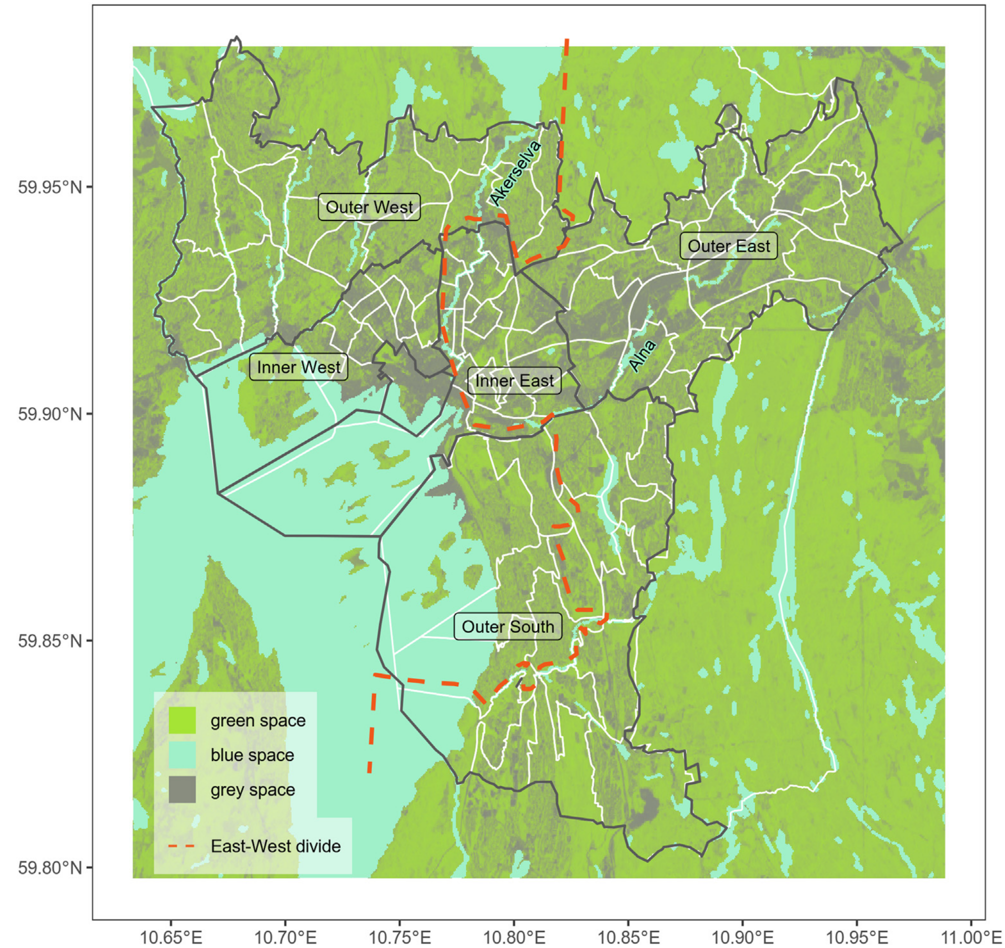

Fig. 1. Map of Oslo characterizing a gradient of blue, green and grey space. City sub-districts are outlined in white while regional groupings are outlined in black. The grey to green space gradient is defined by the normalized difference vegetation index (NDVI) from the Sentinel-2 satellite, while the blue space is defined by a national land cover dataset. The historical east-west divide, defined by socio-economic differences, is indicated with a dashed-red line.

service a limited number of people and are therefore not representative blue spaces in terms of public exposure. Proximity was calculated using a Euclidean distance between residential areas and the closest water body.

In addition to blue-green space availability, we also quantified two environmental hazards including air pollution and extreme heat. For air pollution we used an air pollution zonation map that informs government recommendations on how air quality should be managed in municipal land-use planning (Tarrasón et al., 2018; https://www.luftkvalitet-nbv.no/). The zones are defined based on a combination of air pollution concentrations for nitrogen dioxide (NO_2) and particulate matter <10 μm in diameter (PM10) based on 100 m resolution maps for the year 2015. We calculated the percentage cover of hazardous zones in each city sub-district to define exposure to hazardous air pollution. Hazardous zone, as defined by Oslo's regulations, include daily mean NO_2 concentrations exceeding 40 $\mu g\ m^{-3}$ and PM10 concentrations exceeding 35 $\mu g\ m^{-3}$. These areas put people with respiratory or cardiovascular disease at risk of adverse health effects and are areas where the municipality should exercise caution in allowing the establishment of buildings or activities with purposes of use that are sensitive to air pollution (Tarrasón et al., 2018).

