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Development of an interdisciplinary conceptual framework to understand marine energy transitions in North Sea coastal communities

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ABSTRACT

This perspective paper outlines a framework to reimagine and theorise marine energy transitions, defined as shifts from historic whaling to oil and gas, through to contemporary offshore renewables, to improve how we understand such transitions in the past, and how we might predict and manage their development for more sustainable futures for coastal communities. We advocate for an interdisciplinary place-based and relational approach to understand changes in marine energy transitions and how these complex changes have impacted coastal communities. We present an integrated interdisciplinary approach that looks at community connections with the marine environment addressing social, economic and environmental challenges. Whilst some marine transitions have been well studied, comparatively little attention has been given to marine energy transitions and therefore this paper proposes a new way of thinking. It will support researchers, policy-makers, and local stakeholders seeking a more holistic, people-centred approach to energy transitions. Crucially, we argue for more inclusive and interdisciplinary research that engages a wider range of community voices and perspectives alongside the interests of the state and capital. We suggest that such approaches can generate more nuanced and inclusive theories as planners and policy makers conceptualise how marine energies, their transitions, and their governance might be organised in our shared futures.

Introduction to coastal communities and marine energy transitions

Our coasts and seas, along with the services they provide, support human activities which in turn can affect both the marine environment and the coastal communities that depend on them. Coastal communities are defined here as people whose lives, livelihoods or interest are closely connected to the coastal and marine environment, and includes communities of place, practice and interest [1]. Coastal communities, in the North Sea for example, have experienced multiple industrial transitions, ranging from historical shifts in whaling, fisheries, coal export, oil and gas, and aggregate extraction, to more recent developments in offshore renewables, other energy sources and the expansion of sectors such as shipping, tourism, and recreation [2–4]. These transitions have impacted on coastal communities through social (e.g. heritage loss and identity change [5]), economic (e.g. communities facing economic hardship and social fragmentation [6]) and environmental (e.g. Habitat change and biodiversity loss [7]) change. Many of these industries have followed boom-and-bust cycles [8] requiring communities to adapt in response to changing economic, social and environmental conditions, a challenge often exacerbated by reliance on a limited number of extractive maritime industries [9,10]. Whether communities thrive [11] or struggle [12] during these transitions, is guided by several factors, including socio-economic conditions, the political economy,

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governance, and environmental pressures. The collapse or restructuring of North Sea coastal industries represents a significant socio-economic shift. While some industry transitions have been relatively well studied [13–16] and share common drivers such as global markets, policy changes, and environmental pressures; transitions in the marine energy sector differ in important ways, including their resource base, transboundary considerations, governance frameworks, and long-term technological trajectories.

This paper explores Marine Energy Transitions (METs). Our specific focus is on exploitation of marine energy resources, from whaling (1740s to 1800s) to fossil-fuel extraction (1964 to present day), which has reshaped ecosystems and patterns of coastal development, and newer industries such as offshore wind (1991 to future) which bring different but equally complex dependencies. We recognise that METs are a process of accumulation [17], where overlapping energy regimes co-exist, resulting in the growth and decline of marine energy industries, including energy production, infrastructure, regulation and consumption. Despite their scale, METs remain poorly understood in relation to their social, cultural, and institutional impacts. We argue that a new way of thinking is required, one that recognises that METs are multi-dimensional, multi-temporal and cumulative processes, shaped by interlinked dynamics of natural capital, heritage and justice. This perspective reframes transitions as place-based and relational, involving complex trade-offs between economic renewal, environmental sustainability, and social justice. Aligning with eco-social-economics approaches found in natural capital valuation research [18–20], we propose an interdisciplinary framework, that can feed into the impact assessment and planning processes, and integrates environmental and social sciences, with arts and humanities [21], challenging the dominance of siloed models, and calling for a more inclusive understanding of change [22]. It is intended to guide future studies, policy design and marine planning, providing a practical tool for identifying trade-offs, highlighting overlooked community perspectives and supporting more adaptive governance.

