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Opportunistic climate adaptation and public support for sand extraction in Greenland

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Climate change leads to the deposition of substantial amounts of sediment along the coasts of Kalaallit Nunaat (Greenland) amid rapidly growing global demand for these resources. Yet, little is known about what the predominantly Inuit population of Kalaallit Nunaat thinks about adaptation opportunities arising from the melt of the Greenland Ice Sheet. Here we conduct a nationally representative survey ($N = 939$) of Kalaallit (Greenlanders') views on glacially derived sand extraction, finding that large majorities support extracting and exporting sand but oppose foreign involvement. This pattern of support persists at both the national and subnational levels. Public preferences largely align with Kalaallit Nunaat's current mineral policy mandating environmental and economic impact assessments of new resource opportunities. In addition, those aware of human-caused climate change have significantly higher odds of both supporting sand extraction and prioritizing environmental impact assessment. Our results reveal broad support for domestically involved, environmentally assessed and economically appraised opportunistic adaptation to Greenland's melting ice sheet and accumulating sand resources.

Construction materials such as sand, gravels and crushed stone are fundamental for human development[1] and constitute the most mined materials on Earth. Anthropogenic influences, global population growth and climate change increase the need for these materials[2], and their extraction greatly exceeds natural renewal rates[3]. In the Arctic, climate-change-induced melt of the Greenland Ice Sheet[4] increases the transport of meltwater carrying vast amounts of sediment to the coastal zone. Sediment deposition causes progradation, extending the coast into the sea. It has been proposed that these accumulating resources provide an opportunity for Kalaallit Nunaat (Greenland) to become a global exporter of aggregates[5] to relieve increasing global sand demand[3]. Both the economic potentials[6] and possible negative environmental spillovers of sand extraction and export have been discussed[7]. However, resource exploration in Kalaallit Nunaat—and climate adaptation initiatives globally—have historically often failed to include public perspectives early on[8,9], and recent externally financed mining propositions in Kujalleq (Southern Greenland) have met fierce opposition from residents[10], becoming a flashpoint in parliamentary elections[11]. Although public views and environmental attitudes regarding oil exploration and mining activities in the Arctic have previously been solicited via social impact assessments[12–14] and household surveys[15–19], to date, public opinions on initiating a glacially derived sand extraction industry in Kalaallit Nunaat have yet to be systematically sampled by means of a nationally representative survey. Nevertheless, scholars and stakeholders have recently acknowledged that social support or resistance by local communities will greatly influence sand mining prospects[7].

Impacts of Arctic warming

Arctic warming proceeds at a pace over twice the global average[20], generating risks for local economies and threatening cultural heritage and infrastructure[21]. In Kalaallit Nunaat, Inuit livelihoods and subsistence activities are sensitive to shifts caused by climate change interacting with underlying social and ecological factors[22]. Indeed, a prior nationwide survey of Kalaallit Nunaat in 2019 found that personal experiences of climate change and perceptions of climate-related risks to individuals, society and ecosystems are widespread[16]. Furthermore, while nearly all residents surveyed thought that climate change was happening, awareness of human-caused climate change was more limited, potentially posing a barrier to adaptation. While Arctic communities actively confront the consequences of rapid climatic and environmental changes[21], adaptation opportunities are also surfacing[5]. In Kalaallit Nunaat, for instance, the coastal zone largely defies the general Arctic erosional trend[23]. The melting Greenland Ice Sheet and associated mass loss deliver substantial amounts of sediment to the nearshore zone and cause hundreds of deltas in Kalaallit Nunaat to prograde, extending them into the sea[24]. As a consequence of the ongoing melt of the Greenland Ice Sheet, Kalaallit Nunaat's rivers deliver 7–9% of the global suspended river sediments into the ocean[25].

Opportunistic climate adaptation

Opportunistic adaptive behaviour is a tenet of most ecological systems, whereby life adapts to the opportunities afforded by an arising niche[26]. The motivating factors of opportunistic climate adaptation—the process of adjusting to opportunities emerging from a changed environment—remain poorly understood[27] relative to predictors of defensive adaptation[9,28], despite their theorized importance for local transformation in the Arctic[29,30]. The IPCC acknowledges this duality in their definition of climate adaptation as "the process of adjustment to actual or expected climate and its effects", emphasizing that "in human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities"[31,32]. In the Arctic, changing access on land and at sea due to ice cover retreat is stimulating interest in, inter alia, new shipping routes, the region's minerals and other non-living resources[33–36]. Recent national survey evidence suggests that a greater percentage of Kalaallit (Greenlanders) think that

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climate change will benefit mining, shipping, tourism and farming than those who believe it will harm these same industries, whereas the opposite pattern is apparent for Kalaallit Nunaat's traditional hunting and fishing industries[16].