For heat hazard, we used a map of maximum summer air temperatures for Oslo derived from satellite observations and citizen weather stations during 2018 at 30 m resolution (Venter et al., 2020a). In the absence of Norwegian guidelines, we adopted a threshold outlined in the heatwave plan for England (Public Health England, 2018), defining heat risk actions when air temperatures exceed 30 °C. We therefore defined heat hazard zones exceeding 30 °C in the 2018 maximum temperature map and calculated the percentage cover of these zones per city sub-district.

Table 1
Description of socio-economic and blue-green space variables included in the spatial analysis.

Variable	Description	Data type	Spatial resolution (m)	Time frame
Income	Gross annual income	Vector	–	2008–2019
Income trend	Annual trend in annual income	Vector	–	2008–2019
Norwegian natives	Percentage population Norwegian natives	Vector	–	2000–2021
Densification	Annual trend in total population	Vector	–	2000–2021
Green space	NDVI	Gridded	10	2020
Blue space	Euclidean distance to water body	Gridded	2.5	2020
Air pollution hazard	Percentage area cover $NO_2 > 40$ $\mu g\ m^{-3}$ and $PM10 > 35\ \mu g\ m^{-3}$	Gridded	100	2015
Heat hazard	Percentage area cover air temperature > 30 °C	Gridded	30	2018

2.4. Statistical analysis

Simple linear regression was used to estimate the spatial association between socio-economic variables (response variable) and blue-green space availability and environmental exposure (explanatory variable). Due to the exploratory nature of our analysis, we did not place emphasis on hypothesis testing, however we did calculate the Pearson's correlation coefficient to test for statistical significance of association between socio-economic and environmental exposure variables. In addition, we calculated the 95 % confidence intervals around the regression estimates and interpreted the magnitude of the estimate along with the variance relative to the other estimates being considered.

3. Results

3.1. Spatial associations of environmental exposures with income and immigration background

The average per capita annual income before tax in Oslo is US$ 46,000 which has been growing at an average rate of US$ 1500 per year between 2009 and 2018 (Fig. 2B). The highest incomes are found on the Bygdøy peninsula south-west of the centre (Inner West), in the Outer West region, and on the Nordstrand plateau south-east of the centre (Outer East). The poorest sub-district in Oslo (Fossum) has income levels that are less than a third of the richest sub-district (Slemdal).

The spatial gradient of income is positively associated with NDVI and proximity to water and negatively associated with ambient air pollution hazard, yet is not associated with spatial gradients in heat hazard (Fig. 3). Specifically, a US$ 3000 increase in annual income corresponds to a 10 % increase in NDVI, and residents living within 100 m of a water body earn on average US$ 20,000 more per year than citizens living 500 m away from water. To put this in perspective, residents in Oslo are exposed to an average NDVI of 0.45 (expressed as 45 %), and live an average of 522 m away from blue space. Similarly, every 10 % increase in the area a sub-district is exposed to hazardous air pollution is associated with a US$ 1670 decrease in income. Furthermore, while there were no sub-districts with >75 % air pollution hazard earning on average above US$ 50,000 per annum, there were 20 sub-districts earning on average above this amount in areas with <25 % air pollution hazard.

Norwegian natives make up 65 % of the population in Oslo, although there are some city sub-districts with as little as 11 % (91 % immigrants, Fig. 2C). The spatial gradient in the immigration demographic is less correlated to blue-green space and environmental hazards than income status is (Fig. 3). However, immigration proportions were significantly correlated with proximity to water, where there is 3 % increase in the proportion of immigrants with every 100 m increase in distance from water. Furthermore, there is a 1 % increase in the proportion of immigrants with every 10 % increase in heat hazard cover. Exposures to green space and air pollution are not strongly correlated with city sub-district immigration profile (Fig. 3).

