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PRACTICAL TOOLS

Using standardized fish-specific autonomous reef monitoring structures (FARMS) to quantify cryptobenthic fish communities

Simon J. Brandl[1,2] | Lee A. Weigt[2] | Diane E. Pitassy[2] | Darren J. Coker[3] | Christopher J. Patrick[4] | Matheus H. Luchese[5,6] | Michael L. Berumen[3] | Edward J. Buskey[1] | Jordan M. Casey[1] | Maikon Di Domenico[5] | Marcelo Soeth[6,7] | Zachary M. Topor[8] | J. Emmett Duffy[9] | Carole C. Baldwin[10] | Mary Hagedorn[11,12] | Lynne R. Parenti[10]

[1]Department of Marine Science, The University of Texas at Austin, Marine Science Institute, Port Aransas, Texas, USA; [2]Laboratories of Analytical Biology, National Museum of Natural History, Smithsonian Institution, Washington, District of Columbia, USA; [3]Red Sea Research Center, Division of Biological and Environmental Science and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia; [4]Department of Biological Sciences, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA; [5]Center for Marine Studies, Federal University of Paraná, Paraná, Brazil; [6]Postgraduate Program in Coastal and Oceanic Systems, Federal University of Paraná, Paraná, Brazil; [7]Marine Fish Ecology Laboratory, North University Center of Espírito Santo, Federal University of Espírito Santo, São Mateus, Brazil; [8]University of Louisiana at Lafayette, Lafayette, Louisiana, USA; [9]Tennenbaum Marine Observatories Network and MarineGEO Program, Smithsonian Environmental Research Center, Edgewater, Maryland, USA; [10]Department of Vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, District of Columbia, USA; [11]Smithsonian's National Zoo and Conservation Biology Institute, Smithsonian Institution, Front Royal, Virginia, USA and [12]Hawai'i Institute of Marine Biology, University of Hawai'i at Mānoa, Kāne'ohe, Hawai'i, USA

Correspondence
Simon J. Brandl
Email: simon.brandl@austin.utexas.edu

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Abstract

1. Biodiversity inventories and monitoring techniques for marine fishes often overlook small (<5 cm), bottom-associated ('cryptobenthic') fishes, and few standardized, comparative assessments of cryptobenthic fish communities exist. We sought to develop a standardized, quantitative survey method for cryptobenthic fishes that permits their sampling across a variety of habitats and conditions.
2. Fish-specific autonomous reef monitoring structures (FARMS) are designed to sample cryptobenthic fishes using a suite of accessible and affordable materials. To generate a variety of microhabitats, FARMS consist of three layers of stacked PVC pipes in three different sizes, as well as a bottom and top level of loose PVC-pipe fragments in a mesh basket. We deployed FARMS across a variety of habitats, including coral reefs, seagrass beds, oyster reefs, mangroves, and soft-bottom habitats across six locations (Hawai'i, Texas, Panama, Saudi Arabia, Brazil, and Curaçao).
3. From shallow estuaries to coral reefs beyond 100 m depth, FARMS attracted distinct communities of native cryptobenthic fishes with strong site or habitat specificity. Comparing the FARMS to communities sampled with alternative methods (enclosed clove-oil stations on coral reefs in Panama and oyster sampling units on oyster reefs in Texas) suggests that FARMS yield a subset of cryptobenthic fish

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species that are representative of those present on local coral and oyster reefs. While FARMS yield fewer individuals per sample, they are efficient sampling devices relative to the sampled area.

4. We demonstrate that FARMS represent a useful tool for standardized collections of cryptobenthic fishes. While natural substrata are bound to yield more mature communities with a larger number of individuals and wider range of specialist species, the potential to deploy and retrieve FARMS in turbid environments, beyond regular SCUBA depth, and where fish collections using anaesthetics or ichthyocides are forbidden suggests that they are a valuable complementary technique to survey fishes in aquatic ecosystems. Deploying FARMS in locations and habitats where cryptobenthic fish communities have not been studied in detail may yield many valuable specimens of unknown or poorly known species.

KEYWORDS
artificial habitat, biodiversity, biogeography, coral reef fishes, fish trap, fisheries-independent sampling, taxonomic inventory

1 | INTRODUCTION

From the poles to tropical coral reefs and from shallow tidepools to the deepest trenches, ray-finned fishes (Actinopterygii) occupy nearly all marine habitats. To persist in these habitats, they have evolved a remarkable diversity of life history traits, ranging from tiny, bottom-dwelling gobies (e.g. the midget dwarf-goby *Trimmatom nanus*) to giants that roam the open ocean (e.g. the giant oarfish *Regalecus glesne*). This diversity begets large differences in detectability, which are further compounded by the surrounding habitat. Medium-sized, mobile fishes that populate the clear waters of shallow, tropical coral reefs are easily detected and enumerated by snorkelers or SCUBA divers (Edgar & Stuart-Smith, 2014). Conversely, fishes at the extreme ends of the size spectrum in turbid or aphotic environments are much more challenging to survey (Thomsen et al., 2016).

