Centipede nets improve fish sampling efficiency and reveal unseen diversity in Atlantic East Pacific mangroves

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Introduction

Mangrove forests provide habitat and nutrients for fish and other organisms, and myriad other ecological and societal benefits. Despite their ecological and societal value, there has been a global loss of 20% to 35% of mangrove area in the last 50 years, primarily due to the growth of aquaculture and agriculture, climate change, and coastal development (Bhowmik et al. 2022). Mangroves are seen as "nursery habitats" because they can provide abundant nutrients and protect juvenile fish and shrimp from predators, but the degree to which this occurs varies among mangrove systems (Bradley et al. 2024). The predator refuge hypothesis—the idea that fish are protected from predators within complex vegetative structure and the turbid, shallow water associated with mangroves—is a common paradigm for explaining the value of mangroves as fish habitat (Wanjiru et al. 2023), but the difficulty of sampling fish within the complex woody structure created by mangrove trees limits our understanding of the ways and degree to which fish utilize these habitats. Faunce and Serafy (2006) found that over one third of ostensible mangrove-fish studies included gears that cannot be used in vegetated microhabitats, and 20% did not sample directly within mangrove areas at all. Visual census techniques (e.g., human observers or remote underwater videos) can only be used during the day and in clear-water systems, so a direct sampling method that could be easily used and standardized to capture fish effectively within diverse mangrove forests could bolster our understanding of mangrove-fish dynamics.

The "centipede net" is a relatively recently developed fish trap that has quickly become popular with fishers in Southeast Asia (**Figure 1**) (Wang et al. 2009) because it can be deployed directly within vegetated mangrove habitats. Centipede nets show promise, but they have not been used scientifically outside of the Indo-West Pacific floral realm. The purpose of this study was to compare centipede nets with traditional sampling gears in the Atlantic East Pacific floral realm to determine how catch rates, species accumulation rates, and community characteristics vary among gears, and to identify how abiotic factors may influence performance of this novel gear to inform the development of a standardizable sampling approach.

Methods

We collected fish and environmental data at six mangrove sites within the Gulf of Nicoya on the Pacific coast of Costa Rica, collecting replicate day and night samples during the rainy season and the dry season. Fish were collected with a cast net (1.5-m radius, 6.3-mm square mesh, and 1.5 kg/m weights), a bag seine (7-m long, 1.5-m tall, with 6-mm delta mesh and a 1.5-m deep x 1.5-m wide bag), and three-net tandem centipede net groups (each centipede net was 2.4-m long with ten 20-cm x 25-cm frames at 16-cm intervals, 8 funnel-shaped side entrances [each with a 10-cm diameter opening], and 4-mm square mesh throughout [**Figure 1**]; each three-net group was approximately 7.2-m long). We placed centipede nets within mangrove vegetation at low tide when the prop roots were exposed and allowed those nets collect fish throughout the high tide, while we took environmental

Figure 1. Top-down view of a centipede net, showing the alternating side entrances and tied-off ends of the net.
Net is 2.4-m long with ten 20-cm x 25-cm rectangular frames.

measurements (bank steepness, dominant substrate, percent of understory occlusion, Secchi depth, temperature) and collected fish with cast nets and seines. We then retrieved the centipede nets before the tide receded. We identified all fish to the species level and recorded standard length and weight. For each sample, we calculated species richness, Shannon diversity, Simpson diversity, and standardized catch per unit effort (CPUE) values for each gear.

We utilized a bootstrapped interpolation and extrapolation (iNEXT) approach (Gotelli et al. 2024) to assess sample coverage (i.e., the proportion of the estimated true diversity detected), sampling efficiency (i.e., the estimated number of samples required to reach a target level of sample coverage), and diversity estimates from each gear and combination of gears. To assess potential abiotic drivers of mangrove fish diversity, as well as to detect potential environmentally-driven gear biases, we used a model selection approach (Burnham and Anderson 2010; Harrison et al. 2018). We created candidate linear mixed models to predict CPUE, species richness, Shannon diversity, and Simpson diversity using a set of environmental predictors that we hypothesized would impact the mangrove fish community (daylight percent, mud dominance, occlusion, steepness, Secchi depth, season, and temperature). We included first-order interactions with gear type and a random variable for site. We ranked models by AICc and created an averaged model from any models with $\Delta AICc \leq 2$ to simplify inference and visualization (Harrison et al. 2018).