3.2. Densification and income segregation

The population in Oslo has become more affluent over time and has been growing at a rate of 104 people per city sub-district per year, with only one sub-district (Holmlia Nord) experiencing a net decline (Fig. 2D). The sub-districts in which the heaviest population densification has taken place are all located within the Inner East region of the city, except in two areas that extent slightly outsize into the Outer West zone, west of the river Akerselva (see Fig. 1 for spatial reference). The relationship between income and blue-green space exposure mirrors the relationship with income trends (Fig. 3). Areas that have increased in income are more exposed to blue-green space and less exposed to environmental hazards, although the correlations for NDVI and heat hazard cover were non-significant.

City districts that are densifying more than others tend to be less green, further from water and have higher levels of air pollution and heat hazard (Fig. 3). Although some of the most intensely densifying sub-districts border the fjord, the large majority of residents in the densification zone are either moderately or poorly exposed to water and green space coverage.

3.3. Overlapping effects

The sub-districts with the strongest combination of low income and poor green space coverage (light grey sub-districts, Fig. 4A) are largely

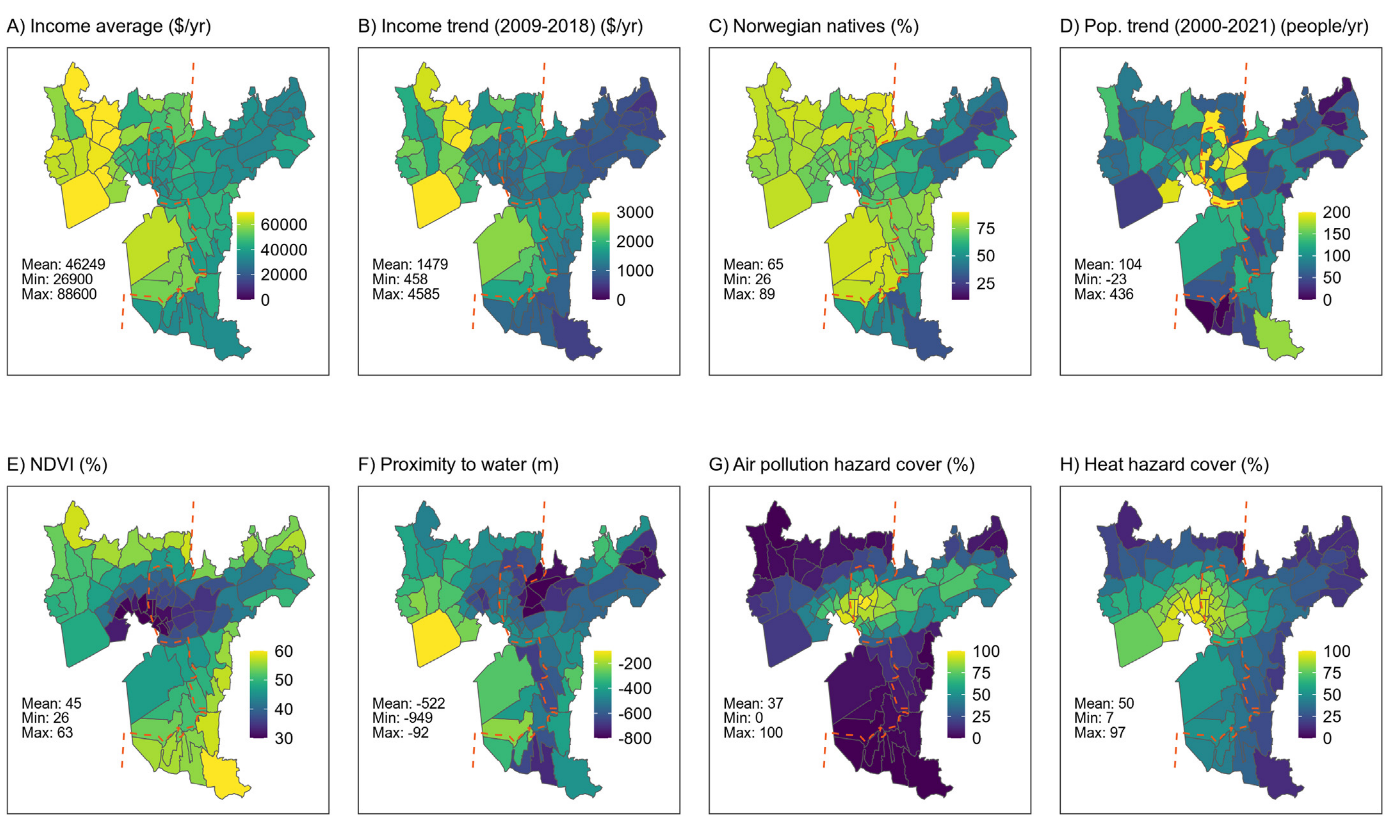

Fig. 2. Spatial distribution of socio-economic variables (top row) and blue-green space and environmental hazard variables (bottom row) across city districts in Oslo, Norway. The historical east-west divide is indicated with a dashed red line.

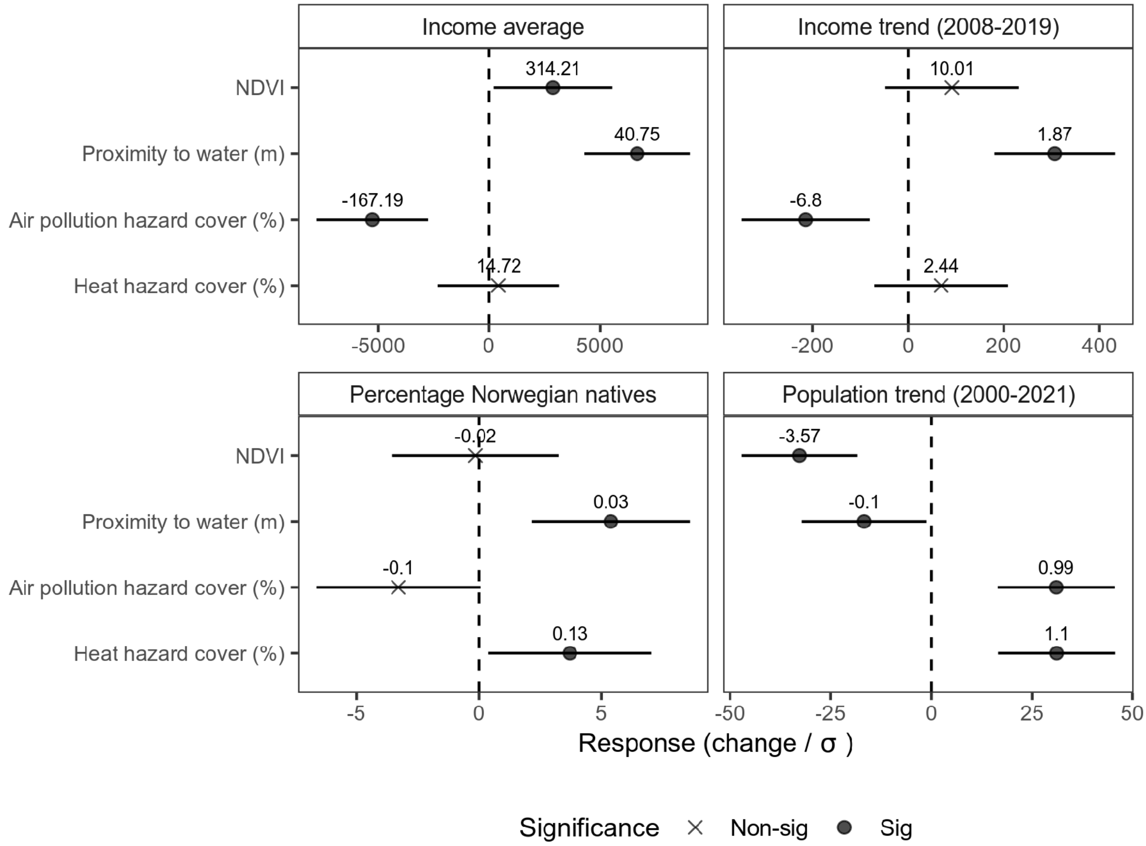

Fig. 3. Linear empirical estimates of the association between socio-economic characteristics (separate panels) and blue-green space availability and environmental exposure. Points and lines represent the standardized model estimates (change in dependent variable per standard deviation σ increase in the independent variable) and 95 % confidence intervals. Non-standardized estimates (change in dependent variable per unit increase in the independent variable) are presented as text above each point and are derived from the slope of the linear regression line, therefore positive values indicate positive correlations, and negative values indicate negative correlations. Solid points indicate significant associations ($p < 0.05$).