Indigenous perspectives on mining

Increased resource access and extraction activities convey complex opportunities and challenges for Indigenous populations. A recurring barrier to equitable adaptation in Arctic regions has been the lack of inclusion and engagement of Indigenous voices and local communities in the exploration of new resource opportunities[28,29], and Kalaallit Nunaat is no exception[10,35]. In response, scholars have called for closer interfaces between communities, researchers and policy development[37,38]. The lack of meaningful engagement concerning extractive activities is a known phenomenon for other Indigenous groups outside of the Arctic[39], such as the Indigenous peoples of Australia, where the Niapiali, the Yinhawangka and the Panyjima people neighbouring mining operations live with the localized effects of the resource curse[40]. Nonetheless, some Indigenous communities in Australia have shown support for mining operations as a means to reduce poverty and to enhance livelihood opportunities if appropriate frameworks are established between Indigenous peoples and external groups[40]. Parallels can be drawn to Indigenous communities in the Arctic, where extractive activities are seen by many as a possibility for socio-economic development, if the potential negative impacts on communities and the environment are assessed and minimized[33,41,42].

Resource extraction in Kalaallit Nunaat

Mining in Kalaallit Nunaat for commercial purposes goes back over 200 years[43], with documented extraction of copper, cryolite, zinc, lead and precious metals and gems[44]. Since 2009, Kalaallit Nunaat has had self-rule status within the Kingdom of Denmark and the rights to manage all natural resources in the country from 2010, as stipulated by the Mineral Resources Act[45]. Naalakkersuisut (the government of Greenland) continues to consider extractive industries a cornerstone in the future diversified economy of Kalaallit Nunaat[46], with ambitions to offset Denmark's annual block grants amounting to roughly half of Kalaallit Nunaat's national budget (ca. US$650,000,000)[10]. Sand extraction from the seafloor already exists at a small and local scale[47]. In 2019, Bendixen et al.[5] discussed the promises and perils of establishing a glacially derived sand industry in Kalaallit Nunaat to diversify the country's economy while relieving the pressure on current known global sand resources. Following this finding, in the spring of 2019, Naalakkersuisut requested an economic assessment of the potential for establishing a sand industry. Recently, the economic feasibility of shipping sediment from Kalaallit Nunaat to Europe or North America in today's market has been questioned[6,7]. However, public opinion on glacially derived sand extraction and related policies remains unknown.

Given the dearth of prior evidence in this setting, we pose several exploratory research questions without specifying directional, causal hypotheses. First, since public opposition and support are theorized to play a consequential role in shaping the outcomes of large-scale climate adaptation projects[48], to what extent does Kalaallit Nunaat's adult population tend to favour or oppose the proposed extraction and export of Kalaallit Nunaat's glacially derived sand? Second, given the historical context of resource extraction in Kalaallit Nunaat[33,35], do Kalaallit tend to prefer domestic or foreign involvement to extract sand? Third, since it remains unclear how public environmental and economic preferences apply to opportunistic climate adaptation projects[5,7], does the public prefer that the government assess the environmental impacts of opportunistic sand extraction and export, the economic impacts, or both (in line with current mineral policy)? Finally, since climate change knowledge has previously been shown to predict adaptation behaviours[28], environmental preferences and social views[49], are Kalaallit residents who are aware of human-caused climate change more or less likely to support sand extraction and export, prioritize environmental impact assessment, and prefer foreign co-operation?

Here we adopt a systematically inclusive approach to invite a representative subset of an Arctic population, as opposed to select stakeholders, to provide input on possible societal adaptation actions. Specifically, we solicited initial public opinion on opportunistic climate adaptation preferences related to glacially derived sand exploration, foreign co-operation, and environmental and economic preferences by conducting a large ($N=939$), nationally representative phone survey of Kalaallit Nunaat's adult population (Fig. 1 and Methods). The analyses were weighted for representativeness using probability weights reflecting 2020 Statistics Greenland demographic registry data (Table 1), and weighted logit regression models were employed to assess and test predictors of sand-related adaptation policy preferences (Fig. 2, Methods and Supplementary Table 1). Ninety per cent of the population identified as Kalaallit (Greenlandic) both pre- and post-weighting, mirroring Kalaallit Nunaat's 2020 population composition.

Results

The nationwide survey results represent over 2.5% of Kalaallit Nunaat's adult population to document the public's opinion on sand extraction opportunities and preferences.

Public support for sand extraction. Kalaallit Nunaat—the world's largest island—is inhabited by over 56,000 people living in coastal settlements, villages and towns (Fig. 3b). Drawing on the results, we find that a vast majority of residents strongly support sand extraction and export (Fig. 1a). More than eight in ten (84%) adult residents are in favour of sand extraction, with 76% (95% confidence interval, 73–79%) strongly in favour and 8% (6–9%) somewhat in favour. By contrast, fewer than one in ten (8%) express opposition, with just 2% (1–3%) strongly opposing.

The Sermeq Outlet in Sermilik Fjord in the western half of Sermersooq municipality (South Western Greenland) is the most rapidly prograding delta in Kalaallit Nunaat[24]. This site exports roughly a fourth of the total suspended sediment load from the Greenland Ice Sheet to the coast (depicted as the largest circle in Fig. 3b)[25]. We show that public support for sand extraction and export in this region—the most highly populated area in Kalaallit Nunaat—is similarly elevated (Fig. 3a). In fact, across all of Kalaallit Nunaat's primary municipal regions, we observe remarkably consistent responses: large majorities strongly favour the possibility of extracting and exporting glacially derived sediments.

