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REVIEW ARTICLE

Connectivity Without Permanence: Intermittent Thermal Corridors in a Dynamic Ocean

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ABSTRACT

Increasingly anomalous ocean conditions driven by climate change are fundamentally altering marine ecosystems, reshaping the distributions and movements of highly mobile species. Many migratory species rely on environmental and thermal cues to time their movements between foraging and breeding grounds, ensuring that migration occurs under favorable conditions essential for physiological processes, such as growth, development, and reproduction. Importantly, as ocean temperatures rise, intermittent corridors to essential habitats for foraging, reproduction, and development, known as "thermal corridors," may lead to spatiotemporal shifts of the migratory patterns for many marine species. In this paper, we identify several examples of thermal corridors that vary across space and time. We discuss the periodicity of these thermal corridors, the physical features that define their spatial extent, and differences in species use. We synthesize existing evidence to suggest that intermittent thermal corridors may be more common than previously assumed, with serious implications on the life history traits and population dynamics of migratory species in a changing climate. Importantly, a deeper understanding of these climate-driven shifts in migratory patterns is vital to inform conservation and management efforts in the context of rapidly-changing ocean conditions.

1 | Introduction

Migration can be broadly characterized as a persistent, directed form of locomotion across greater spatial and temporal scales than routine movements, distinguished by its population-level ecological consequences (Dingle 2014). The ability of migratory species to navigate across habitats is an integral part of completing life history phases, ensuring population persistence, and maintaining genetic diversity (Hilty et al. 2012; Newmark 1987; Pendoley et al. 2014; Williams et al. 2022). Many species migrate consistently between habitats on a seasonal or annual cycle in concordance with various life history traits, such as the phenology of growth and reproduction (Bauer et al. 2020; McNamara et al. 1998). The timing of migration is an essential factor in maximizing benefits or minimizing costs associated with travel, including refuge from predation (Kubelka et al. 2022; Skov et al. 2013), avoiding adverse environmental conditions (Alonso et al. 2009; Sur et al. 2020), and access to food (Chapman et al. 2014; Newton 2023).

It is well documented that global climate change is shifting the abundance, distribution, and habitat use of marine species, including fish, cetaceans, pinnipeds, and seabirds (Becker et al. 2019; Bryndum-Buchholz et al. 2019; Channell and Lomolino 2000; Chetkiewicz et al. 2006; Engelhard et al. 2014; Erauskin-Extramiana et al. 2020; Harley et al. 2006; Last et al. 2011; McBride et al. 2021; Poloczanska et al. 2016; Reisinger et al. 2022; Silber et al. 2017; Sojitra et al. 2022; Wassmann et al. 2011). Global mean surface temperatures during 2011–2020 were 1.1°C higher compared to 1850–1900 as a result of human-induced greenhouse gas

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emissions (IPCC 2023). Climate-driven changes in ocean conditions are particularly consequential for migratory species, whose life histories depend on predictable environmental cues and spatial connectivity across habitats. Understanding shifts in migratory patterns with respect to climate change and warming water temperatures requires an in-depth look at phenology, philopatry (broadly defined as "relatively localized dispersal;" Shields 1983), and species' range and distribution (Anderson et al. 2013).

Increasing technological advancements (e.g., satellite telemetry tracking, biologging, remote sensing, capture-mark-recapture surveys, genetic analysis, stable isotope analysis) have greatly improved our understanding of animal movements, spatial ecology, and the relationship between marine organisms and their environment (Boulet and Norris 2006; Calò et al. 2013; Hart and Hyrenbach 2009; Kot et al. 2023). Research linking technology and climate models have already documented poleward shifts in biodiversity and climate-driven habitat use in the North Pacific (Briscoe et al. 2025; Hazen et al. 2013; Su et al. 2013), South Pacific (Chang et al. 2021), North Atlantic (Barton et al. 2016; Braun et al. 2023; Pinsky et al. 2020), Arctic (Frainer et al. 2017), Gulf of Mexico (Braun et al. 2023) and Southern Ocean (Hill et al. 2013; Rogers et al. 2020). While climate-driven range shifts are becoming increasingly documented, less is known about how anomalous conditions (e.g., marine heatwaves or El Niño events) influence the presence or persistence of migratory corridors (Briscoe et al. 2017). As these events become more frequent under climate change, understanding their effects on the stability of migratory corridors and the impacts on marine connectivity become increasingly important.