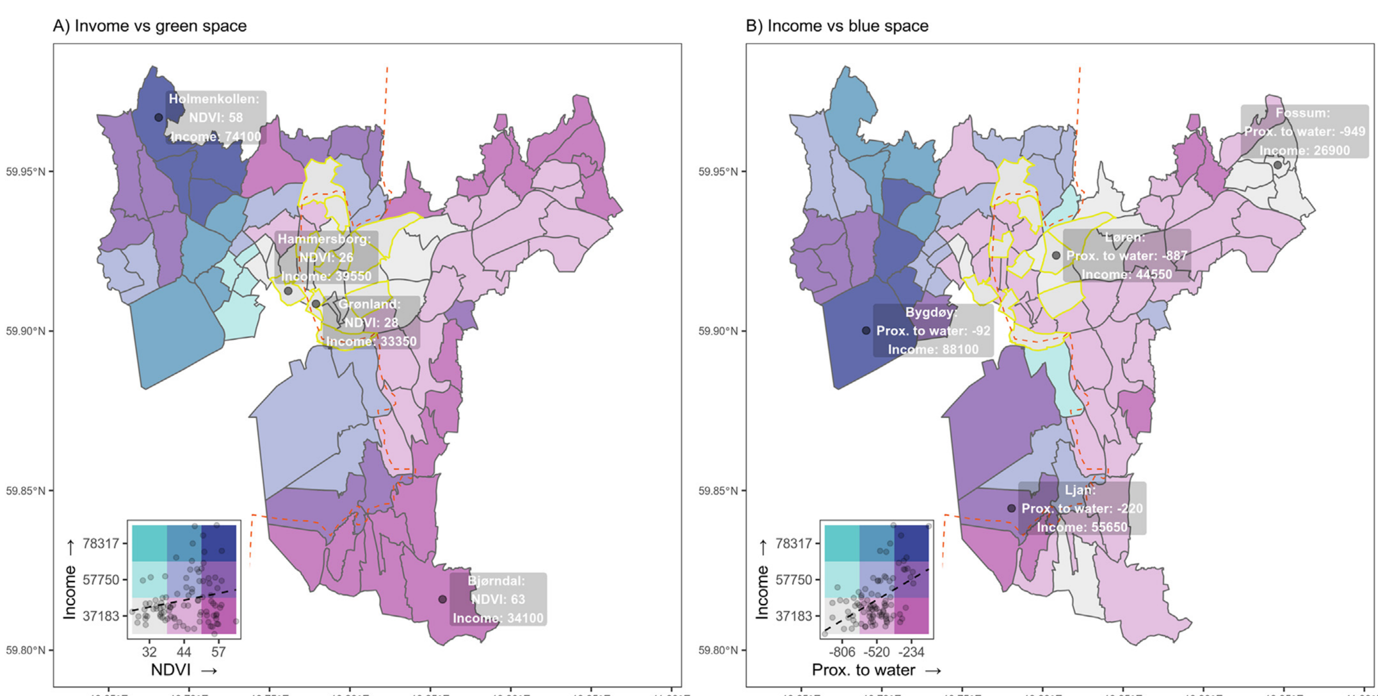

Fig. 4. Bivariate choropleth maps for the relation between income and NDVI (A), and income and proximity to water (B). The colour legends contain points corresponding to each district in the map along with a linear regression line. Two districts with the highest and lowest respective NDVI, and proximity to water are identified with points and boxes reporting the data values. The sub-districts with the highest rates of population densification are outlined in yellow. The historical east-west divide is indicated with a dashed red line.

located within the densification zone identified above – more precisely in the Inner East region and adjacent areas in the Outer East region of the city. Conversely, the sub-districts with the highest combined scores on income and green space exposure (dark blue sub-districts, Fig. 4A) are located in the Outer West zone, alongside or close to the protected green belt “Marka”.

With regard to water proximity, it is most strongly associated with wealth in two areas of Oslo (dark blue sub-districts, Fig. 4B): one alongside or close to the fjord on the West End (Inner West) and the part of the eastern bank of the fjord that we have previously described as the “Eastern West End”. Of the 16 sub-districts with the combined lowest scores on income and proximity to water (light grey sub-districts, Fig. 4B), 14 are located on the East End, mostly in the Outer East zone.