Domestic versus foreign co-operation preferences. A similar large majority of 75% (72–77%) prefer that Kalaallit Nunaat's sand exploration remain a national project, whereas just 15% (13–18%) indicate that they believe Kalaallit Nunaat should co-operate with another country to extract the sand (Fig. 1c). Furthermore, we find that compared with those living in Kujalleq (Southern Greenland)—the site of recent mining disputes involving residents concerned about exposure to contaminants from the Kuannersuit (Kvanefjeld) mine (a deposit believed to contain both rare earth metals and uranium)—those living in Southwest (West Sermersooq) and West Greenland (Qeqqata) are respectively 2.5 (odds ratio, 1.2–4.8) times and 2.3 (odds ratio, 1.1–4.8) times greater odds of supporting cooperation with other countries to mine sand, even though majorities in all of these regions still prefer national involvement to foreign participation (Supplementary Table 1).

Environmental and socio-economic assessment preferences. We show that a combined majority of Kalaallit think that environmental impacts should at least be included in the self-government's

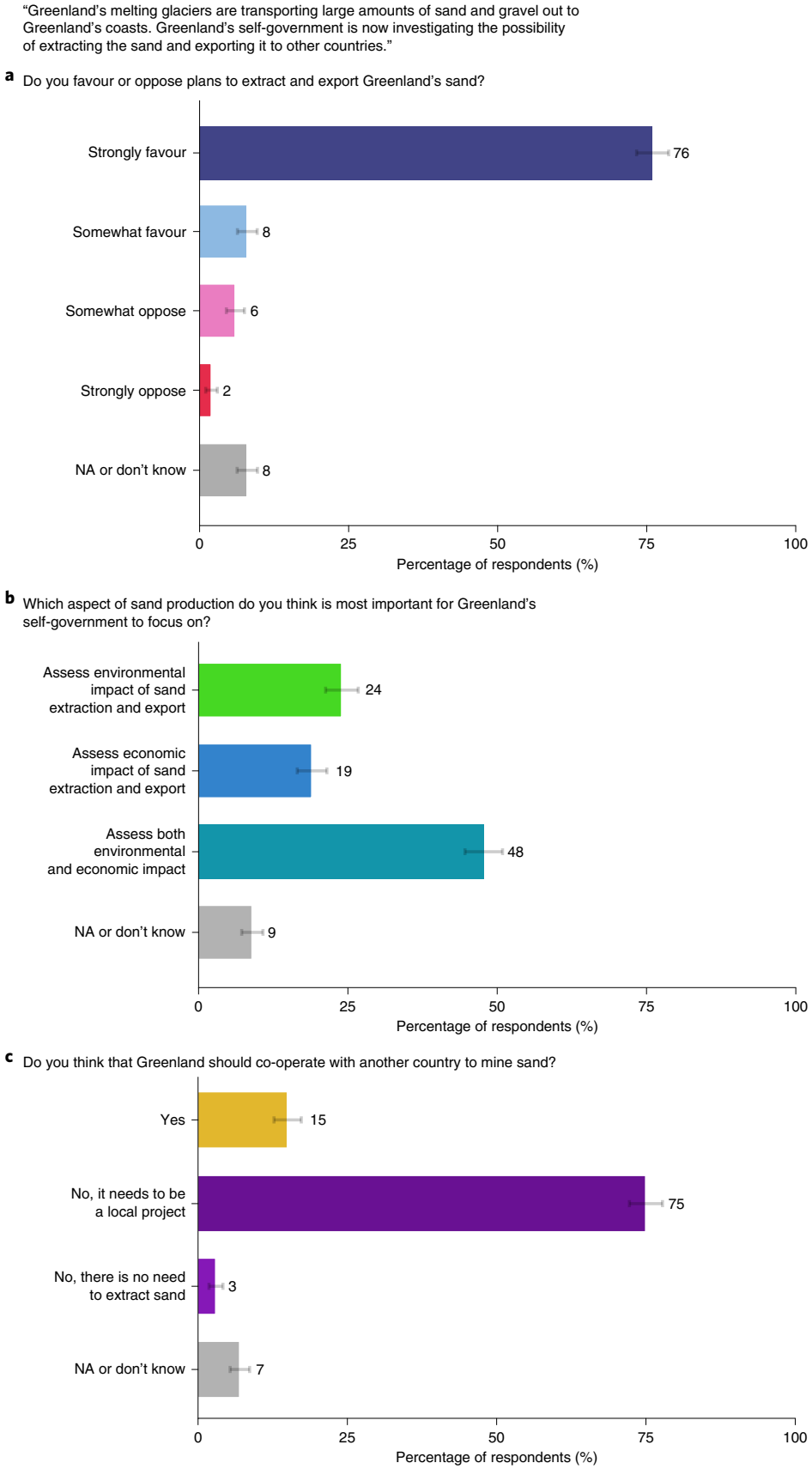

Fig. 1 | Public views in Kalaallit Nunaat on sand-related extraction, environmental policies and extra-national co-operation from a random-sample Kalaallit Nunaat nationwide survey ($N = 939$). a–c, The error bars depict 95% confidence intervals. NA, not applicable. Before responding to these policy questions, the participants were read a brief background information statement (the text at the top in quotation marks), summarizing the findings of Bendixen et al.[5] and announcing the ongoing assessment by Kalaallit Nunaat's self-government.