Fish communities are most commonly studied using data obtained from underwater visual surveys (UVCs) or fishery-dependent surveys that target only commercially valuable species (Murphy & Jenkins, 2010). Since both techniques are biased towards medium to large-bodied species, small-bodied, bottom-dwelling (i.e. 'cryptobenthic') fish species are rarely considered (Brandl et al., 2018; Depczynski & Bellwood, 2003). Cryptobenthic fishes populate most nearshore habitats worldwide, including rocky and coral reefs, mangroves, soft-bottom habitats or dock pilings (Brandl et al., 2018), sometimes accounting for more than 90% of fish individuals in a given system (Galland et al., 2017). They combine life history traits that not only make them difficult to survey but also affect their dispersal, population connectivity, speciation patterns, environmental tolerances or preferences, and functional roles (Brandl et al., 2019; Depczynski & Bellwood, 2004, 2006; Tornabene et al., 2015). Specifically, due to small body size, low batch fecundity, benthic spawning, parental care, short life cycles and high mortality, cryptobenthic fishes exhibit limited dispersal compared to larger fishes, which may lead to high population structure at relatively small spatial scales (D'Aloia et al., 2015; Farnsworth et al., 2010; Milá et al., 2017; Riginos & Victor, 2001; Volk et al., 2021) and, in some cases, rapid speciation within or across regional scales (Taylor & Hellberg, 2005; Tornabene et al., 2015; Wagner et al., 2019). Thus, it is probable that there are hundreds of species of cryptobenthic fishes that have yet to be described (Brandl et al., 2018), and the dynamics that govern cryptobenthic fish community assembly and functioning are poorly understood. To date, taxonomic inventories based on in situ surveys of these fishes are lacking in most locations (Brandl et al., 2018), and little comparative work across locations or bioregions has been performed (Ahmadia et al., 2018; González-Cabello & Bellwood, 2009).

Cryptobenthic fishes on coral reefs are efficiently collected by dousing a small section of habitat with fish anaesthetics or ichthyocides (Ackerman & Bellwood, 2000, 2002; Allen et al., 1992; Brandl et al., 2018; Smith-Vaniz et al., 2006). This technique yields excellent locally representative communities but requires the visual detection and collection of anaesthetised specimens, relatively calm conditions, approximately 60 min of bottom time, and permission to use anaesthetics or ichthyocides, such as rotenone, quinaldine or clove oil. Unless modified (such as for use on dock-pilings; Brandl et al., 2017), these limitations prevent the application of this technique in less accessible, turbid, deep, turbulent or governmentally restricted habitats. In such habitats, cryptobenthic fishes can be sampled through a variety of artificial structures (Ammann, 2004; Arney et al., 2017; Freedman et al., 2020), including by filling a hollow mesh basket or crate with biogenic material present in a given habitat (such as oyster shells or coral reef rubble) and retrieving the structure after a given immersion time (Reustle & Smee, 2020; Valles et al., 2006). Similarly, at depths beyond regular SCUBA diving limits,

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cryptobenthic fishes are sampled through roving collections via either closed-circuit rebreather diving (Pinheiro et al., 2019) or piloted submersibles that are fitted with equipment that can administer anaesthetics and catch anaesthetised fishes (Baldwin et al., 2018). While both of these techniques have yielded precious insights into the biodiversity of cryptobenthic fishes at depth, neither is well suited for efficient, standardized, quantitative collections of entire communities.

Autonomous reef monitoring structures (ARMS) have been used to establish standardized biodiversity inventories across the world's coastal oceans (Brainard et al., 2009; Leray & Knowlton, 2015). These structures are designed to be inexpensive, replicable, easy to deploy and sample, and produced from accessible materials. They have been shown to capture a broad suite of marine organisms across the tree of life using a combination of traditional (e.g. morphological) and modern (e.g. molecular) taxonomic techniques (Casey et al., 2021). Although cryptobenthic fishes frequently find their way into ARMS, the microhabitats provided by these structures are generally more favourable for mobile and sessile invertebrates, which limits the diversity of captured fishes. Here, we introduce fish-specific autonomous reef monitoring structures (FARMS) as a counterpart to ARMS for cryptobenthic fishes.

2 | MATERIALS AND METHODS

FARMS follow the design of ARMS, providing multiple levels of stacked PVC plates, interspersed by PVC structures that provide habitat for cryptobenthic fishes of various sizes and with varying microhabitat preferences. Specifically, a FARMS consists of five levels (Figure 1): flat PVC-coated wire mesh baskets filled with small pieces of loose PVC pipe (approximately 15 1-inch length pieces of 1 inch diameter pipe) on the bottom and top levels, and three levels with large (3-inch diameter), medium (1.5-inch diameter) and small (1/2-inch diameter) PVC pipes. Half of the PVC pipes are plugged on one end with cut-to-size PVC disks to create closed caves and open tunnels of each size. The levels are held in place by flat PVC sheets that are fastened using vertical threaded rods, nuts and bolts. Horizontal pipes are attached to the flat PVC sheets using short screws. The entire unit is mounted on a ½ inch PVC baseplate using the threaded rods, and the entire assembly can be attached to the substrate using stakes, bolts or thick threaded rods via four corner holes (as well as cylindrical weights, if necessary). If all materials are purchased in custom sizes for easy assembly, the cost per unit is approximately US$200. However, based on material costs alone, a unit can be fabricated for less than US$60. Costs can be further reduced by using regular hardware mesh instead of PVC-coated mesh for the PVC-rubble baskets. While this will decrease the longevity of the unit, it may suffice for shorter-term applications. A video documenting the assembly process is provided in the Supporting Information.