We cannot draw any conclusions from these data on whether densification in some areas have led to loss of urban nature in the same areas, or if densification has mainly taken place in sub-districts in which blue-green space were already scarce. What the data do show, however, is that the aggregated effect of urban densification, spatial variations in income, green space availability and proximity to water partly follows the historical east-west axis of Oslo, and partly the inner-outer axis associated with a monocentric compact city. This points to a potential mechanism by which urban densification seems to have concentrated on poorer areas and thereby reduced the amount of green space available to those who live there.

4. Discussion

Despite Oslo's green profile, rich economy and abundance of blue-green space, there are nevertheless clear patterns of environmental inequality that maps to patterns of socio-economic inequality. The portion of Oslo's population that are socio-economically and environmentally disadvantaged are concentrated in the Inner and Outer East regions of the city (Fig. 1), aligning with the long history of an east-west divide, as an axis of class segregation (Fig. 1; Wessel, 2015). As illustrated in Figs. 2 and 4, these areas are among the sub-districts with the lowest average income, poorest access to water, and a disproportionate exposure to air pollution. However, in a city as green as Oslo, access to urban nature could be sufficient even in the areas with the relatively lowest exposure to blue-green space. We argue that this is not the case because these areas are also exposed to environmental hazards beyond recommended thresholds and would benefit all the more from enhanced blue-green space availability. For instance, disadvantaged sub-districts in the Inner East city are exposed to NO_2 concentrations beyond the WHO recommendation of 10 $\mu g/m^3$, and some exceed the threshold of 32 $\mu g/m^3$ set by Oslo municipality which trigger requirements for mitigation measures (Høiskar et al., 2017, Fig. S1). Furthermore, in a European-wide analysis, Barboza et al. (2021) found access to green space in Oslo to be below WHO targets (although the definition of city in this study did not include the Marka forest in the city surroundings).

An important exception to the pattern of environmental injustice is that of heat hazard. We found that Norwegian natives are more exposed to heat exceeding 30 °C in a heat wave scenario compared to immigrant populations (Fig. 3). Furthermore, income was not spatially correlated with heat hazard. This pattern is contrary to that observed in the growing literature on climate justice which shows disadvantaged population groups to be disproportionately exposed to extreme heat (Chakraborty et al., 2019; Schlosberg and Collins, 2014). One potential explanation for this is that we have used air temperatures instead of land surface temperatures; a proxy for heat stress rife in the climate exposure literature which is not as relevant for public health as air temperature (Chakraborty et al., 2022). It is also possible that, because of Oslo's relatively cold climate compared to other European cities, there is competition for properties located in warmer city districts, and that this produces an inverse relationship between heat and socio-economic status.

Importantly, environmentally disadvantaged areas are also the areas in which the population consolidation seems to unfold most intensely. This is illustrated both by the population trend described in Fig. 2D as well as in key planning documents produced by the Municipality of Oslo's (Oslo kommune, 2018). According to these plans, the city is not only supposed to continue to densify “from the centre and out”; the most ambitious goals for future growth in the housing stock is concentrated to areas in the Inner and Outer East city east of river Akerselva. This trend obviously increases pressure on available blue-green spaces, and confirms the monocentric pattern of urban densification described elsewhere (Tiitu et al., 2021) and illustrates the city's commitment to a compact city policy approach (Næss, 2022). At the same time income trends in Oslo indicate that geographic economic segregation has been intensifying over time (Fig. 2B). Taken together, the densification and class segregation trends suggest that Oslo is on a trajectory towards further entrenching environmental injustices rather than alleviating them, unless city planners and municipal managers intentionally incorporate social sustainability agendas into their policy agenda (which they don't seem to do).

To better understand how such environmental inequalities can occur in the capital of a country that is known to be one of the most egalitarian in the world, we must not focus on poverty segregation alone but also take the reverse perspective and look to areas with a strong concentration of wealth. As illustrated in Fig. 4, there is a combined concentration of wealth, vegetation and access to water on the Inner and Outer West regions of the city – in a continuous area that reaches from the peninsula Bygdøy southwest of the centre to the forest “Marka” in the north. There is also a wealthy area with privileged access to blue-green space on the Nordstrand Plateau and Bekkelaget that borders the eastern side of the fjord.