Table 1 | Survey sample composition pre- and post-weighting by the 2020 adult population demographic characteristics from Statistics Greenland

Surveyed demographic or group	No. of respondents (unweighted)	Percentage of sample (unweighted) (%)	Percentage of sample adjusted to Statistics Greenland population data (weighted) (%)
Total	939	100	100.0
Age: 18–29	232	24.7	25.4
Age: 30–39	178	19.0	19.1
Age: 40–49	111	11.8	13.4
Age: 50–64	295	31.4	30.3
Age: 65+	123	13.1	11.7
Self-identified gender: female	447	47.6	48.8
Self-identified gender: male	492	52.4	51.2
Identity: Greenlandic	850	90.5	90.3
Identity: Danish or Danish-Greenlandic or other	89	9.5	9.7
Region: Kujalleq (South)	122	13.0	12.2
Region: West Sermersooq (Southwest)	294	31.3	32.7
Region: East Sermersooq (East)	30	3.2	5.5
Region: Qeqqata (Midwest)	164	17.5	17.3
Region: Qeqertalik (Northwest)	132	14.1	12.2
Region: Avannaata (North)	197	21.0	20.1
Location: town	827	88.1	86.5
Location: village	112	11.9	13.5

assessments of the prospects of sand mining, with 48% (45–51%) of adults indicating that the government's focus should balance environmental and economic considerations (Fig. 1b). By comparison, about one in four (24% (21–27%)) say that Kalaallit Nunaat should primarily focus on assessing environmental impacts, while about one in five (19% (16–21%)) report that Kalaallit Nunaat should prioritize assessing the economic impacts of sand production.

Climate change knowledge and adaptation preferences. Knowledge about climate change is theorized to support adaptation, although little is known about the relationship between awareness of human-caused climate change and support for national opportunistic adaptation actions, particularly in the Arctic. Interestingly, we find that those aware of anthropogenic climate change have both significantly greater odds of supporting mining glacially derived sand (odds ratio, 1.6 (1.2–2.2)) (Fig. 2) and greater odds of preferring that Kalaallit Nunaat's Namminersorlutik Oqartussat (Greenlandic self-government) assesses environmental impacts (odds ratio, 1.5 (1.1–2.1)) than those who do not believe in human-caused climate change (Fig. 3), even when we control for geographic and demographic factors (Supplementary Table 1).

Discussion

Kalaallit Nunaat and its living and non-living elements comprise a complex adaptive system responding to both local and global climate impacts and policies[50]. Regional Arctic adaptation assessments project melting ice cover to increase non-living resource availability and access[33], presenting emergent opportunities for connecting to the global market (for example, through shipping and trade)[36,51]. The present study directly solicited the national opportunistic adaptation preferences of Kalaallit Nunaat's predominantly Inuit population. Here we find that a large majority of Kalaallit expressly support a specific opportunistic climate adaptation action: extracting and exporting glacially derived sand. Resource extraction has long been appraised as a potential means for Kalaallit Nunaat to diversify its fishery-dependent economy but has been met with mixed reactions[52]. These strongly supportive views on glacially derived sand extraction and export seem to differ from recent public responses to other mining activities in Kalaallit Nunaat. In particular, extractive proposals for the Kuannersuit (Kvanefjeld) deposit have been met with uranium-induced resistance from nearby residents[11] and a majority of the general public, according to a poll[53] published before the April 2021 parliamentary election. Interestingly, the same poll found that 52% support mining projects in general, still well below the large majority (84%) shown here to support glacially derived sand extraction.

Historically, resource extraction has been mostly managed by Danish entities, and current mining projects are largely run by foreign-backed companies, with recent international interests in Kalaallit Nunaat's emerging resources possibly elevating the salience of asymmetric extractive relationships[11,34]. Kalaallit Nunaat–run mining operations are limited and predominantly consist of individual or family mining permit holders. Critically, this includes Kalaallit Nunaat's only active sand mining operation[47]. Our survey provides initial evidence that a large majority of Kalaallit oppose foreign co-operation on opportunistic sand extraction projects arising in response to cryospheric changes in the warming Arctic region. However, since public preferences for non-domestic co-operation may differ at the country and corporation levels, future research can strive to understand whether the apparent majority opposition to extra-national co-operation in sand extraction also extends to public views on foreign firms. Nevertheless, residents' strong preferences for domestic involvement may have particular relevance for local expectations of how co-operative agreements are structured with domestic and foreign firms. For instance, co-operative agreements can be developed to help to ensure local capture of revenues, knowledge and capacity building while also safeguarding Inuit languages, knowledge and culture[34,54].