To prevent escape during retrieval, a milk-crate or similar sized container lined with fine mesh and fitted with a rubber rim can be placed over the FARMS and strapped to the baseplate using bungee cords (Figure 1c). The rubber rim creates a tight seal against the baseplate, while the inside mesh lining prevents fishes from escaping through the openings in the milk-crate. The unit can then be inverted for transportation and brought to the surface. Alternatively, the collection can be performed using a simple net, weighted around the perimeter, and draped around the unit, or using throw-traps that engulf the entire unit. Depending on the depth and environmental conditions, the retrieval can be performed while freediving, on SCUBA, or using a piloted submersible. Once retrieved, FARMS are best stored in a bin full of seawater to transport the units to a laboratory or processed immediately on the boat (especially if units are re-deployed).

We constructed, deployed and retrieved FARMS across six locations (Panama, Texas, Hawai'i, Saudi Arabia, Brazil and Curaçao; Figure 2, Supporting Information) and various habitat types, depths and durations in the course of independent case studies. In Bocas del Toro, Panama, FARMS were deployed on coral reefs in the direct vicinity of reef outcrops that were sampled using anaesthetic stations (Ackerman & Bellwood, 2002; Brandl et al., 2018), and in Texas, FARMS were deployed along with oyster sampling units (OSUs; Reustle & Smee, 2020), allowing us to compare the efficiency of FARMS in sampling cryptobenthic fishes to other methods. The remaining deployments were performed to assess the ability of FARMS to sample a broad suite of species across different sites or habitats, but without direct comparisons to established methods. In Hawai'i, FARMS were deployed on coral reefs in triplicates across Kane'ohe Bay; in Saudi Arabia, FARMS were also deployed on coral reefs in triplicates but across a lagoon to offshore gradient; and in Brazil, FARMS were deployed across three habitat types. Finally, we also deployed three FARMS on deep reefs in Curaçao in 60, 146 and 223 m depth using a piloted submersible, where minor modifications enabled deployment and retrieval using hydraulic arms of the *Curasub* submersible (Table 1). All collections in the present study were performed under the following research permits and ethics authorizations: KAUST Institutional Animal Care and Use Committee (IACUC#19IACUC04) (Saudi Arabia), SISBIO #77423-1 and IAT #05.22 (Brazil), STRI IACUC approval 2016-0101-2019 and #SE/AP-2-16 (Panama), NMNH IACUC approval 2018-03 (Hawai'i), Hawai'i Department of Land & Natural Resources Special Activity Permit 2019-70 and Site Plan Approval OA-18-57.

2.1 | Comparative deployments

In February 2016, we deployed nine early prototype FARMS, which did not include the PVC rubble baskets and were assembled using PVC glue, on reefs in the Almirante Bay in Bocas del Toro, Panama. FARMS were deployed adjacent to reef outcrops that were sampled using anaesthetic stations in 2016, as described in (Brandl et al., 2017). FARMS were left in place for one year, and six units were retrieved in March 2017 (three units were lost). To retrieve FARMS, a weighted, fine-mesh net was placed over the unit, fully engulfing the FARMS and its baseplate. While firmly holding

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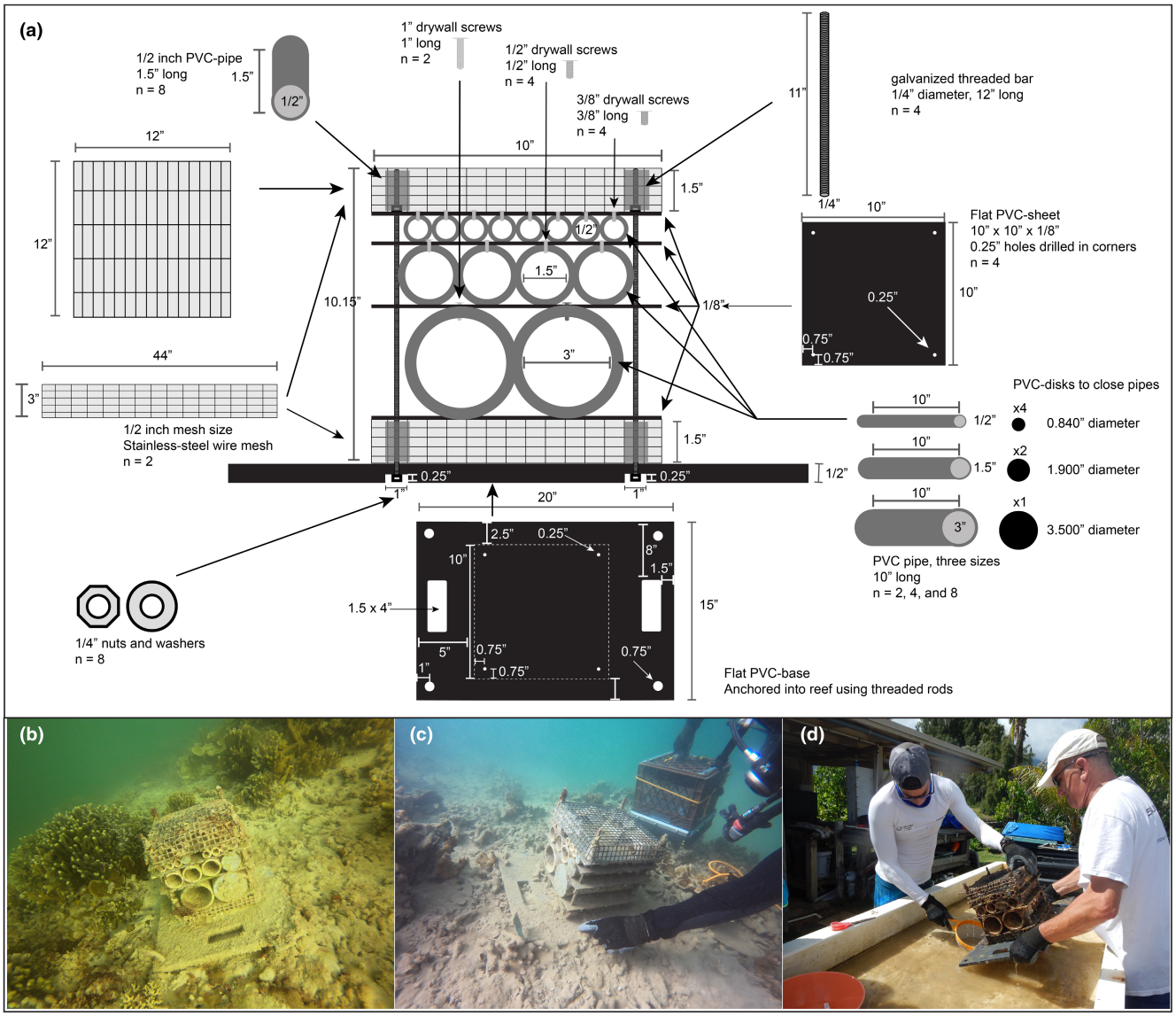