To the extent that Oslo is characterized by affluence segregation along an east-west axis, the distribution of blue-green spaces seems to both reinforce and be reinforced by that pattern. It is well-established that there is a positive feedback loop between the spatial concentration of wealth and blue-green infrastructure through processes like green gentrification (Gould and Lewis, 2016; Soja, 2009). A growing body of literature on green gentrification shows that new green infrastructure can contribute to social and racial disparities in who uses and benefits from green space, thereby increasing environmental and climate injustice (Anguelovski et al., 2022; Haarstad et al., 2022). Access to blue-green space drives up property prices which in turn excludes socio-economically disadvantaged groups from purchasing housing in those areas (Cavicchia, 2021; Łaszkiewicz et al., 2022).

Not only has the pattern of affluence segregation in Oslo shown persistence over time (Haandrikman et al., 2021), the areas in question also seem remarkably resistant to loss of urban nature despite their relatively close location to the city centre. Since these “golden ghettos” (Ljunggren and Andersen, 2014) appear to be protected from heavy densification and removal of green space, compacting efforts must take place elsewhere. Hence, the driving forces behind environmental segregation may be no different from ordinary divisive forces that follows from class differences in access to wealth and power. What we observe, in the case of Oslo, is perhaps a somewhat different dynamic than the one most frequently associated with green gentrification, namely the displacement of disadvantaged groups from inner-city neighbourhoods that are undergoing processes of urban greening and high-density development (Ali et al., 2020; Anguelovski et al., 2022; Haarstad et al., 2022). Whether the areas of Oslo that are subject to compact urbanization will stay relatively disadvantaged also in the future is too early to predict. What appears more certain, is that the wealthy West End sub-districts a bit further from the city centre, but closer to the forest belt and the coastline, will remain “untouched” for quite a while.

One possible explanation for this persistent pattern of affluence segregation is that there has been an unnuanced approach to the compact city policy paradigm combined with a blindness to socio-economic differences in matters of urban development. In a recent study of housing accessibility in Oslo, Cavicchia (2021) argues that questions of equity and social justice appear to be an almost taboo topic in Norwegian housing policies. Our results point to the same mechanism in the area of urban nature policies. In planning for densification and compact building, the Municipality of Oslo seems to have paid little attention to environmental justice, possibly due to a combination of equity being taken for granted and a lack of political will to address the increasing socio-spatial differences in Oslo (Wessel, 2015). The large, preserved greenbelt "Marka" that surrounds the city may also serve as a pretext for not engaging with the question of environmental justice. However, as much as the "Marka" forests are publicly available, they remain at a certain distance from many sub-districts and may not be as easily accessible to all citizens. This distance represents in particular a barrier to vulnerable groups, such as children and people with reduced mobility (Gundersen et al., 2015; Gurholt and Broch, 2019). The mere existence of a large forest belt can, in other words, not fully compensate for the lack of intra-urban blue-green space which is integral in addressing the SDG 11, and the aim of making human settlements inclusive, safe, resilient and sustainable. Moreover, distance to "Marka" is not merely of a physical nature. Social and cultural barriers to make use of the large forest that surrounds Oslo may be equally important, making access to local urban blue-green spaces even more important, and reduction in accessibility extra harmful (Figari et al., 2009).

There are important economic and environmental benefits associated with Compact Cities (Ahlfeldt et al., 2018). However, the social sustainability dimension of densification – and the role urban nature plays in achieving or failing to achieve spatial justice – is still poorly understood (Madureira and Monteiro, 2021). It also tends to be the least investigated by planning authorities (Cavicchia, 2021). Uncritical pursuit of a compact densification strategy may lead to a "tipping point", after which the urban environment becomes too crowded, too stressful, too noisy, too alienating, to be socially resilient (Giddings and Rogerson, 2021; Teller, 2021). This is even more problematic if such burdens are unequally distributed across social groups. According to Van Ham et al. (2015) "[g]rowing inequalities in Europe, even in the most egalitarian countries are a major challenge threating the sustainability of urban communities". Oslo is an especially strong case in point. With all its economic and blue-green resources, this study confirms that environmental inequality appears to be the rule and not the exception.