Prior research indicates that residential proximity to resource extraction and export projects may influence environmental preferences and beliefs[55–57]. Our finding that respondents outside Kujalleq (South Greenland) had greater odds of being in support

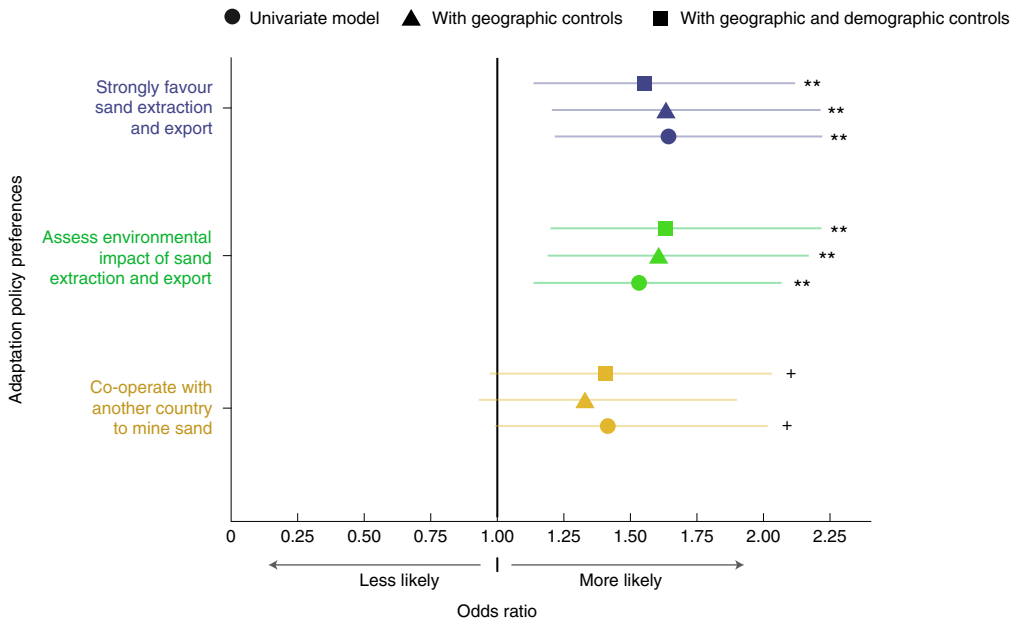

Fig. 2 | Likelihood of adaptation preferences given awareness of human-caused climate change. Estimated odds ratios of adaptation policy preferences for the subpopulation group that believes in human-caused climate change ($N = 479$) compared with the group that does not ($N = 460$). The odds ratios are from alternative plausible statistical model formulations describing a univariate weighted logistic regression model (circles), also controlling for geographic differences (triangles) and further controlling for demographic factors (squares). The error bars depict 95% confidence intervals. $^{+}P < 0.1$, $^{**}P < 0.01$.

of co-operating with other countries to mine sand suggests that proximity to prior foreign-led mining projects may constrain future willingness to co-operate with international partners on adaptive resource exploration. This spatial pattern is consistent with the regional differences in mining opposition recently found in Kujalleq, the region containing the Australian-firm-led Kuannersuit mine[53]. However, this regional difference may arise due to other unobserved factors, so other explanations should be carefully considered or ruled out in future research.

Climate change may alter both the economic prospects and the environmental impacts associated with exploring, extracting and exporting raw materials[34]. Running on a climate-centred policy platform, the newly elected Naalakkersuisut (April 2021) has established that they are in favour of mining activities that do not pollute nearby residential and agricultural areas[53]. A prospective large-scale sand extraction and export industry would probably require large socio-economic and environmental adjustments by the Kalaallit Nunaat society. While the establishment of a sand industry has the potential to contribute significantly to the economy and create jobs[5], it could also have a variety of environmental and social ecological implications. Extraction, processing and transport activities could produce systematic changes in ecological communities[58,59], affect local marine ecosystems[60], introduce invasive species[61], and impact the increasingly economically prosperous tourism industry[62] and possibly also the fishing industry. To date, however, there still exists a great deal of uncertainty around the social ecological consequences of sand extraction, and no public environmental or social impact assessments were available at the time of survey administration[5,7]. In this regard, our survey results imply that the largest proportion of residents prefer that both environmental and economic impacts are weighed in ongoing assessments of glacially derived sand extraction, consistent with Kalaallit Nunaat's current requirement that mining operations eventually undergo both social and environmental impact assessments[63]. Well-coordinated management and assessment involving Indigenous communities, scientists and industries will be essential to sustainably develop opportunistic adaptation activities that promote prosperity while minimizing negative spillovers.

Knowledge about climate change has been shown to be an important motivator for both defensive adaptation and environmental policy preferences in non-polar climates[28,64]. Although we do find that those aware of human-caused climate change have greater odds to think the government should prioritize environmental impact assessments than those who are not, we also uncover compelling evidence that those aware of the human signal in climate change have higher odds to support extracting and exporting glacially derived sand. Our results suggest that knowledge about human-caused climate change may motivate, or alternatively be linked to, opportunistic adaptation preferences. One possible interpretation is that awareness of human-caused warming may be associated with expectations about future melt and resource availability, informing opportunistic adaptation preferences via an information channel. While a causal interpretation is not possible given the cross-sectional design of the present study, future pan-Arctic experimental and longitudinal studies should seek to investigate whether raising awareness of anthropogenic climate change promotes a variety of opportunistic and defensive adaptation actions. Our divergent findings that residents privy to human-caused climate change are more likely to be simultaneously pro-emerging resource extraction and pro-environmental assessment are consistent with recent climate policy narratives in Kalaallit Nunaat that seek to balance the national objectives of profiting from emerging opportunities in furtherance of financial sustainability and minimizing further environmental degradation in service of environmental sustainability[35].

