Evolution and Conservation of Marine Biodiversity in the Coral Triangle Hotspot

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The tropical seas of the Coral Triangle (a region comprised of the Philippines, Malaysia, Indonesia, East Timor, Papua New Guinea, and the Solomon Islands) are the richest in the world. Despite levels of biodiversity that far exceed the Caribbean or the Great Barrier Reef, the prototypical poster children of coral reef ecosystems, the Coral Triangle has been virtually ignored by scientists. For each publication on the Coral Triangle, there are six publications that focus on the Caribbean and 60 on the Great Barrier Reef. This research inequity is particularly troubling because the Coral Triangle is the premier global hotspot for marine biodiversity as well as the most critically threatened coral reef ecosystem in the world.

Left: Map of the Coral Triangle courtesy of The Nature Conservancy and Coral Geographic (Veron et al. unpublished data). Right: Coral Reef in Papua New Guinea (photo courtesy of Reef Check).

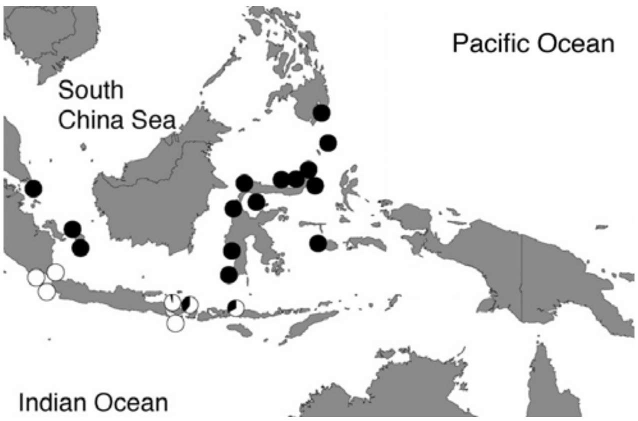
For the past 10 years, my research program has been focused on understanding the processes that generate the Coral Triangle biodiversity hotspot. There are two primary competing theories. The "Center of Origin" theory suggests that speciation occurs within the Coral Triangle, creating elevated levels of biodiversity within this region. The "Center of Accumulation" theory counters that speciation occurs in the isolated islands of the Pacific and Indian Oceans, and that this diversity is exported towards the Coral Triangle, where it accumulates over evolutionary time scales. Testing these theories distills to two simple questions: 1) where do species originate, and 2) how do their ranges change over time?

Our research has focused largely on the first question, which seems straightforward. It is almost universally accepted that speciation largely occurs in allopatry. That is, a barrier to dispersal prevents the exchange of individuals and genes between populations on either side of the barrier. If the exchange is limited for a sufficiently long time, populations become reproductively incompatible, creating new species.

In terrestrial environments, it is easy to visualize how rivers, mountain ranges, vast deserts, etc. can be barriers to dispersal. The situation in marine environments, however, is more challenging because most marine species have a life history where adults are completely or relatively sedentary and dispersal is achieved through a larval stage capable of traveling for weeks or months on ocean currents, creating a large dispersal. Unfortunately, the minute size of these larvae, combined with the vastness of the open sea, means following larvae directly is all but impossible. Other methods are needed.

Although we cannot follow larvae directly, we can tell where they have been through genetics. When a larva spawned on one reef disperses and settles on a distant reef, it takes its genes with it. If such dispersal occurs frequently, the gene pools of the geographically isolated populations will be homogenized. Alternatively, if larvae cannot disperse among reefs, the populations will evolve a unique genetic signature easily detectable through DNA sequence analysis. It was in this way that we first showed, in 2000, that despite the potential to disperse over 600 kilometers, there were clear barriers to dispersal among populations of mantis shrimp separated by only 250 kilometers. Thus, by comparing the genetic similarities and differences among populations, we can reconstruct the history of larval dispersal among them and identify regions where there are barriers.

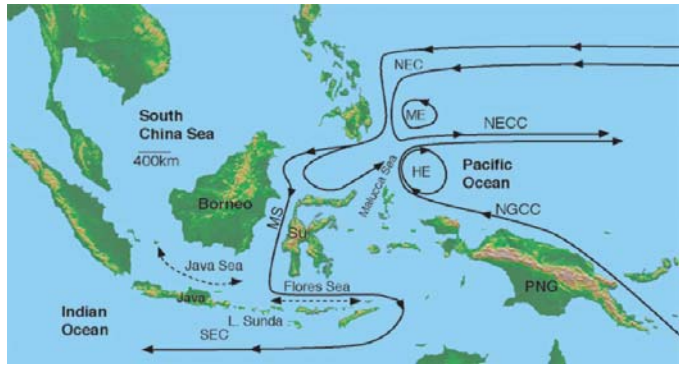
For the past five years, funded by a National Science Foundation (NSF) CAREER award, we have examined genetic patterns in multiple species across Indonesia, the heart of the Coral Triangle. We have been bringing graduate and undergraduate students to Indonesia as part of the Diversity Project (www.eeb.ucla.edu/Faculty/Barber/TDP.htm), a program that aims to discover the origins of high marine biodiversity while fostering an increase in diversity among marine scientists. By comparing genetic patterns of more than 40 species of coral, giant clam, mantis shrimp, a rainbow of coral reef fish, and many other species, common patterns have emerged that indicate significant barriers to dispersal within the Coral Triangle.