Interdisciplinary Conceptual Framework

Our proposed framework emphasises two intersecting dimensions: (1) spatial (place-based) and (2) temporal, integrating environmental, social, and cultural perspectives to understand how energy transitions are experienced, represented, and contested in coastal communities. Across the marine energy sector, the location, history, and production methods influence how communities engage with infrastructure, the social-ecological system and the geographical setting. Whaling was embedded in local economies and cultures (such as Dundee, Scotland where whaling occurred for over 150 years, directly supporting the city's textile industry) [23], while fossil fuel industries operate through global corporate structures and regional workforces (such as North Sea oil and gas companies headquartered in international cities but employing local crews for offshore rigs and onshore support services). Some renewable energy models offer community ownership and benefit-sharing (such as financial compensation and participation in planning [24]), though this varies significantly across regions [25,26], Spatial shifts in energy production affect the structure and stability of local labour, for instance when offshore wind farms replace or limit fishing areas, forcing some fishers to leave the industry while creating new jobs in turbine installation, maintenance, and port services [27,28], The reduced visibility of marine energy infrastructure makes it harder for communities to understand and influence developments, highlighting the need for better mapping of how they perceive and interact with these grey (e.g., harbour walls, substations) and blue (e.g., water-based, wind turbines) structures.

This framework therefore places resilient coastal communities at its core, recognising their importance as both actors and subjects in METs, and conceptualises transitions through three intersecting themes: Natural Capital approaches (NC), *Re*-peopling the Past (RP), and Just Transitions (JT) (Fig. 1). Natural capital provides evidence on environmental, economic and socio-cultural conditions; re-peopling the past situates present-day transitions within longer histories of work, identity and landscape change; and just transition principles guide how benefits, burdens and participation are addressed in governance and planning. Across energy transition research and policy, there is growing recognition that decarbonisation pathways play out unevenly across places, and that transition planning must account for place-specific socio-economic challenges and include local voices in decision-making [29,30]. At the same time, approaches that monitor or evaluate transitions through narrow or technocratic indicators risk marginalising less easily quantified socio-cultural dimensions, including identity, narratives and recognition [30]. Its novelty lies in the integration of environmental valuation, heritage-informed perspectives and justice-oriented approaches, into a single interdisciplinary Theory of Change (ToC) (Fig. 1) for METs. The framework operationalises these intersections (NC+JT, JT+RP and RP+NC), through a set of recommendations (Rec. 1–7; Table1) discussed in Section 3, providing a structured architecture for interdisciplinary research, assessment and decision-support.

Fig. 1 further articulates how natural capital, re-peopling the past and the just transition function as interconnected and independent dimensions of a place-based theory of change, rather than being treated as separate strands of analysis. Their interaction highlights that METs are cumulative, relational and unfold over time, and that ecological change, cultural meaning and social justice jointly shape coastal community outcomes. Together, these dimensions provide a practical way to identify trade-offs, reveal overlooked impacts, and support policy and planning decisions that are environmentally robust, socially fair and grounded in local experience.

Historically, North Sea energy industries have evolved through successive or overlapping phases shaped by technological change and global demand. From 18th-19th century whaling, which supplied lighting fuel and industrial lubricants [31], to the dominance of coal and later oil and gas, each transition reconfigured coastal infrastructures and livelihoods including, for example, through rapid expansion of harbour and transport infrastructure and major restructuring of local employment, as offshore oil development transformed coastal economies in North East Scotland [32]. The rise of petroleum-based energy embedded fossil-fuel economies deeply within North Sea communities [33,34], and these legacies continue to shape how current decarbonisation efforts and offshore renewables are experienced and governed [35,36]. These phases reveal how energy systems leave enduring social, cultural, and material legacies that continue to influence coastal resilience and identity. Our proposed framework addresses these challenges by combining elements of three disciplines (Fig. 1), leading to an integrated theory of change.

Natural capital approach

Natural capital approaches recognise the links between ecosystem assets, flows of ecosystem services and the benefits they provide for society which can be valued in ecological, economic and/or socio-cultural terms [37]. However, spatial data are often limited or proprietary, or too coarse to capture community-level transformations [30]. The ecological and societal diversity of coastal communities, and the intangible nature of some ecosystem services, especially cultural services, pose challenges for planning and decision-making. Valuing these services is further complicated by differences in interpretation among stakeholders [38,39]. Existing assessments of the socio-cultural dimensions of natural capital, including well-being, often rely on indicators that may not reflect community perspectives [40,41], highlighting the need for more participatory, bottom-up approaches [37]. Applying a natural capital approach enables the capturing of a wider range of benefits that society obtains from the marine environment and therefore accounts for ecological and socio-cultural values which have previously been overlooked with the focus being solely on