Arctic livelihoods are shaped by the confluence of climate, society, ecology and geology and are particularly prone to shifts caused by climate change[65]. Yet, Arctic populations' perspectives on these changes are generally under-surveyed relative to those of other populations[54,66], with much Arctic social research historically favouring

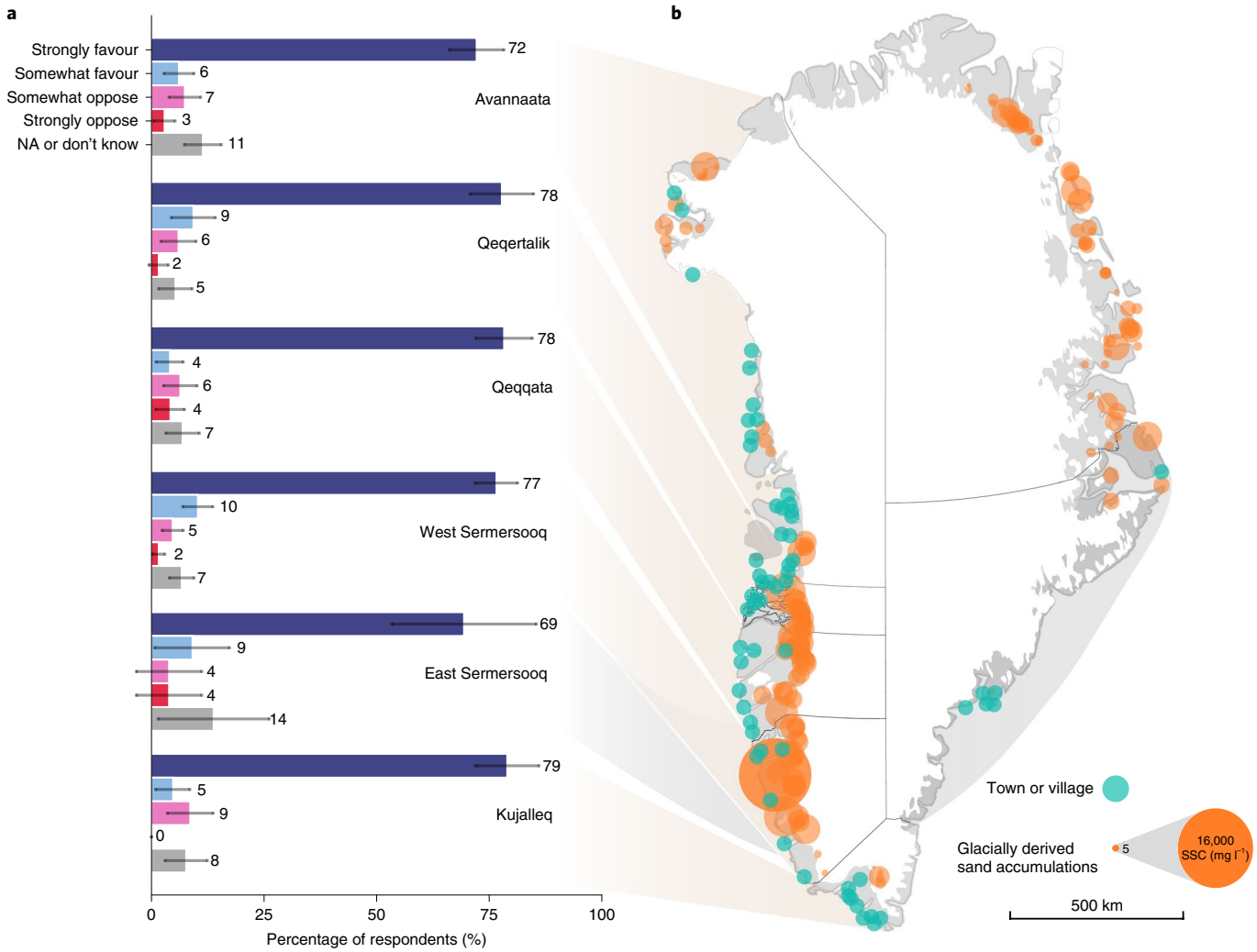

Fig. 3 | Regional distribution of sand mining support and opposition and of glacially derived sand deposits. a,**b**, Sand mining exploration preferences by geographic (kommune) region (**a**) and distribution of sand deposits (**b**). The Sermersooq municipality has been divided into west and east subregions according to the Greenland Ice Sheet natural boundary. The error bars depict 95% confidence intervals. SSC, suspended sediment concentration. Beige shadings refer to western (kommune) regions, and grey shading refers to the eastern half of the Sermersooq region.

small samples and non-probability sampling approaches that do not provide an equal chance of inclusion. As the cryosphere responds to warming, adjusting strategies to emerging conditions requires a delicate balance of developing national interests and valuing, respecting and safeguarding local values and ecosystems. The systematically inclusive approach used in this study to invite representative public input on adaptation actions may complement community participatory methods for Arctic resource exploration and knowledge co-production[51,67]. Indeed, mixed methods approaches supporting multiple modes of public participation that enable depth of involvement and breadth of representation will be key to ensuring social inclusion and engagement before, during and after adaptive development projects. These insights can be triangulated with the findings of, for example, open public consultation and hearing processes.