Left: Genetic patterns in the mantis shrimp Haptosquilla pulchella *showing the geographic distribution of two highly distinct genetic types. Notice that the white type occurs only along the margins of the Indian Ocean, while the black type occurs along the Pacific Ocean down to the border with the Atlantic Ocean, suggesting their evolutionary origins. Right: Paul Barber (right) giving an underwater lesson on coral identification to postdoctoral researcher Eric Crandall (left).*

There is one major barrier we cannot see today because it is no longer there. However, during the height of Pleistocene glacial periods, sea levels dropped by 130 meters, exposing the shallow continental shelves of Asia and Australia. The result of this sea level drop was that the exchange of larvae between Pacific and Indian Ocean populations was limited. With fewer larvae moving their genes between these regions, populations diverged, generating biodiversity within the Coral Triangle.

The second major barrier has been present for millions of years. The Halmahera Eddy is a large vortex of ocean that spins north of Halmahera, an island between Western Papua and Sulawesi, Indonesia. This oceanographic feature limits the exchange of larvae and their genes between the island of Papua and the rest of Indonesia. Both of these barriers act to create species diversity within the Coral Triangle, supporting the Center of Origin theory, although we have other studies that support the Center of Accumulation theory. In an area as vast and diverse as the Coral Triangle, support for multiple mechanisms is not surprising.



Left: A reconstruction of Pleistocene coastlines based on Harold Voris, 2000. Dark green indicates present coastal margins while light blue indicates coastal margins during Pleistocene periods where sea level was up to 130 meters lower than today. Visit http://www.eeb.ucla.edu/Faculty/Barber/IndonesiaSeaLevels.htm for an animation of sea level changes. Right: Schematic of the major ocean currents of the Coral Triangle. The North Equatorial Current (NEC) travels through the Makassar Strait (MS) and into the Indian Ocean, becoming part of the South Equatorial Current (SEC). New Guinea Coastal Current (NGCC) waters are deflected by the island of Halmahera, creating the Halmahera Eddy (HE), which limits water movement from the island of Papua into Indonesia.

While our work provides insights into the origins of the Coral Triangle biodiversity hotspot, it is equally important that this information is helping to guide conservation policy in this region. The data we have generated showing common barriers to dispersal has been used by Conservation International to help define management regions for conservation efforts. However, I believe the most important aspect of our work has only recently begun. One of the biggest challenges to marine conservation in the Coral Triangle is the absence of basic research to support conservation efforts, and the lack of scientists to do both basic research and applied conservation work.

In 2008, funded by an NSF Partnerships for International Research and Education (PIRE) award and in collaboration with Old Dominion University, Duke University, and universities throughout the Coral Triangle, we began a program where graduate students from the United States, the Philippines, Indonesia, and Malaysia are trained side by side (http://sci.odu.edu/impa/ctpire.html). In April 2008, we set up two molecular genetic labs in the Philippines, staffed by two postdoctoral researchers and four graduate students. We ran training courses for five students from the United States and 10 students from the Philippines on the application of molecular methods to marine conservation. Together, we collected samples from sites all over the Philippines and analyzed these samples in the lab to learn how reefs are connected through larval dispersal. In May 2009, we moved to Bali, Indonesia, where we trained 20 graduate and undergraduate students from Indonesia and four undergraduates from the United States, with additional trainings scheduled for January and June 2010. In August 2010, we will move to Malaysia and continue the cycle.

Coral Triangle Partnerships for International Research and Education (CT-PIRE) team members at the University of the Philippines Marine Science Institute marine lab, in Bolinao, Philippines, finishing a training on field collections and taxonomic identification in June 2008.

Through generating data on larval dispersal across the majority of the Coral Triangle, we are providing conservation managers with data on larval exchange among reefs, information recently listed as a “critical gap” in our ability to design effective marine reserve systems. But, more importantly, this project is developing the next generation of United States and foreign scientists who have both the interest and the expertise to conduct research in the Coral Triangle. It is the efforts of these students, and the students that they will train, that will catalyze the transformation of this biodiversity hotspot into a hotspot for marine biodiversity and conservation research. The fate of the world’s most diverse oceans depends on it.

Leaving Romblon Island, Philippines, after completing fieldwork.