FIGURE 1 Blueprint for FARMS construction and photos of FARMS deployment, retrieval, and processing from Kane'ohe Bay, Hawai'i. (a) Sketch of components and assembly of a FARMS (all measurements in inches due to US-suppliers). (b) FARMS deployed for 5 months in Kane'ohe Bay. (c) Retrieval of FARMS using a milk-crate lined with fine mesh. (d) Processing of a FARMS on a large wet table. Photos by Diane Pitassy.

the net around the baseplate, the unit was inverted and the net was pulled tight around the bottom of the baseplate. The unit was then brought to the surface, placed in a bin full of seawater, and all fishes were removed from the FARMS, net and bin. For the anaesthetic stations (performed in 2016 as per Brandl et al., 2017), we followed the standard procedure of covering a small section of the reef with a fine-mesh net and an impermeable tarp, after which 2 L of clove-oil: ethanol solution (1:5) were injected into the sampling area. After a short period, the tarp was removed and all anaesthetised fishes were collected while gently folding back the net (Ackerman & Bellwood, 2002; Brandl et al., 2018). For both FARMS and anaesthetic stations, fishes were placed in an ice-water slurry, brought to the laboratory, identified, measured and photographed. While the exact sampling area for both FARMS and the sampled reef outcrops is difficult to determine (due to the interior, three-dimensional structure), the estimated outer surface area of FARMS was 0.465 m^2, while the estimated mean outer surface area of sampled reef outcrops was 3.410 m^2.

In Texas, thirteen FARMS were deployed among three coastal lagoons on the Gulf coast in early March of 2019. Nine of these were set in shallow water (~1-2 m depth) and deployed alongside an oyster sampling unit (OSU; or 'biobox'; Reustle & Smee, 2020). OSUs were 0.25 m^3 and constructed from a wooden frame with a 1 cm^2 mesh bottom holding a volume of sterilized oyster shell equal to five gallons, while the estimated volume for each FARMS was 0.03 m^3 (one cubic foot). Deployments sites were characterized by high cover of the seagrass *Halodule wrightii* (Laguna Madre), rocky rubble colonized by intertidal oysters (Oso Bay)

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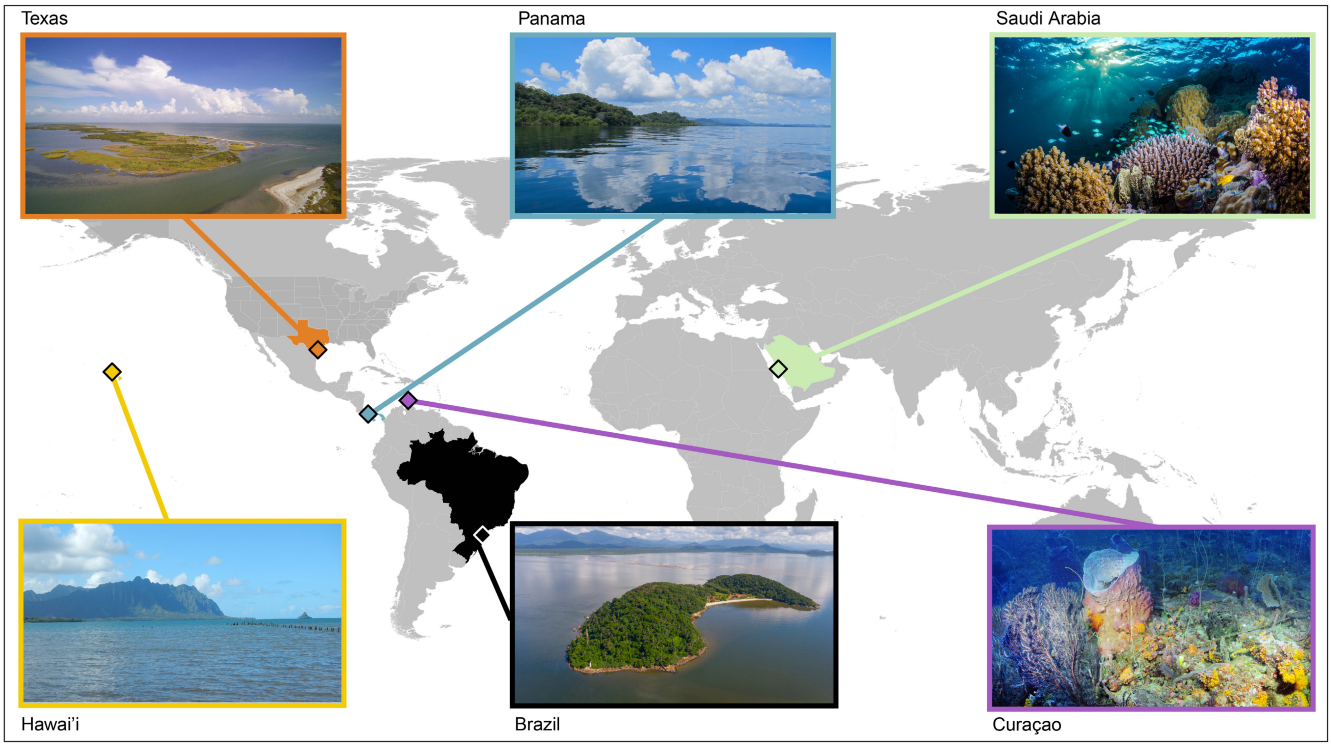