Migratory corridors – "any space identifiable by species using it that facilitates the movement of animals or plants over time between two or more patches of otherwise disjunct habitat;" (Hilty et al. 2012; Lidicker 1999) – have been widely discussed in literature (Hilty et al. 2020; Horton et al. 2017; Newmark 1993; Perault and Lomolino 2000; Podda and Porporato 2023). Movement through corridors can occur across a range of spatial and temporal scales and represent a primary means by which connectivity—the extent to which a species or population can move amongst landscape elements—is achieved (Hilty et al. 2012; Merenlender et al. 2025; Taylor et al. 1993; Tischendorf and Fahrig 2000). Beyond facilitating species' movements from one place to another (Hobbs 1992), migratory corridors can also restore connectivity of habitats previously isolated by fragmentation (Haddad et al. 2003; Lennox et al. 2025; Montes-Rojas et al. 2024; Tewksbury et al. 2002). The existence and benefits of migratory corridors in terrestrial habitats have been long documented (e.g., monarch butterflies (Dingle et al. 2005; Zylstra et al. 2021); birds (Alerstam et al. 2006; Juhant and Bildstein 2017; Phipps et al. 2019); bats (Cortes and Gillam 2020); ungulates (Merkle et al. 2023)). Research on marine habitats have focused primarily on identifying key corridors connecting breeding and foraging habitats (Olavo et al. 2011), and fidelity to migratory corridors (Block et al. 2011). Generally, research regarding migratory corridors in both terrestrial and marine systems have primarily operated under the assumption that migratory corridors are predictable habitat features operating on seasonal or cyclical temporal scales. However, climate change may challenge this assumption, by making migratory corridors increasingly transient in space and time.

Migratory corridors that reliably open and close temporarily can be recognized as ecological bridges (Briscoe et al. 2017; Fromentin et al. 2014). Ecological bridges can emerge with shifts in either geographic (e.g., continental shelf breaks, narrow straits, island chains) or environmental (e.g., temperature, nutrients, oxygen) conditions temporarily facilitating movement between otherwise disconnected habitats. A thermal corridor is a specific type of ecological bridge in which temperature governs species' access between habitats, either persistently or through periodic opening and closing (Figure 1). In many cases, environmental variability may cause these corridors to open and close intermittently and unpredictably, such that connectivity is not constant but episodic, shaping when and how species can access otherwise disjunct habitats. Climate-driven shifts in habitat suitability may alter the frequency and availability of corridors, which can be dependent upon temperature, light, or nutrient levels (Briscoe et al. 2017; Merenlender et al. 2025). Assessing documented shifts in spatiotemporal access to thermal corridors under anomalous conditions can offer valuable insights into how this phenomenon may evolve under climate change.

This perspective advances the concept of intermittent thermal corridors as a mechanism through which oceanographic variability and climate change can restructure marine migratory connectivity. Rather than providing a comprehensive review, we synthesize documented examples of thermal corridors to evaluate their spatiotemporal dynamics, ecological significance, and potential role in shaping migratory connectivity for marine species under climate change. In doing so, we identify several key knowledge gaps that currently limit understanding of thermal corridors and outline priority directions for future research. These include the limitations of long-term telemetry datasets capable of resolving genuine changes in corridor access and use, and the inconsistent identification and characterization of thermal corridors across studies, which complicates efforts to identify relevant studies and compare spatiotemporal and taxonomic patterns. Together, these limitations constrain our ability to anticipate and adaptively manage how thermal corridors will respond to continued climate change, underscoring the need for more targeted, long-term and consistently framed research. By bringing together these examples, we highlight the need to determine how the timing, location, and reliability of thermal corridors influence migratory connectivity across species and oceanographic settings.

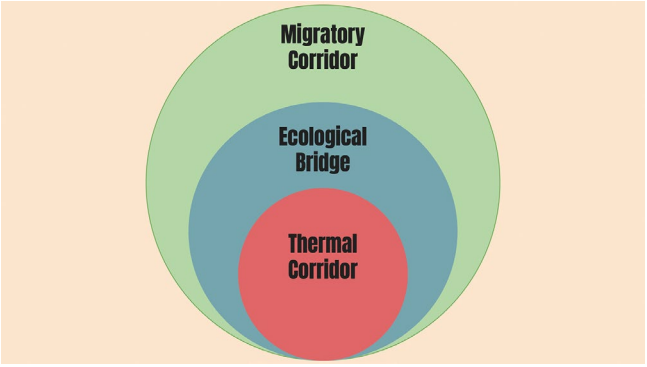


FIGURE 1 | Conceptual diagram illustrating the relationships and distinctions among key terms used in this study.