This survey provides data for debate by citizens, decision-makers and stakeholders. However, it provides only a snapshot in time of public opinion. As scientific knowledge and public discourse coevolve on this emerging topic, future survey waves can track how the population responds to both opportunistic and defensive adaptation policies, as well as future climate mitigation measures in Kalaallit Nunaat. Such time-series data can also enable the comparison of attitude trajectories over time between glacially derived sand and other resources in Kalaallit Nunaat, such as rare earth metals and uranium. Two major developments have transpired since we conducted the survey that warrant future study. First, although the government of Greenland long operated under a territorial reservation from the Paris Agreement[16], the newly elected government in Kalaallit Nunaat recently revisited the decision and during the 2021 United Nations Climate Change Conference (COP26) signalled plans to ratify the Paris Agreement[68]. If passed by Inatsisartut (Greenland's parliament), such a change in emissions policy may alter how Kalaallit Nunaat's population and Namminersorlutik Oqartussat evaluate the environmental footprint and economic prospects of opportunistic adaptation measures—including sand mining—moving forward.

Second, shortly following this announcement, Naalakkersuisut published its official assessment of the economic potential of mining and exporting Kalaallit Nunaat's sand internationally[69]. Although the report left open the possibility of future sand extraction if market conditions evolve, it concluded that the economic case for sand extraction and export was presently insufficient given the estimated combination of transport costs and assumed quality of the material[69]. However, no in situ measurements of material characterization or detailed mineral processing analyses have

been made at this point to determine the suitability[69]. In this regard, the prospect of linking Greenlandic sand to the global market is following a similar exploration trajectory to numerous other resources in Greenland (including certain resources that have recently become economically viable). For instance, increasing global demand for rare earth elements needed in electric vehicles has recently elevated prospects for rare earth mining in Kalaallit Nunaat[11], while conversely, market fluctuations have led to the sudden closure of the Nalunaq Goldmine following years of operation and earlier prospecting[33]. Climate-change-driven melt of the Greenland Ice Sheet is simultaneously contributing to local sand accumulation and to global geographic variability in sea-level rise[70], presenting starkly different local adaptation opportunities and global adaptation challenges. Indeed, projected urbanization to house the growing human population and construction of coastal defences to protect low-lying regions from sea-level rise are both expected to demand extraordinary sedimentary resources[7,71].

Prior research on both climate adaptation and sand mining impacts in Kalaallit Nunaat has predominantly focused on defensive adaptation to negative climate risks, extractive externalities and possible spillovers, rarely inviting direct input from Kalaallit Nunaat's majority Indigenous population on large-scale adaptive actions. Our work reveals that a surprisingly large majority—three out of four Kalaallit residents—strongly support opportunistically extracting and exporting glacially derived sand to the global market, and a majority prefer local over foreign involvement. Our results challenge broad assumptions about Arctic Indigenous populations being predominantly conservationist in a warming climate. Indeed, those aware of human-caused climate change have even greater odds of supporting opportunistic adaptation, in addition to having higher odds of prioritizing the assessment of environmental impacts. How Kalaallit Nunaat's population adapts to its changing climate opportunity and risk landscape over time will have complex implications for both local prosperity and global sustainability. Future research should seek to understand the primary and second-order economic, socio-ecological and psychosocial effects of opportunistic climate adaptation actions in the Arctic (and globally) to guide policy and planning in this domain.

Methods

We conducted a nationwide phone survey between December 2020 and January 2021 with a representative sample of Kalaallit Nunaat's adult population ($N=939$). Telephone interviews were administered by trained, native-speaking personnel from the independent, Nuuk-based polling institute HS Analyse. The interviewers dialled randomly drawn phone numbers belonging to adult residents spanning all of Kalaallit Nunaat's municipal regions. The list of telephone numbers included all registered landline, mobile and pre-paid numbers in Kalaallit Nunaat (the latter is quite rare in survey research). Informed consent was obtained from the participants, and no participant compensation was provided. The response rate was 47%, as calculated according to American Association for Public Opinion Research standard definition 4 (ref. [72]). To account for any potential sampling biases, probability weights were computed for the survey to keep the results representative for the Kalaallit Nunaat adult population. The analyses were weighted for representativeness by age, sex and municipal division, using 2020 demographic data from Statistics Greenland (www.stat.gl). The survey sampling complied with all relevant ethical regulations, included 12 primary questions and several background demographic questions, and was available in three languages: Kalaallisut (Greenlandic), Danish and English. Each question was tri-lingually translated and reverse-translated during this process. The survey question items adopt the framing of widely used multiple-choice policy preference questions used to solicit public opinion about proposed and prospective national policies. This item structure has been used in previous nationally representative surveys of Arctic nations, including in Kalaallit Nunaat[16,73–75]. Additionally, standard climate beliefs questions were also included[66], along with demographic background items (Supplementary Data 1).