FIGURE 2 Map of the six study locations where FARMS were deployed between 2016 and 2021. Photos provided by Jace Tunnell (Texas), Jordan Casey (Panama), Morgan Bennett-Smith (Saudi Arabia), Gabriel Marchi (Brazil), Lynne Parenti (Hawai'i) and Barry Brown (Curaçao).

TABLE 1 Information for FARMS deployments across the five locations. *N* = total number of deployed and retrieved units; Depth = depth of deployments; Habitats = primary habitat of deployments; Duration = duration of deployments. Additional information is found in the Supporting Information.

Location	*N*	Depth	Habitats	Duration
Hawai'i	30 (30)	5–18 m	Coral reef, soft-bottom	6 months
Saudi Arabia	33 (27)	1–25 m	Coral reef, seagrass	4 months
Texas	13 (13)	1–5 m	Oyster reefs, seagrass, soft-bottom	3 months
Brazil	14 (14)	1–3 m	Mangroves, rocky shore, docks	1–2 months
Panama	9 (6)	3–8 m	Coral reef	12 months
Curaçao	3 (3)	60–223 m	Deep reef	12 months

and a subtidal oyster reef (Aransas Bay). Four additional FARMS were deployed in deeper (up to ~3 m) sites co-located with water quality data stations maintained by the Mission Aransas National Estuarine Research Reserve (MANERR) in Aransas Bay. FARMS and OSUs were left for 3 months (retrieved in early to mid-June of 2019). FARMS were retrieved as described above but without the use of SCUBA. OSUs were collected by deploying a square throw trap over the unit and lifting the box out of the trap and placing it in a plastic basin for sorting. The trap was then continuously swept with a custom 1 mm mesh sweep net the same width as the trap until three consecutive sweeps yielded zero fish. At the surface, all fishes were removed from the FARMS, OSUs, netting and the bins. Fishes were placed in an ice-water slurry, brought to the laboratory, identified, counted and measured, and unique specimens were photographed.

2.2 | Non-comparative deployments

In Hawai'i, Saudi Arabia, and Brazil, FARMS were not deployed alongside other collection methods but across different sites and habitats to test whether FARMS harbour site-specific communities throughout a location or reflect a broad, homogenous pool of potential recruits that settle on the FARMS. In Kane'ohe Bay, 30 units were deployed in triplicates between 5 m and 18 m depth, and spanned different conditions from inshore, turbid environments to exposed, coral dominated patches (one triplicate set was buried in sediment and excluded from this study). In Saudi Arabia, 33 FARMS were deployed on coral reefs and 27 were collected (six units were lost) across an inshore to offshore (and depth) gradient. Sites ranged between depths of 1 to ~6 m for all inshore sites, and at 10 and 25 m on mid-shore and offshore reefs.

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In Brazil, 14 FARMS were deployed in the shallow subtidal zone across three habitats at the outermost sector of the Paranaguá Estuarine Complex (PEC): mangroves (Perequê tidal creek; $N = 3$), rocky shores (Cobras Island; $N = 6$) and artificial dock structures (DNOS artificial channel; $N = 5$).

2.3 | Statistical analyses

For deployments in Panama, we compared the community composition between FARMS and adjacent anaesthetic stations using an nMDS on the Raup-Crick dissimilarity matrix of species' presence or absence in a sample. We opted for binary data structure based on presence/absence due to the large differences in sampled area between FARMS and anaesthetic stations. We also compared the relative abundance and species richness of FARMS and anaesthetic stations (based on estimated outer surface area) using Bayesian models with a log-normal distribution, and tested whether the number of individuals and species in the FARMS and reef outgroups correlated across the six deployments. For the latter analyses, we ran Bayesian linear models using the log-transformed values from FARMS deployments as the response variable and the values from reef based collections as the explanatory variable.

For the Texas deployments, we compared the community structure and composition between FARMS and simultaneously deployed oyster sampling units (OSUs) across the sites. For community composition, we performed an nMDS on the Bray–Curtis dissimilarity matrix. To compare abundances, we performed a Bayesian model with a negative binomial error structure and log-link function, while we compared species richness using a Poisson error structure. Since both OSUs and FARMS represent discrete sampling units and their inner sampling volumes are difficult to compare, we did not standardize obtained estimates by sampling volume.