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Examples were not selected according to formal inclusion or exclusion criteria; instead, we drew on peer-reviewed, English-language literature published within approximately the last 20 years, reflecting the relatively recent emergence of thermal corridor research rather than a deliberate temporal constraint. Geographically, examples were not limited to a specific region but were restricted to species that use oceanic or ocean-adjacent habitats (e.g., anadromous species) and whose movements align with the definition of migration provided in this manuscript. Given the relatively limited literature currently available on thermal corridors, we reviewed publications on marine migration broadly to identify cases in which species' movements were consistent with thermal corridor use, even when not explicitly described in those terms. This perspective therefore draws on selected examples to illustrate key concepts and emerging patterns rather than attempting a comprehensive synthesis of all published work. We have aimed to highlight examples from a variety of marine environments and taxa, although we recognize that these examples are not exhaustive within the field. In lieu of emphasizing individual case studies, we focus on identifying broad patterns in where and when thermal corridors emerge in the marine environment, the oceanographic processes that sustain them, and how species utilize them. We first examine the spatial distribution of documented thermal corridors across regions and oceanographic contexts, highlighting commonalities across habitats. We then consider the taxonomic breadth of corridor use, emphasizing differences in dependence, flexibility, and vulnerability across species. Finally, we explore the temporal dynamics of corridor availability and assess how environmental variability may influence their persistence and reliability. Together, the examples discussed in this paper provide a conceptual foundation for understanding the ecological relevance of thermal corridors while underscoring gaps in current knowledge. As climate change continues to alter ocean conditions, continued research into how shifting species distributions and habitat availability reshape ecological connectivity will be critical for informing adaptive conservation and management strategies.

2 | Spatiotemporal Dynamics and Ecological Uses of Thermal Corridors

Documented evidence indicates that thermal corridors are ecologically significant features which emerge at the intersection of species' movements, physiological tolerances, and habitat preferences (Table 1). Several oceanographic features and geographic regions have been identified as playing a crucial role in supporting species' migration (Briscoe et al. 2017; Lett et al. 2024). For example, in the northeastern Pacific Ocean, two important dolphinfish (*Coryphaena* spp.) hotspots are connected by a thermal corridor running from the Gulf of Tehuantepec along the Equatorial Upwelling Zone, allowing passage across the Eastern Pacific Warm Pool (Marín-Enríquez et al. 2018) (Table 1). El Niño years are known to increase sea surface temperatures within the central and eastern Pacific Ocean (Wang et al. 2016), while also intensifying "Tehuano" winds (Romero-Centeno et al. 2003). During the first months of the year, when "Tehuano" winds peak, this wind intensification drives strong upwelling that cools surface waters into the preferable thermal range for dolphinfish (Lee-Sánchez et al. 2026; Trasviña et al. 2003; Trasviña and Barton 2008), opening the thermal corridor. This upwelling-driven cooling also generates nutrient-rich conditions that support dense prey aggregations, reinforcing the corridor's importance for dolphinfish foraging (Marín-Enríquez et al. 2018).

Similarly, a thermal corridor has also been recorded in a region where the Indian and Atlantic Oceans meet. A subpopulation of Pacific sardines (*Sardinops sagax*) exhibits an annual "sardine run" off the coast of South Africa that is well documented, yet poorly understood (Fitchett et al. 2019). This mass migration begins along the southern coast in Agulhas Bank in the austral winter as juveniles move northward until they arrive in Durban

TABLE 1 | A summary of migratory species referenced with brief descriptions of their thermal corridor usage.