Results

Centipede nets caught more total species, a greater proportion of unique species, and a more diverse assemblage of fish than cast nets and seines (**Figure 2**). Centipede nets also detected the greatest proportion (91%) of the estimated true species richness of any single gear. Combining centipede net samples with either other gear yielded greater sample coverage than the traditional gear pair (cast nets and seines), and the assemblage detected using all three gears was the most complete. However, our iNEXT analysis indicated that even when pooling all three gears, more than 7% of the full fish community still went undetected.

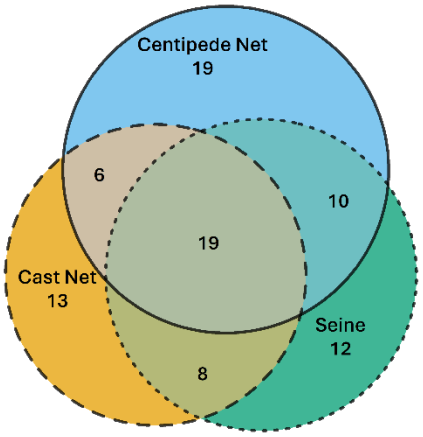

Figure 2. The number of species detected using each gear or intersection of gears throughout this experimental evaluation of centipede net effectiveness within the mangroves of the Gulf of Nicoya, Costa Rica in 2022 and 2023.

Species richness, Shannon diversity, and Simpson diversity all decreased in daytime samples, at steep sites, and in the rainy season for all three gears. Shannon diversity and Simpson diversity also decreased with increased understory occlusion and Secchi depth, and they increased with water temperature across all three gears. However, there were some gear-specific patterns detected as well. Bank steepness had a strong negative effect on centipede net catch rates and diversity, which differed from the other gears. Increased effort correlated with greater species richness and diversity in centipede net samples.

Discussion

We found that centipede nets effectively sample a portion of the mangrove-associated fish community that is not readily detected with traditionally used sampling gears (cast nets and seines). Centipede nets outperformed cast nets and seines in the Gulf of Nicoya in many respects: they captured more species, a higher proportion of gear-exclusive species, more diverse samples, and a greater proportion of the estimated true species richness than cast nets or seines. Unlike other direct sampling techniques like RUVs, centipede nets sample effectively in low-visibility

conditions (where we saw the greatest diversity occurring in the Gulf of Nicoya), and they were the only gear in this study that could be deployed directly within vegetated microhabitats where many presumed benefits of mangroves are available. Centipede nets also improved sampling when used in combination with one or both traditional gears (cast nets and seines). The combination of centipede nets and cast nets produced estimates of Shannon diversity and Simpson diversity within the 95% confidence intervals of the three-gear estimates, which no other pair achieved. So, with respect to diversity, adding a third gear to centipede nets and cast nets would provide little advantage. The proportion of species caught exclusively in centipede nets was lower in our study (22%) than in China (32%), likely due to differences in study design. Nevertheless, excluding any single gear from our study would reduce the observed species richness by 14% to 20% and Shannon diversity by 9% to 22%, suggesting that researchers interested in the complete mangrove-associated fish assemblage should consider using three or more gears. But to maximize efficiency when time and/or project budget are constrained, we recommend that single-gear protocols use centipede nets and that two-gear protocols use centipede nets and cast nets.

Care should be taken to minimize potential external impacts to centipede net performance. Based on our results, we recommend that researchers sample during tides that will allow at least a two-hour centipede net deployment, and consideration should be given to potential standard deployment times to allow for direct comparison between samples. Managers should be cautious when comparing centipede net samples across sites with very different bank steepness until a controlled study with a known fish assemblage can be conducted to determine if bank steepness alters centipede net effectiveness.

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