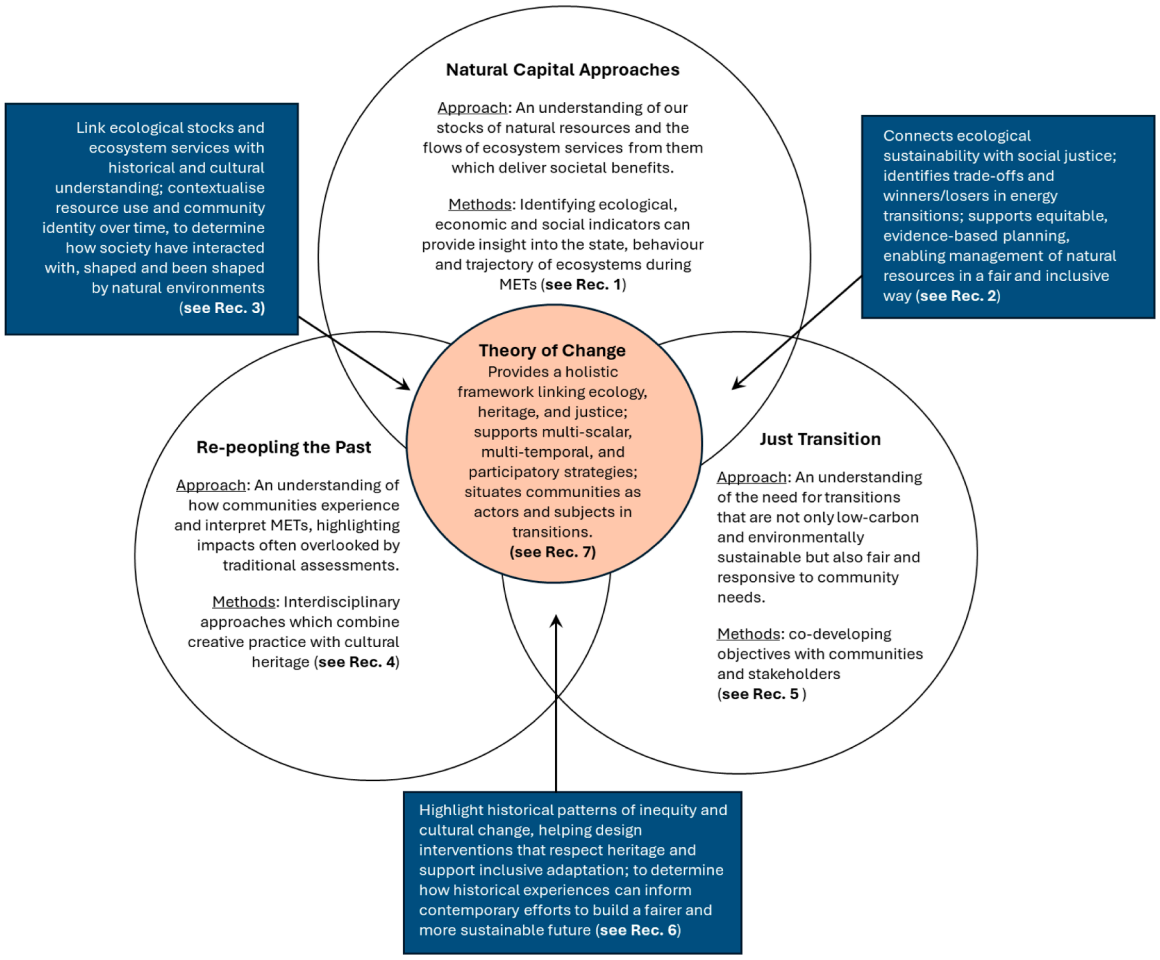

Fig. 1. Interdisciplinary conceptual framework for investigating METs, over space and time, for achieving coastal community resilience (see Table 1, Section 3 for Recommendations).

economic values.