Species		Description
	Dolphinfish (*Coryphaena spp*)	"Tehuano" wind–driven thermal corridor enables passage across the Eastern Pacific Warm Pool during El Niño.
	Pacific sardines (*Sardinops sagax*)	Seasonal shifts in physical dynamics and temperature enable northward movements along the eastern coast of South Africa.
	Alaska chum salmon (*Oncorhynchus keta*)	Seasonal shifts in temperature facilitate regular migratory movements between the Bering Sea and the Gulf of Alaska.
	Steelhead trout (*Oncorhynchus mykiss*)	Cool water tributaries formed from glacierized runoff provide refuge during a summer run along a consistent migratory pathway.
	Loggerhead sea turtles (*Caretta caretta*)	Anomalously warm temperatures facilitate the opening of a thermal corridor across the cool California Current.
	Japanese sardines (*Sardinops melanosticta*)	Anomalously warm temperatures facilitate movement across the North Pacific, previously limited by thermal barriers.

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between late May and early June (Van Der Lingen et al. 2010). Studies speculate that it may simply be prompted by favorable environmental conditions, whereby temperatures are temporarily cooled to a preferable thermal range (< 21°C, Coetzee et al. 2010; Costalago et al. 2018) via cyclonic eddies, wind-driven advection, and vertical mixing (Teske et al. 2021) (Table 1). Although temperature helps enable movement of this species, it may not be the primary driver, and the physical processes underlying these thermal shifts are intermittent and variable in timing, occurring annually but unpredictably (Coetzee et al. 2010). Under future climate conditions, the run may become increasingly irregular or cease to exist altogether, though this remains uncertain given the unpredictability of the event and the incomplete understanding of its underlying drivers (Fitchett et al. 2019). While geography defines where thermal corridors occur, their ecological significance emerges from how species exploit these features to support movement and persistence.

When accessible, thermal corridors may function as pathways that connect primary habitats and structure regular migratory movements. For instance, western Alaska chum salmon (*Oncorhynchus keta*) migrate seasonally between the eastern Bering Sea and the Gulf of Alaska (Urawa et al. 2018) early in their life histories before traveling to fresh water to spawn. This species uses the Aleutian Islands Passes as a thermal corridor, which is seasonally available and dynamically shifting, with persistent thermal suitability (1.3°C–12.6°C, Langan et al. 2024) only along parts of the route (Lemagie et al. 2025) (Table 1). This corridor breaks at its ends, with northern segments towards the Bering Sea severed in the winter and southern segments towards the Gulf of Alaska severed in the summer (Lemagie et al. 2025).

Beyond facilitating connectivity, thermal corridors can also function as transient refugia, providing temporary relief that supports the replenishment or maintenance of energetic stores for spawning and long-distance travel. In mountainous watersheds such as the Babine River of British Columbia, Canada, glacierized and snow-covered mountains runoff into tributaries, lowering water temperatures enough to allow comfortable passage by Pacific salmon and other fish requiring cooler habitats (Pitman and Moore 2021). Steelhead trout (*Oncorhynchus mykiss*), like other poikilothermic fishes, use the Columbia River in the Pacific Northwest of the United States as a migratory corridor for their summer run (Quinn 2018). This route extends from the Pacific Ocean, through Bonneville Dam towards spawning grounds in upper Columbia River tributaries between April and November (Keefer et al. 2009, 2018). During the summer run, steelhead trout move into small, cool water tributaries when this migratory pathway warms beyond their thermal tolerance (> 30°C) (Hess et al. 2016; Sloat and Osterback 2013; Snyder et al. 2022) (Table 1). The length at which these tributaries are used for refuge may vary from hours to months depending on the surrounding temperatures. Individuals who are able to begin the migratory journey earlier in the season have the benefit of cooler water temperatures within the main corridor; therefore, they need to spend less time in tributaries and can complete their migration in less time (Keefer et al. 2009, 2018).