Weighted national and subnational response summaries were computed using the 'Survey' package in R (ref. [76]). To quantitatively assess and test predictors of sand-related adaptation policy preferences, we estimate three weighted logistic regression models. This type of model is regularly used to investigate categorical dependent variables in survey research. Assuming that $p(y_i=1)$ denotes the conditional probability of a specific policy preference response (for example, strong support for sand extraction and export) for the individual respondent, the odds of this response are given as $O(y_i=1)=p(y_i=1)/p(y_i\neq 1)$. This logistic regression specification models the conditional log odds as a function of k predictor variables $x_{1i}, x_{2i}, \ldots, x_{ki}$:

$$\ln[O(y_i=1)] = \ln\left[\frac{p(y_i=1)}{p(y_i\neq 1)}\right] = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_k x_{ki} + \epsilon_i \quad (1)$$

We estimate the coefficients of equation (1) using maximum likelihood estimation and further exponentiate the estimated coefficients to obtain odds ratios, which can be interpreted as the multiplicative effects on $O(y_i=1)$. To aid interpretation, odds ratios greater than 1.0 imply that higher values of an independent variable are associated with higher odds that $y=1$ and thus signify 'positive effects'. Conversely, odds ratios below 1.0 mean that higher x values are associated with lower odds that $y=1$ and thus describe 'negative effects'.

We specify predictors for each model and outcome listed on the left side of Table 1, proceeding sequentially from a univariate model estimating the conditional probability of specified adaptation policy preferences as a function of awareness of anthropogenic climate change (base: not aware), to models that add a geographic categorical control variable with levels for each primary municipal region (base: Kujalleq (Southern Greenland) (Fig. 3b)), to a model that additionally includes demographic controls for age group (base: >65) and self-identified gender (base: female). Awareness of anthropogenic climate change—a common measure in studies on climate-related opinions and behaviours[77]—was coded using the responses from two standard survey items previously piloted and adapted for use in nationwide surveys in Kalaallit Nunaat, one assessing climate belief ("1. Do you think that climate change is happening? i) Yes ii) No iii) Don't know") and one assessing knowledge about the cause of climate change ("2. If climate change is happening, do you think it is caused mostly by…? i) Natural changes ii) Human activities iii) Neither iv) Other v) Don't know"). Thus, participants who responded 'Yes' to climate change happening and 'Human activities' as the predominant cause of climate change were coded as being aware of anthropogenic climate change (AACC = 1), while those who responded otherwise were coded as being not aware of human-caused climate change (AACC = 0).

Ethics statement. The survey research administration and analysis followed the American Association for Public Opinion Research code of ethics. All respondent information was anonymized in a pre-processing stage, and only aggregate statistics are reported.

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The data that support the findings of this study are available at https://doi.org/10.7910/DVN/CQ4CY4 (ref. [78]).

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Author contributions

M.B. and K.M. framed the scope of the manuscript and together with R.L.N. developed the survey questionnaire. K.M. and J.L.P. structured the data. All authors analysed the data, and K.M. produced the graphics. All authors contributed to the writing, editing and revision of the manuscript.

Competing interests

The authors declare no competing interests.

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Software and code

Policy information about availability of computer code

Data collection	All data analyses executed for this study was carried out using the R software platform (version 3.1.0. or later)
Data analysis	Custom code written using R software platform was used to quantitatively assess and test geographic, demographic and climate change belief predictors of sand-related adaptation policy preferences.

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Study description	We conducted a nationwide phone survey with a representative sample of Greenland's adult population (N = 939).
Research sample	2.5% (n=939) of the Greenlandic adult population were interviewed. Analyses were weighted for representativeness by age, sex and municipal division, using 2020 demographic data from Statistics Greenland(www.stat.gl). The survey included 12 primary questions and several background demographic questions and was available in three languages: Greenlandic, Danish, and English. Each of the questions were tri-lingually translated and reverse-translated during this process.
Sampling strategy	Telephone interviews were administered by trained, native speaking personnel from the independent, Nuuk-based polling-institute HS Analyse. Interviewers dialed randomly drawn phone numbers belonging to adult residents spanning all of Greenland's municipal regions. The list of telephone numbers included all registered landline, mobile, and also pre-paid numbers in Greenland; with the latter quite rare in survey research.
Data collection	Interviews were recorded, answers noted with pen and paper and conducted as a phone survey. The trained phone surveyors were not informed about experimental conditions prior to conducting the telephone interviews. Informed consent was obtained from the participants and no participant compensation was provided.
Timing	The phone survey took place From December 2020 to January 2021.
Data exclusions	No data was excluded from the analysis.
Non-participation	The response rate was 47%, as calculated according to AAPOR standard definition 430. To account for any potential sampling biases, probability weights were computed for the survey to keep results representative for the Greenland adult population.
Randomization	Participants were not allocated into experimental groups.

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Population characteristics	See above
Recruitment	Interviewers dialed randomly drawn phone numbers belonging to adult residents spanning all of Greenland's municipal regions. The list of telephone numbers included all registered landline, mobile, and also pre-paid numbers in Greenland; with the latter quite rare in survey research.
Ethics oversight	The survey research administration and analysis followed the AAPOR code of ethics. All respondent information was anonymized in a pre-processing stage and only aggregate statistics are reported.

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