The importance of taking a natural capital approach is further illustrated by the whale economy which demonstrates a full transition in the UK, from exploitation to protection and tourism [42], shifting from sources of oil and baleen to indicators of ecosystem health [43–45]. However, this trajectory is not globally universal, and, in some societies (e.g. Greenland), whaling continues to hold cultural, dietary or economic significance [46], reflecting values that may conflict with global conservation goals. During the UK's whaling era, whales were primarily valued for their provisioning services, which provide material goods such as food, energy, or raw materials [47]. Today, however, their value extends beyond provisioning services, contributing to societal benefits from both regulating (e.g. carbon cycling) and cultural (e.g. recreation, tourism, education) services [48]. These non-extractive societal benefits remain poorly quantified in economic terms but reflect a broader shift from extractive to conservation-based marine economies. This transition requires new forms of labour, local acceptance, policy frameworks, and identity formation. Coastal communities are increasingly challenged to adapt to these less tangible, but potentially more sustainable, forms of marine resource use, shaped by conservation goals, climate change, and the growth of marine tourism.

Re-peopling the past

Cultural heritage and creative practice, including tangible heritage such as archaeological artefacts and monuments, and intangible heritage such as songs and stories, contributes to a sense of place and identity, especially in times of change [49,50]. As the Petrocultures Research Group [51]. suggests, these cultural narratives make visible the emotional, social, and ethical dimensions of energy. They also reinforce identity and belonging, strengthening community resilience during transitions [52]. Arts-based approaches, including visual, narrative and participatory practices, offer valuable ways to surface lived experience, emotional responses and place-based knowledge that are often absent from conventional socio-economic assessments, yet are critical for inclusive planning and socially legitimate transition governance.

Coastal communities have a complex place-based relationship with energy infrastructure. While offshore projects may be out of sight, their effects are still impactful, for example the impact of related onshore infrastructure and manufacturing and decommissioning activities. For inshore developments, sensory elements, such as turbine noise, visual or industrial activity, can affect mental health and well-being [53], while changes to the seascape and coastal infrastructure may influence or change local identity and public perception [54]. The changing aesthetics of marine spaces and places, disruptions to daily routines, and transformations in cultural meaning all shape community responses and are often overlooked in technical assessments [55].

Transitions are by their very nature temporal, making awareness of the heritage perspective essential [56]. Heritage is not static, but a dynamic tool for navigating change and enhancing cultural sustainability [52]. The justice dimension of transitions ensures that transition processes are not technologically neutral, but embedded in culture, values and the political economy of place, underpinning the need for a wider scope and perspective of social change. Additionally, by its nature, stocks of natural capital and flows of ecosystem services will change

over time because of natural and anthropogenic influences [57]. Furthermore, coastal communities often possess long-standing traditions, intergenerational knowledge, and identities tied to the sea, which are vulnerable to displacement or commodification through industrial change. In some cases, such as Aberdeen and Orkney in Scotland, Hull in England or Esbjerg in Denmark, energy infrastructure has become part of local identity and heritage [49,58]. Yet, these changes can also erode cultural sustainability and social cohesion [59]. Understanding METs as temporal, cultural, and political processes, rather than purely technological shifts, highlights the need to consider heritage, justice, and identity in shaping equitable and sustainable coastal futures.

Just transition

In coastal communities, METs unfold as spatially embedded, socially mediated processes shaped by geography, labour and identity [60–62]. For example, in places with long-standing offshore histories (e.g., NE Scotland), energy transitions have been described as reshaping not just job availability but occupational identity and place-based narratives linked to offshore work, with justice concerns extending beyond 'new jobs' to questions of community continuity, recognition and belonging [63]. This accumulation is at times influenced by conflicting policy frameworks [60,64], which are subject to change over political cycles. The cumulative impacts of successive energy transitions are particularly pronounced in coastal communities, given economies have often been anchored in a small number of place-bound traditional and extractive industries [9], with deep-rooted cultural and heritage ties that make energy transitions socially and symbolically consequential as well as economic [65]. Energy developments have therefore left significant material, ecological and socio-cultural legacies in coastal places, highlighting the roles that local communities have played in these industries, as well as their wider effects [8]. METs have redefined labour markets and community resilience, raising well-documented concerns around social justice [66].

