Frontiers in marine movement ecology: mechanisms and consequences of migration and dispersal in marine habitats

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Dispersal and migration are important ecological processes that influence rates of propagule exchange, colonization, extinction and speciation for a wide array of taxa in terrestrial and aquatic systems. The role of movement patterns in the marine environment is particularly critical, because a majority of marine species have a mobile phase at some stage of their life history. Indeed, seminal works that lay the foundation of modern ecology as a science recognized the importance of mobility—whether driven by currents or by swimming—to the dynamics of marine communities. The origins of movement ecology can be traced to the HMS Challenger expedition (1872–1876) led by Sir Charles Wyville Thomson, which was the first scientific survey of the world’s oceans. Thomson [1] hypothesized that high dispersal abilities of benthic organisms played a role in homogenizing deep sea communities given that ‘most marine animals pass a longer or shorter period of their lives as minute free-swimming larvae, and while in that condition are borne along and scattered by tides and currents.’ (p. 39). This perspective persisted, such as in the pioneering 1914 work by Johan Hjort [2] on factors that drive population fluctuations of commercially important fishes. Prior to Hjort’s work, the prevailing theory was that temporal variations in fishery yields were driven primarily by adult migrations, but Hjort’s careful analyses indicated that year-class strengths were, instead, defined by survival through an early life-history ‘critical period’, with survival being dependent in part on larval dispersal [3]. These hypotheses have been altered, expanded, debated, supported and refuted by subsequent generations of marine ecologists. Indeed, regarding larval dispersal, Hjort [2] himself noted, ‘It would be especially desirable to determine the extent of such movement . . . ’ (p. 206), and this desire has continued throughout the subsequent century.

Paradigms about the role of movement and its relative importance at different ontogenetic stages have shifted during recent decades. For example, marine ecology in the 1980s was dominated by ‘supply side’ theory, focusing on the notion that marine populations were limited by recruitment [4], which inspired debates about whether such processes were dependent or independent of population density [5]. The idea that marine populations were well mixed on large spatial scales and therefore fundamentally ‘open’ with respect to dispersal and recruitment began to change at the beginning of the twenty-first century with recognition of potentially significant amounts of self-recruitment and natal homing [6]. This shift to a focus on characterizing degrees of population connectivity among marine metapopulations continues and it underlies many of the papers in this special feature.

Despite the long-standing interest in marine dispersal and migration, movement patterns for most species are poorly characterized. The reasons for this lack of knowledge are largely practical. Many species have a dispersive larval
stage during which they are small, suffer high mortality rates, and are diluted in large volumes of water, all of which eliminate the possibility of tracking individual larvae in real time from birth to settlement. Species that are highly migratory during juvenile or adult phases can traverse large distances over long time periods, and their oceanic distribution patterns are often unknown. Recent advances in development of a variety of ecological tools, however, have allowed unprecedented insight into movement dynamics, and many of these approaches produced the ecological insights gained by the studies included in this special feature. These include telemetry techniques [7,8] analysis of geochemical signatures in calcified structures [9,10] and targeted sampling using advanced oceanographic technology [11]. Furthermore, models and experiments that explicitly incorporate mobile phases in their design advance our understanding of movement, leading to refinements in theory or improved management of natural systems [12,13]. And finally, new conceptual models about the importance of movement at different life-history stages set the stage for future work [14].

The questions being investigated in marine movement ecology are growing in complexity and sophistication. When characterizing the dispersal dynamics of mobile life-history stages, it is no longer sufficient to merely identify dispersal trajectories. Instead, we now ask how environmental conditions intersect with variable dispersal patterns to drive post-settlement recruitment dynamics. This intersection is examined by Shulzitski et al. [15], who link larval growth performance (which is highly correlated with survivorship) with transport in highly productive and prey-replete mesoscale eddies. Similarly, Shim a et al. [9] demonstrate that retentive or dispersive pathways have a significant effect on larval growth and energetic condition, with implications for metapopulation persistence. Temporal fluctuations in habitat quality are also critical in spatially structured populations and communities. Using an experimental approach, Munguia [13] shows that, for species with sex-biased dispersal, propagule availability in source populations can have profound effects on demographic characteristics of sink populations. These strong and important short-term dynamics are complemented by research on postlarval movement in soft sediment systems, and Pilditch et al. [14] argue that ‘secondary’ dispersal can be of greater importance to the structure of benthic metacommunities. It is also critical to understand migratory pathways of highly mobile adult stages. Eggleston et al. [8] identify migratory corridors of adults that link oceanic spawning to estuarine recruitment. Further, White [12] uses a stage-structured model to evaluate the importance of ontogenetic migrations to the design of spatially explicit marine reserves, thereby illustrating the relevance of movement ecology for fishery management and conservation.

Coinciding with paradigm shifts from recruitment limitation to connectivity and metapopulation structure, there has been a growing interest in the ecological consequences of individually variable behaviours [16]. Much of this work involves quantifying the degree to which populations are made up of ‘contingents’—groups of individuals that display distinct migratory patterns [17] such as partial migration, whereby populations are composed of migrants and residents. Such migratory diversity can be a critical driver of population resilience to environmental change [18]. Although partial migration has been well recognized in avian and terrestrial insect species, the extension of this conceptual framework to marine organisms has only recently gained traction [19]. In this special feature, Gillanders et al. [10] identify partial migration in estuarine-dependent fishes as a key driver of growth with strong implications for population persistence in dynamic environments. Similarly, Cagua et al. [7] recognize cryptic residency as a crucial but overlooked population component for highly migratory species. These studies emphasize the need for continuing work that evaluates the role of individually variable migratory behaviour in driving population persistence. Efforts to quantify the importance of migratory diversity will benefit from the new electronic technologies and methods of analysing spatial data that are emerging from the field of biologging [20], and the intersection of behavioural diversity and environmental conditions remains a frontier where the mechanisms driving divergent migratory patterns must be explored. Continued work expanding the frontiers of marine movement ecology will be required given that fishery pressure, habitat modification and shifting climatic conditions are altering the structure of marine populations worldwide. The ecology of migration and dispersal is critical for future efforts to manage spatially structured marine populations in the face of changing environments.

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References