The extent to which thermal corridors support connectivity or refugial use ultimately depends on their temporal reliability, which ranges from persistent and predictable to episodic and highly variable. For instance, the aforementioned dolphinfish example illustrates a corridor that is seasonally reliable rather than continuously available. During early summer, when "Tehuano" winds are weakest, sea surface temperatures exceed the thermal tolerance (> 27.5°C) of dolphinfish (Yen et al. 2026), temporarily rendering the thermal corridor unsuitable for movement (Table 1). As wind-driven upwelling resumes later in the year, suitable temperatures are restored and connectivity is re-established. Consequently, northward movements are restricted during periods when the corridor is unavailable, despite suitable habitat existing on the other side. In contrast, anomalously warm periods (i.e., marine heatwaves or El Niño events), can also function to facilitate the emergence or expansion of thermal corridors. Such conditions have been theorized to open a thermal corridor (Briscoe et al. 2021; Fromentin et al. 2014) allowing intermittent access for juvenile loggerhead sea turtles (*Caretta caretta*), whose movements closely follow the 18°C isotherm (Polovina et al. 2000), passage across the cool California Current (Table 1). Likewise, a recent study identifying the first recorded presence of Japanese sardines (*Sardinops melanosticta*) along the western coast of North America suggests that temperatures above 4°C, corresponding to this species' minimum thermal tolerance (Muko et al. 2018) may have temporarily opened a thermal corridor across the North Pacific (Longo et al. 2024) (Table 1). The spatial distribution of this temperate species has been believed to be limited by thermal barriers (Longo et al. 2024; Martínez-Porchas et al. 2009), but like many species in the North Pacific, there has been documented evidence of the tropicalization of species amid anomalously warm temperatures like the 2014–2016 marine heatwave (Gold et al. 2024). As these examples illustrate, thermal corridors are not static features but dynamic ones, whose temporal reliability is as consequential for species' use of them as their spatial extent—a distinction that will become increasingly important for predicting their role under changing ocean conditions.

3 | Implications of A Changing Ocean on Thermal Corridors

Climate-driven changes in ocean temperature can impact species' access to thermal corridors and shift migratory patterns in space and time. The examples synthesized in this paper (Table 1) showcase where thermal corridors occur, how a variety of species use them, and how the availability and predictability of thermal corridors appear across environmental conditions. Understanding how our rapidly changing climate may impact the availability and reliability of thermal corridors is critical, given that these shifts can influence movement patterns, population dynamics, and life history traits of marine migratory species, with important implications for conservation and management concerns. Below, we discuss these implications in more detail.

Across marine systems, thermal corridors do not solely function as fixed migratory routes; rather, they arise when and where physical gradients of temperature, chlorophyll, and nutrients are strong and dynamic (Block et al. 2011; Briscoe et al. 2016). As a result, their presence is not continuous but intermittent, and their location, duration, and intensity can vary across seasons, years, and oceanographic states. Studies differ in spatiotemporal

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coverage, resolution, and focal taxa (Chung et al. 2021), meaning that some observations coincide with corridor formation, while others capture periods when connectivity is interrupted or inactive. This variability helps reconcile why they appear rare in certain systems (e.g., loggerheads and Japanese sardines in the North Pacific) and are readily observed in others (e.g., Alaska chum salmon in the Aleutian Islands), while simultaneously complicating efforts to anticipate how climate change will alter their role in marine connectivity. Consequently, projecting further connectivity requires understanding not only warming trends but also how climate change reshapes variability and extremes that govern when and where thermal corridors materialize.

Climate change may alter the reliability and predictability of thermal corridors, rather than fully eliminating them. Warming trends and shifting circulation patterns may weaken some physical gradients while intensifying others (Wilson et al. 2016; Van Gennip et al. 2017), resulting in corridors that form more frequently in novel locations, but persist for shorter or less predictable durations. These changes could make it harder for species to rely on these corridors for movement and resource use. Climate-driven shifts in the timing of habitat accessibility are widely documented to influence species' life histories and migration phenology (Bitterlin and Van Buskirk 2014; Crear et al. 2023; Langan et al. 2021; Lin et al. 2017), and changes in the timing of corridor availability may therefore be as consequential as changes in spatial extent, particularly when they disrupt alignment with spawning, foraging migrations, or overwintering (Charif et al. 2020; Bowerman et al. 2018; Hauser et al. 2017). Thus, even if a thermal corridor exists in space, if it opens too early or too late it may no longer serve its ecological function. In some systems, corridors may persist as physical features while becoming decoupled from shifts in prey distribution and abundance, such that historically beneficial pathways supporting foraging or stopover use could become energetically inefficient or maladaptive under future environmental conditions. Given the complex needs of marine migratory species, these corridors could quickly become ecological traps. Ecological traps arise when organisms preferentially select habitats that have become maladaptive, undermining individual fitness and population persistence (Battin 2004; Swearer et al. 2021). The consequences of spatial and temporal mismatches between habitat availability and species' migratory timing depend on which life-history stage is disrupted. Movement into poor foraging habitat may reduce individual fitness and juvenile survival, whereas mismatches involving reproductive or nursery habitats can more directly impair recruitment, gene flow, and long-term population persistence (Sherley et al. 2017). Although the immediate consequences vary among habitat types, these mismatches ultimately reduce population resilience and increase the risk of local extirpation, highlighting the importance of understanding how changing ocean conditions influence the timing, location, and temporal reliability of thermal corridors.