METs occur in coastal economies shaped by layered industries, including shipping, fishing, aquaculture, and tourism. Marine renewables intersect with these sectors, sometimes complementing, but often competing for space [67]. Persistent inequalities, such as energy poverty, exclusion from planning, or rapid shifts in labour markets compound the vulnerability of many coastal regions [68–70]. Their resilience is shaped not only by natural and financial capital but also by governance structures, cultural assets, and their capacity to adapt to infrastructure changes that shape their communities.

Policy frameworks, such as the Scottish Government's draft *Energy Strategy and Just Transition Plan* [71], highlight the multisectoral impacts of transition and the importance of equity, voice, and governance [29,30]. Governance choices, shaped by institutional histories, influence outcomes e.g., offshore wind debates reveal tensions between centralised, industrial-scale projects and decentralised, community-led initiatives [72], and highlights that the research remains concentrated on oil and gas and offshore wind, with little attention to historical aspects of coal or emerging sectors such as carbon capture or hydrogen. These institutional dynamics also interact with social and cultural dimensions. In addition to affecting marginalised groups, such as indigenous communities and low-income areas [6], transitions can unsettle long-standing occupational identities and social status. For example, oil and gas workers, once central to regional economies, may need to navigate shifts in identity and status as sectors decline. Similar patterns have been observed in past blue economy transitions, where fishers previously held significant social standing but later faced loss of influence and cultural recognition (e.g., [73]).

Regional variation in response to METs is significant. In some regions, the move to renewables has revitalised local economies e.g., [74–76]. In others, it has encouraged an experimental, participatory approach to energy democracy [49,77]. Elsewhere, the same technologies are perceived as externally driven projects which have led to resistance, social division, deprivation or skepticism on employment prospects [68,78–81]. Some areas, that have been more recently engaging with large-scale offshore wind in "nationally significant infrastructure" projects, have reported limitations to the consultation process and provision of local benefits such as employment or utility reductions [82].

As the Just Transition discourse grows globally, the challenge is not only to decarbonise energy systems at pace and scale, but to do so in ways that are just, place-based, and community-informed [29]. A place-based and temporal approach is key to understanding how past transitions influence present perceptions, offering lessons from history and showing how identities remain shaped by former energy practices.

Theory of change

When applied, the framework will enable cross-sectoral comparisons to examine how legacy industries shape coastal communities and influence their readiness for change, while also revealing the lived experiences and governance challenges that underpin transition processes. This approach will support the use of multi-method evidence, integrating demographic, ecological, and ethnographic data to inform more equitable and robust decision-making [29,30]. In doing so, it will contribute to the development of a holistic Theory of Change, with the potential to support coastal communities in identifying pathways and strategies that deliver locally preferred outcomes from METs.

Recommendations to chart the way forward

We therefore call for a more inclusive, interdisciplinary, and community-rooted approach to METs that integrate local, cultural, qualitative, and expert knowledge, leading to robust, equitable, and trusted decisions. Coupling ecological and heritage-based assessments highlights the importance of regionally sensitive planning that considers cultural identity and social resilience alongside economic imperatives. Reframing ecosystem services to elevate cultural and relational values deepens understanding of the marine environment as integral to people's lives, histories, and communities. Embedding community voices through participatory frameworks will help ensure METs are not only technically sound but also socially just and capable of delivering long-term, equitable, and sustainable outcomes.

This integrated approach can be understood through the three key interacting topics:

- Linking **Natural Capital + Just Transition** ensures that ecosystem governance accounts for labour transitions, community participation, and intergenerational equity, highlighting that ecological benefits and burdens must be distributed fairly.
- Connecting ***Re*-peopling the Past + Natural Capital** recognises that historic uses and cultural landscapes shape how communities value and interact with ecosystems, allowing planning to capture both ecological functions and the lived, remembered significance of coastal spaces.
- Combining **Just Transition + *Re*-peopling the Past** demonstrates how past energy regimes continue to influence community experiences, showing that addressing future benefits also requires acknowledging historical harms, losses of identity, and social meanings tied to work and place.

A series of recommendations can be made for applying such an integrated interdisciplinary approach to METs (see Table 1). Understanding METs requires interdisciplinary research that captures ecological, social, and cultural dimensions alongside economic ones. This broader evidence base supports local-scale stakeholder engagement and informs planning that reflects community priorities. Several emerging regulatory and policy drivers highlight the need for such an approach. In Scotland, the Climate Change (Emissions Reduction

Table 1
Recommendations for an integrated interdisciplinary approach to assessing METs.