We also examined location-specific patterns in cryptobenthic fish communities obtained from the FARMS and, where available, comparative sampling techniques, using multivariate examinations of community composition best suited for the data. Furthermore, where appropriate, we performed univariate comparisons of the abundance and species richness (either among sites or sampling techniques). A more detailed overview of these analyses is provided in the Supporting Information. All data analyses and visualizations were performed in R (R Core Team, 2021) using the packages VEGAN (Oksanen et al., 2022), BRMS (Bürkner, 2017), TIDYBAYES (Kay, 2018), MODELR (Wickham, 2020), SF (Pebesma, 2018) and FISHUALIZE (Schiettekatte et al., 2019).

3 | RESULTS

Overall, 102 FARMS were deployed across the six locations, of which 93 were collected. Regional (γ) diversity across all FARMS was highest in Saudi Arabia (23 species), followed by Hawai'i (8), Panama and Texas (7 each), and Brazil (5). The three FARMS on deep reefs in Curaçao contained five species at 60 m, two species at 146 m and no fishes in the deepest FARMS (223 m), likely due to the limited deployment duration.

In Panama, species sampled in the FARMS represented a small subset of the reef outcrop community based on presence/absence (Figure 3). While a much larger number of individuals (97.2 individuals per sample ± 17.2 SD) and species (11.3 species per sample ± 2.42 SD) was sampled from the reef outcrops compared to individual FARMS (10.5 ± 5.1 and 3.5 ± 1.4, respectively) in absolute terms, estimates of fish density and species density relative to the estimated sampled surface area revealed high efficiency of FARMS in obtaining a diversity of species (Figure 3). Indeed, species density (i.e. species per m^2) was lower on reef outcrops compared to FARMS (mean posterior estimate: FARMS = 7.1 [5.25 lower credible interval, 9.70 upper credible interval], reef outcrops = 3.30 [2.44, 4.43]), while there was no clear difference in fish density (individuals per m^2). Finally, there was no correlation in the number of individuals obtained from FARMS and reef outcrops, but there was a positive correlation between species richness estimates (posterior parameter estimate: 0.38 [0.12, 0.64]; Figure 3).

In Texas, compositional differences among sites were evident using both FARMS and OSUs (Figure 4), but the two techniques differed in their community composition (as indicated by non-overlapping polygons in multivariate space, despite almost complete overlap on the first axis). Species with the largest influence on the separation between OSUs and FARMS in the second dimension include *Anchoa mitchilli*, *Lagodon rhomboides*, and *Bairdiella chrysoura*, which are generally classified as epibenthic species rather than cryptobenthics. While there was no difference in the abundance of cryptobenthic fish species between the two methods, OSUs yielded a larger number of species than did FARMS (mean posterior estimates: OSUs = 7.1 [5.6, 9.0]; FARMS = 2.9 [2.0, 4.0]).

Finally, in Hawai'i, Saudi Arabia, and Brazil, FARMS units showed clear differences in species richness, abundance, and community composition between sites, shelf positions, and habitats, respectively (Supporting Information Figures S1–S3). In Curaçao, only the two shallower FARMS yielded fish, while no fish were caught on the deepest FARMS (223 m). The FARMS at 146 m depth yielded the second known specimen of *Psilotris laurae* (Figure 5), a species described based on a single specimen from Bonaire (Tornabene et al., 2016). The dominant species obtained from the FARMS in each location (except Curaçao) are summarized in Table 2.

4 | DISCUSSION

The artificial nature of FARMS generally raises concerns about their ability to capture diverse communities that are typical of the surrounding habitat. Indeed, several of our deployments were dominated by a single, generalist species, such as *Asterropteryx semipunctata* in Hawai'i, *Gobiosoma bosc* in Texas, *Coryphopterus personatus* in Panama, and *Bathygobius soporator* in Brazil. Yet, it is possible that the numerical dominance of select species simply reflects local