The spatiotemporal existence of thermal corridors has important implications for species' distributions and movement strategies through range expansion and habitat fragmentation. Opportunistic species may exploit thermal corridors to expand their ranges, contributing to range shifts and changes in community composition. An example of this pattern is emerging in the Arctic, where the loss of sea ice is altering long-standing barriers to movement. The Northwest Passage, which links the Pacific and Atlantic Oceans through the Arctic, has been largely inaccessible to marine megafauna since past interglacial warm periods (Dyke et al. 1996; Polyak et al. 2010). However, continued sea ice loss is thought to have reopened this route as a viable migratory corridor (Corbyn 2007; MacLeod 2009; McKeon et al. 2016), increasing the potential for movement between ocean basins. Consistent with this hypothesis, gray whales (*Eschrichtius robustus*) – whose Atlantic population was extirpated centuries ago (Alter et al. 2015; Bryant 1995), leaving only two extant North Pacific stocks (Swartz 2018) – have recently been sighted in the Atlantic basin and adjacent waters, including the Mediterranean Sea (Israel), the eastern North Atlantic (Spain), and the South Atlantic (Namibia) (Elwen and Gridley 2013; Paterson 2013; Scheinin et al. 2011). These observations are consistent with the hypothesis that some individuals have traversed the Arctic from the eastern Pacific into the Atlantic via the increasingly accessible Northwest Passage. Regional sea surface temperatures have risen as sea ice extent has declined (Chen et al. 2021), increasing the accessibility of Arctic sea passages (Chen et al. 2020; McKeon et al. 2016). Similar responses have been documented in bowhead whales (*Balaena mysticetus*), whose increasing usage of these passageways has also been linked to reduced sea ice cover (Heide-Jørgensen et al. 2012), suggesting that corridor reopening under climate change is influencing movement patterns across multiple marine species. These dynamics are likely to vary across life stages, with juveniles and adults differing in their capacity to detect, access, and utilize thermal corridors. For example, as individuals mature, accumulated experience along migratory routes may enhance the ability to recognize and respond to suitable pathways, a capacity that may be more limited in juveniles (Péron and Grémillet 2013). Further, for land-dependent marine species, such as sea turtles and pinnipeds, the impacts of shifts in thermal corridors may be compounded by affecting the timing or accessibility of terrestrial habitats needed for breeding or reproduction (Blondin et al. 2022). If thermal corridor availability at sea does not align temporally or spatially with land-based life history requirements, these species may face increased risks of disrupted reproductive success. As a result, changes in corridor availability may influence not only individual movement patterns, but also population structure and long-term distributions.

Thermal corridors pose a challenge to conventional conservation and management strategies that assume static habitats and stable species' distributions. Given that corridors are defined by dynamic physical processes, their presence often extends across fixed geopolitical boundaries and jurisdictions, allowing species to freely move between areas governed by differing management mandates, regulatory frameworks, and enforcement capacities (Harrison et al. 2018). This misalignment between ecological connectivity and governance structures can create gaps in protection, increase the potential for user conflict, and complicate coordinated conservation responses (Pinsky et al. 2018; Santos et al. 2024). Standard management tools, such as static marine protected areas or seasonal closures based on historical conditions, may be insufficient to safeguard species whose movement patterns shift in time and space. For example, the degree to which protected areas capture the core habitats of highly migratory marine species varies considerably: humpback whale

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(*Megaptera novaeangliae*) core habitats are substantially encompassed by U.S. National Marine Sanctuaries, whereas Kemp's ridley sea turtles (*Lepidochelys kempii*) and Pacific blue whales (*Balaenoptera musculus*) show minimal overlap with existing MPA networks, even when their movements parallel protected coastlines (Conners et al. 2022). Ocean warming has driven poleward distribution shifts in species such as tiger sharks (*Galeocerdo cuvier*) and North Atlantic right whales (*Eubalaena glacialis*), moving core habitats beyond the fixed boundaries of marine protected areas established under earlier climate conditions (Hammerschlag et al. 2022; Meyer-Gutbrod et al. 2018). For other species, such as Adélie penguins (*Pygoscelis adeliae*), mismatches arise not from long-term range shifts but from seasonal or life history stage specific habitat use that periodically moves individuals outside protected boundaries, even when their broader range remains stable (Thiebot et al. 2019). Fixed management boundaries often fail to encompass the full extent of species' dynamic movements, underscoring the need for conservation approaches that are flexible and responsive to shifting connectivity pathways.