As much as spatial equity and environmental justice are crucial goals for socially sustainable cities, a reasonable question is whether it is at all achievable? Comprehensive reviews of the literature on environmental justice reveal that there are very few examples of cities that have achieved spatial equality, or something similar to it, in the distribution of blue and green spaces in the Global North (Rigolon, 2016; Schüle et al., 2019). Similarly, literature on climate justice shows that disadvantaged population groups are consistently exposed to extreme temperatures and flood risks more than wealthy groups (Schlosberg and Collins, 2014). Singapore is one remarkable example of a city that has managed to achieve equitable distribution of green and blue spaces and the ecosystem services they provide (Nghiem et al., 2021). The success of Singapore can probably be ascribed to its brand of centralised environmental governance. From early on Singapore's government has led careful socio-economic desegregation efforts and early incorporation of environmental management practices into urban development plans, which has maximized the provision and upkeep of urban green spaces for all people (Law et al., 2022). Oslo, a city with comparable socio-economic status to Singapore, has not managed to establish comparable environmental justice, in spite of its reputation as a green and sustainable city. Environmental injustice possibly becomes the status quo unless governments intentionally regulate urban planning to prevent it.

The current analysis considered aspects of blue-green space availability, but we did not quantify accessibility or quality of blue-green spaces in Oslo. Availability, access and quality are, however, often strongly spatially correlated (Rigolon et al., 2018; Venter et al., 2020b). Even so, and although they are more challenging to quantify using traditional spatial analysis methods, accessibility and quality are two aspects that warrant more research – in Oslo and elsewhere. Access to blue-green space, moreover, varies at different spatial scales. While aggregate statistics, like the ones presented here at sub-district level, capture broad-scale spatial inequalities, there may be important street- or even block-scale inequalities that are important to quantify. This is particularly important in the case of vulnerable population groups (e.g. children or those with restricted mobility) whose barriers to access blue-green spaces are only revealed through more detailed spatial analysis, preferably in combination with data on individual level. Aggregate statistics on exposure to environmental hazards including air pollution and air temperature are also fraught with uncertainty due to the various factors that influence personal exposure. When the data become available, including covariates like population mobility, and more nuanced measures of the environmental hazard such as an air quality index or thermal comfort index (incorporates air temperature, humidity and wind speed), may elucidate different patterns of spatial inequality. Finally, subjective access (e.g. the feeling of closeness to urban nature) and vertical access (i.e. upper levels of apartment dwelling) are underdeveloped research areas in the domain of environmental justice (Sharifi et al., 2021).

5. Conclusion

Blue-green space and environmental-climatic hazards are unequally distributed in Oslo despite the city's egalitarian policy ambitions and reputation for sustainability. The municipality's aggressive densification strategy, in line with the Compact City paradigm, appears to have sacrificed aspects of social sustainability in the drive for economic growth and environmental sustainability. Furthermore, the spatial aggregation of affluence and blue-green space availability indicates a history of green segregation which may, at least partly, be attributed to the municipality's hands-off approach to managing the property market and reluctancy to engage with socio-economic consequences of urban greening strategies. Environmental justice and spatial equity are achievable based on the precedent set by cities like Singapore, however it requires strategic and effective urban planning and governance policies. If Oslo is to implement urban greening initiatives, it should take socio-economic geographies and spatial inequalities into account, and also avoid the pitfalls of green gentrification whereby poorer residents are displaced by affluent residents following urban greening. Furthermore, changes to Oslo's future development strategies that foster equitable distribution of blue-green space can have significant benefits for disadvantaged population groups, given their greater dependency on proximate nature. For instance, less wealthy citizens tend to live in high rise apartments to the east and north. Unable to create their own green living space they are relatively more reliant on public blue-green spaces. Finally, research is needed on small scale differences in blue-green space availability, group-specific barriers to access those spaces, and the socio-spatial distribution and perceived attractiveness of different blue-green qualities.

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CRediT authorship contribution statement

Zander S. Venter: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Helene Figari:** Conceptualization, Funding acquisition, Writing – original draft. **Olve Krange:** Conceptualization, Writing – review & editing. **Vegard Gundersen:** Conceptualization, Writing – review & editing.

Data availability

Data will be made available on request.

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.

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