Recommendations		
Rec. 1	NC	Advance natural capital thinking beyond traditional economic valuation, recognising the marine and coastal environment not only as a natural asset but as integral to sustainability, local histories, cultural traditions, and community cohesion.
Rec. 2	NC+JT	Integrating top-down and bottom-up engagement for both market and non-market values to communicate values across the diverse range of stakeholders that derive benefits from natural capital.
Rec. 3	RP+NC	Integrate ecological assessments and heritage-based methods to support inclusive, regionally sensitive planning that addresses environmental sustainability, social justice, wellbeing, and resilience alongside economic priorities.
Rec. 4	RP	Prioritise community voices through co-production of knowledge developing cross-disciplinary assessment frameworks and indicators that acknowledge human–nature relationships to support Just METs.
Rec. 5	JT	Incorporate a justice lens that includes labour transitions, local ownership, participation, and the resolution of historic and contemporary inequities.
Rec. 6	JT+RP	Respecting diverse cultural values, safeguarding rights and dignity, acknowledging local knowledge systems, and addressing historic marginalisation in decision-making (see [86, 87])
Rec. 7	ToC	Incorporate knowledge from multiple sources, quantitative, qualitative, local, and expert, into decision-making to ensure inclusive, robust, and equitable outcomes, increase trust, and identify impacts and opportunities overlooked by traditional assessments.

Targets) (Scotland) Act 2019 explicitly requires future climate plans to give due regard to five "just transition principles" addressing jobs, poverty, infrastructure, and social consensus, supported by independent monitoring from the Just Transition Commission. Across the wider UK, while there is no direct regulatory driver, substantive policy commitments call for broader perspectives, including the Great British Energy Act 2025, which addresses community resilience, local energy, jobs, and supply chains, and the 2025 Carbon Budget and Growth Delivery Plan, which embeds energy security, community wellbeing, and environmental considerations. These policy drivers, alongside, for example, DEFRA's 25-Year Environment Plan [83], Scotland's Blue Economy Vision [84] and the Scottish Government's Just Transition Plan [71] and the UK Research and Innovation (UKRI) strategy 2022–2027 [85], demonstrate a growing emphasis on the importance of interdisciplinary working to address complex challenges and drive innovation, including a focus on diversity, connectivity, resilience and engagement.

Whilst our framework has been conceptually developed, its implementation remains a key task for future research, requiring collaboration across disciplines and sectors. It will support researchers, policymakers, and local stakeholders seeking a more holistic, people-centred approach to energy transitions. By connecting environmental, social and heritage/arts knowledge, the framework provides a way for both the research and policy communities to understand, not just how fast we can decarbonise, but how well communities can live with, benefit from and sustain those changes over time. While our study focuses on METs, the framework has wider applicability across the marine and terrestrial environments as well as in other industries, land-use planning and broader transition processes.

CRediT authorship contribution statement

Kate Gormley: Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Daryl Burdon:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **David Atkinson:** Writing – review & editing, Writing – original draft, Funding acquisition. **Anne Bevan:** Writing – review & editing, Writing – original draft, Funding acquisition. **Jennifer Harland:** Writing – review & editing, Writing – original draft, Funding acquisition. **Sofie Illemann Jæger:** Writing – review & editing, Writing – original draft. **Sandy Kerr:** Writing – review & editing, Writing – original draft, Funding acquisition. **Daniel H.J. Lee:** Writing – review & editing, Writing – original draft, Funding acquisition. **Amy McCarron:** Writing – review & editing, Writing – original draft. **Scott J. McGrane:** Writing – review & editing, Writing – original draft, Funding acquisition. **Lauren H. McWhinnie:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Tavis Potts:** Writing – review & editing, Writing – original draft, Funding acquisition. **Daria Shapovalova:** Writing – review & editing, Writing – original draft, Funding acquisition. **Jack Sheehy:** Writing – review & editing, Writing – original draft. **Antonia Thomas:** Writing – review & editing, Writing – original draft, Funding acquisition. **Karen A. Alexander:** Writing – review & editing, Writing – original draft, Project administration, Funding acquisition.

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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Data availability

No data was used for the research described in the article.

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