Climate-adaptive management approaches may more effectively respond to shifting thermal landscapes and transient habitat connectivity. Dynamic management tools use near real-time or frequently updated data on environmental variability, animal movement, and human activity to adjust spatial and temporal regulations (Maxwell et al. 2015; Welch et al. 2019). TurtleWatch is one such tool, developed to provide timely information on the thermal habitat of loggerhead sea turtles in the North Pacific (Howell et al. 2008). Implemented by the U.S. National Oceanographic and Atmospheric Administration, TurtleWatch demonstrates how near–real-time oceanographic data can be used to forecast species habitat and reduce bycatch through spatially flexible management. Similar dynamic management approaches have been developed and implemented for other taxa including a habitat forecast model for southern bluefin tuna (*Thunnus maccoyii*) in the Great Australian Bight (Eveson et al. 2015; Hobday et al. 2010) and occurrence models with warning maps for Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Delaware Bay (Breece et al. 2021). Comparable approaches could be applied to thermal corridors, using environmental indicators to anticipate when and where connectivity pathways for highly migratory marine species may emerge and adjusting management responses accordingly. Integrating these strategies into recognizing thermal corridors as dynamic features, whose presence and intensity may shift under climate change, could help align conservation strategies with the biophysical dynamics of a warming ocean.

Despite growing evidence for the ecological importance of thermal corridors, substantial knowledge gaps remain. Existing observations of species movements are biased towards well-studied regions and taxa (Briscoe et al. 2017; Lett et al. 2024; McKeon et al. 2016), which limit our ability to assess global prevalence of intermittent thermal corridors, particularly in the open ocean and the southern hemisphere. Likewise, current tagging studies are largely opportunistic, reflecting convenience sampling rather than systematic tests of thermal corridor use (Badger et al. 2024). Telemetry datasets with sufficient temporal coverage to resolve decadal-scale thermal corridors are rare, which constrains our understanding of how they may respond to climate variability. Mechanistic links between corridor use and fitness are poorly quantified, as well as population-level consequences of altered connectivity. An emerging effort through the Loggerhead STRETCH program using targeted, hypothesis-driven tagging and modeling frameworks demonstrates a promising approach to explicitly test thermal corridor dynamics habitat connectivity (Briscoe et al. 2021). Expanding similar frameworks across regions and taxa will be critical for evaluating population-level climate impacts on thermal corridors. Addressing these gaps will require integrated approaches that combine animal telemetry, oceanographic observations, and modeling frameworks which capture both physical variability and biological responses.

4 | Conclusion

This review positions thermal corridors as a central, but understudied mechanism shaping marine connectivity under climate change. Much of what remains unknown stems from a basic constraint: telemetry records needed to detect changes in thermal corridor access are still rare, leaving considerable uncertainty in how these pathways will behave as ocean temperatures continue to rise. As a result, this perspective raises more questions than it resolves, but doing so is a necessary step toward generating testable hypotheses about when, where, and for which species thermal corridors will persist, shift, or disappear under future climate scenarios. Answering these questions will require sustained, hypothesis-driven research paired with longer-term monitoring efforts, an investment that carries direct consequences beyond ecology. As fixed management boundaries and static conservation frameworks struggle to accommodate increasingly dynamic connectivity pathways, governance structures will similarly need to evolve toward more adaptive, real-time approaches. Only with this kind of coordinated response across both science and policy can conservation and management strategies hope to keep pace with an ocean changing faster than our ability to track it.

Author Contributions

Bianca S. Santos, Larry B. Crowder, and Dana K. Briscoe conceived the framework for this manuscript. Sydney A. Hampton led and all authors helped draft, revise, and approve publication.

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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