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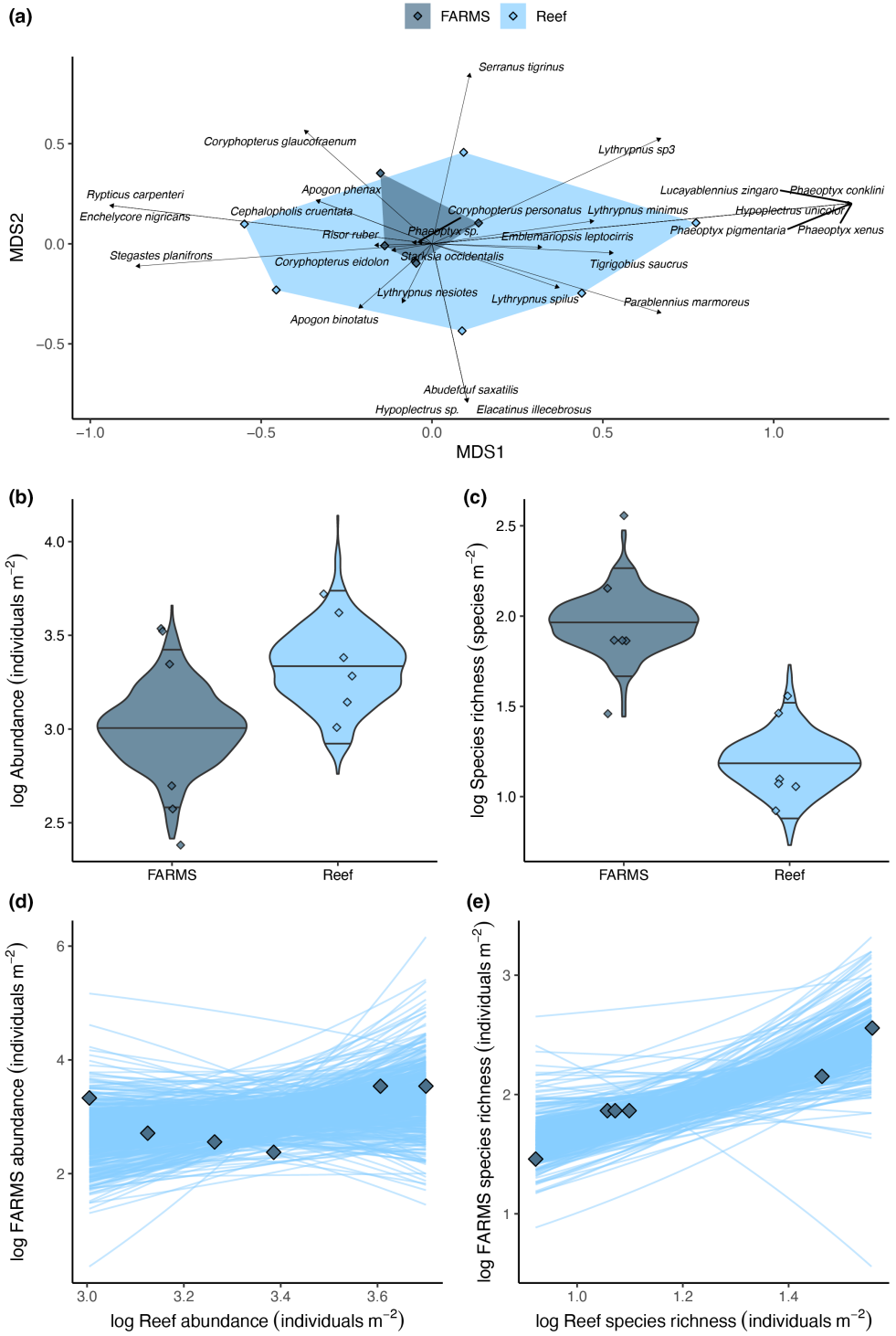

FIGURE 3 Cryptobenthic fish communities from FARMS deployed in Bocas del Toro, Panama. (a) nMDS ordination, where different sampling methods are delineated by colours and polygons. Species are overlaid from the origin of the ordination. (b and c) method-specific differences in density (abundance per m^2) and species density (species per m^2). Violin plots reflect posterior distributions based on 500 draws from Bayesian models, while diamonds represent the raw data (jittered horizontally). Black lines in the violins mark the 2.5%, 50% and 97.5% quantiles. (d and e) show correlations between abundance and species richness estimates across sites, with lines reflecting 500 fitted draws from the posterior, while points represent raw values.

abundances regardless of artificial versus natural substrate. This is supported by the two locations where we simultaneously sampled natural (reef outcrops in Panama) and seminatural (OSUs in Texas) habitats. In both cases, the most abundant species were comparable among sampling methods, and in Panama, the numerical dominance of *C. personatus* was weaker on FARMS than on reef outcrops.

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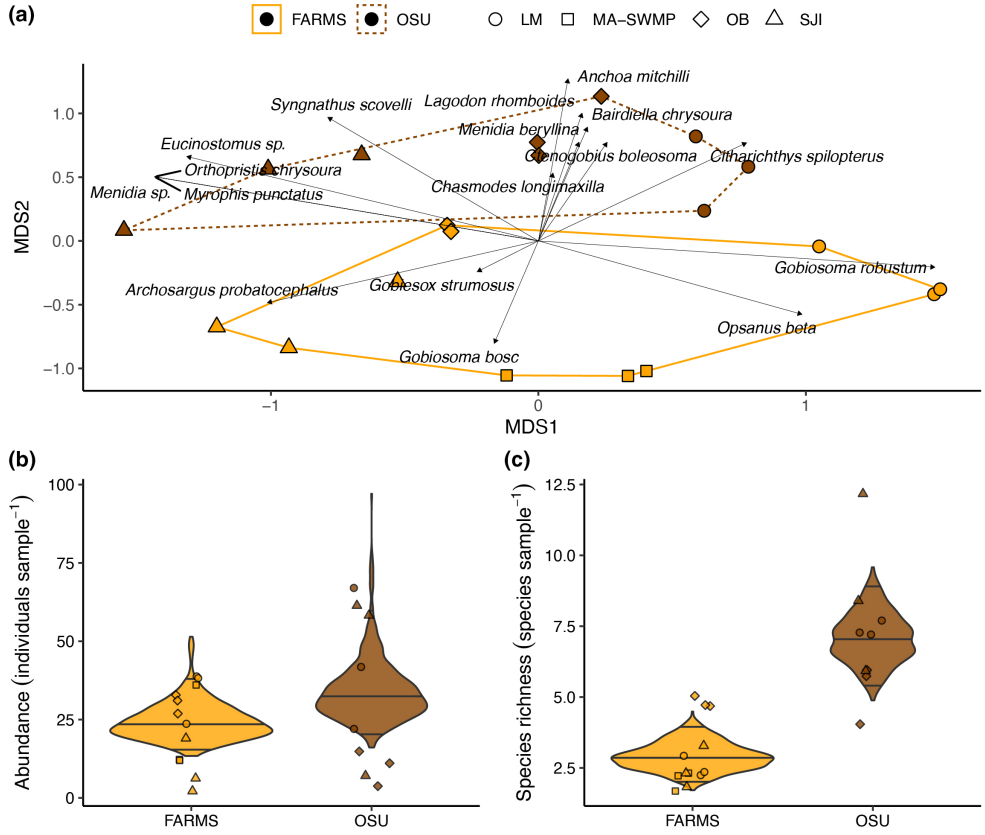

