Quantifying dispersal from hydrothermal vent fields in the western Pacific Ocean

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Hydrothermal vent fields in the western Pacific Ocean are mostly distributed along spreading centers in submarine basins behind convergent plate boundaries. Larval dispersal resulting from deep-ocean circulations is one of the major factors influencing gene flow, diversity, and distributions of vent animals. By combining a biophysical model and deep-profiling float experiments, we quantify potential larval dispersal of vent species via ocean circulation in the western Pacific Ocean. We demonstrate that vent fields within back-arc basins could be well connected without particular directionality, whereas basin-to-basin dispersal is expected to occur infrequently, once in tens to hundreds of thousands of years, with clear dispersal barriers and directionality associated with ocean currents. The southwest Pacific vent complex, spanning more than 4,000 km, may be connected by the South Equatorial Current for species with a longer-than-average larval development time. Depending on larval dispersal depth, a strong western boundary current, the Kuroshio Current, could bridge vent fields from the Okinawa Trough to the Izu-Bonin Arc, which are 1,200 km apart. Outcomes of this study should help marine ecologists estimate gene flow among vent populations and design optimal marine conservation plans to protect one of the most unusual ecosystems on Earth.

hydrothermal vents | larval dispersal | deep-ocean circulation | analytical approach

Hydrothermal vent fields in the western Pacific have received substantially less attention than have eastern Pacific vents. Western Pacific vents are mostly distributed along spreading centers in submarine basins behind convergent plate boundaries, whereas those of the eastern Pacific occur mainly at midocean ridges. It is estimated that vent-endemic species in back-arc basins were introduced along now-extinct midocean ridges that bridged the eastern and western Pacific Oceans ∼55 million years ago, with a potential origin at the East Pacific Rise (1, 2). More recent studies suggest the possibility that Indian Ocean ridge systems once connected Atlantic and Pacific vent fields (3). Spreading centers in back-arc basins are active for typically 5–10 million years (4, 5). Thus, life spans of back-arc spreading centers are significantly longer than population lifetimes of vent animals observed in the eastern Pacific (∼1 million years) (6).

Recent genetic studies have addressed the matter of genetic differentiation among vent populations (7–11). Genetic data imply that back-arc basin populations are well-mixed genetic pools (12, 13). In contrast, vent populations in distant basins (∼3,000 km apart) are genetically distinct, suggesting that occasional migrations may have occurred over the course of several hundred thousand generations (14). There is one example of a widespread species (*Bathymodiolus septemdierum* complex) occurring in all western Pacific back-arc basins (15). To interpret gene flows of vent species, it is necessary to understand larval dispersal by ocean circulation, as well as tectonic history (16–18). However, quantitative data regarding dispersal processes in the western Pacific are still woefully inadequate, leaving many unanswered questions. Dispersal patterns among vent populations in the western Pacific basins have not been previously addressed.

Detailed observations and models for eastern Pacific vents have revealed mechanisms of near-bottom circulation strongly influenced by distinct topographic features of midocean ridges (19–23). Conduit-like structures of midocean ridges may shield larvae from cross-axial dispersal and also may enable long-distance dispersal that connects distant vent fields (20). Similar long-dispersal mechanisms, however, do not apply to species in the western Pacific, where midocean ridges do not exist. If dispersal were limited to near-bottom depths, vent species of the western Pacific would largely be contained within a given back-arc basin.

Although most species likely remain near the bottom, some strong-swimming larvae (e.g., shrimp and crabs) may disperse higher in the water column, possibly ∼1,000 m above the bottom, where they can be transported by faster currents (24, 25). Lagrangian measurement methods, using deep-ocean profiling floats programmed to drift at a specified depth or constant density surface, can be used to measure dispersal in the water column. This approach has been used for hydrothermal vent surveys as well (26, 27). One example was the Lau Basin Float Experiment (27), which captured boundary currents within the back-arc basin and westward outflow from the basin resulting from the South Equatorial Current. For various reasons, it is challenging to quantify vent-to-vent transport using only in situ experiments; therefore, one promising approach is to combine dispersal experiments with ocean circulation models.

Properly analyzed, such observation and modeling data should yield reasonable estimates of dispersal processes by ocean circulation and should help marine ecologists understand biogeography and

Significance

Submarine hot springs known as hydrothermal vents host unique ecosystems of endemic animals that do not depend on photosynthesis. Quantifying larval dispersal processes is essential to understanding gene flows and diversity distributions of vent endemic species, as well as to protect vent communities from anthropological disturbances (e.g., deep-sea mining). In this study, we assess the potential frequency of larval exchange between vent fields throughout the entire western Pacific via ocean circulation processes, so that population geneticists can make quantitative comparisons. We show that western Pacific vents in distant basins are potentially connected with strong directionality. This article makes a valuable contribution to a difficult and important area of deep ocean processes.

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