FIGURE 4 Cryptobenthic fish communities from FARMS and OSUs deployed in South Texas. (a) nMDS ordination, where different sampling methods are delineated by colours and polygons. Species are overlaid from the origin of the ordination and sites are denoted by symbols. (b and c) method-specific differences in the abundance per sample and species richness per sample. Violin plots reflect posterior distributions based on 500 draws from Bayesian models, while symbols represent the raw data (jittered horizontally). Black lines in the violins mark the 2.5%, 50% and 97.5% quantiles.

Nevertheless, it is important to consider that FARMS cannot fully mirror the surrounding environment, especially in habitats with no solid structures (such as pure sand or seagrass habitats). In these habitats, FARMS may sample errant recruits to hard-bottom structures rather than species typical for these environments.

The comparisons of cryptobenthic communities obtained from FARMS and OSUs in Texas and FARMS and reef outcrops in Panama permit a careful evaluation of the potential for FARMS to sample cryptobenthic fishes. In Panama, anaesthetic stations encompassed a much larger surface area than FARMS, so the markedly higher number of individuals from reef outcrops is, at least in part, attributable to the sampled area. This may also increase the diversity of species sampled due to the relationship between the number of individuals and species likely to occur in a sample (Gotelli & Colwell, 2001), ultimately leading to the fully nested position of FARMS within the polygon encompassed by the anaesthetic stations. However, when standardizing samples based on the estimated surface area sampled, FARMS yielded a higher number of species per m^2, suggesting that they are an efficient technique to sample local diversity. In addition, the correlation between the number of species obtained from FARMS and reef outcrops across sites in Almirante Bay suggests that FARMS are sensitive to fine-scale differences in the surrounding habitat that may drive differences in fish communities across the bay (Nguyen et al., 2020). In this context, the refined prototype of FARMS that was deployed in later case studies (which features a larger variety of microhabitats) may have further increased the efficiency of FARMS in sampling a diversity of cryptobenthic fish species in Panama. Nevertheless, simply by obtaining a larger number of individuals and covering a larger area, anaesthetic stations likely provide a more thorough reflection of the local community than do FARMS and may therefore remain the preferred method on shallow coral reefs.

For oyster reefs in Texas, no clear differences in abundance were apparent between OSUs and FARMS, but OSUs yielded more species. These differences were largely driven by epibenthic/epipelagic species such as yellow perch (*Bairdiella chrysoura*) and pinfish (*Lagodon rhomboides*). There is an intuitive incentive for filling sampling units with natural, locally abundant substrates (such as oyster shells or coral rubble), as these units closely resemble the surrounding habitat (Reustle & Smee, 2020; Takada et al., 2016; Valles et al., 2006). However, this precludes the standardization of materials across studies. Our results suggest that FARMS adequately captured the core species of the cryptobenthic community, which supports existing evidence that artificial structures can offer

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FIGURE 5 Retrieval of a FARMS unit on the slope of Curaçao using the *Curasub* submersible and its hydraulic arm, and the second-known specimen of *Psilotris laurae*, collected in the FARMS deployed at 146 m. Top and middle photos by C. Baldwin, bottom by Barry Brown.

useful snapshots of cryptic fauna in marine environments (Ransome et al., 2017; Wolfe & Mumby, 2020). Furthermore, both FARMS and OSUs successfully resolved site-specific differences in community composition, suggesting that neither of the two sampling techniques is superior.

The ability of FARMS to reflect gradients in composition and diversity was further supported by the FARMS deployments in Hawai'i, Saudi Arabia, and Brazil. Similar to ARMS (Brainard et al., 2009; Casey et al., 2021; Plaisance et al., 2021), FARMS showed relatively low variability when units were deployed within a few meters of each other but captured differences in communities across sites. This suggests that the units adequately mimic a broad variety of microhabitat requirements for species that are present at a given site. For example, FARMS in the Red Sea harboured multiple species of *Trimma*, whereas FARMS in Hawai'i were colonized by *Priolepis farcimen*. *Trimma* and *Priolepis* gobies are known to favour caves and crevices (Depczynski & Bellwood, 2004), suggesting that the horizontal PVC-pipes of the FARMS adequately imitate these microhabitats on coral reefs. Similarly, deployments in Hawai'i and the Red Sea yielded *Pleurosicya larsonae* and *P. mossambica*, respectively. *Pleurosicya* is associated with hard corals, soft corals and sponges (Depczynski & Bellwood, 2004; Herler, 2007; Troyer et al., 2018), often showing species-specific preferences (Herler, 2007). Of note, *P. larsonae* had only been reported from a single habitat in Oahu and is considered to be extremely cryptic (Greenfield & Randall, 2004), further emphasizing that FARMS can capture elusive, highly specialized species. Finally, deployments in Brazil yielded several individuals of *Hippocampus reidi*, which strengthens existing evidence that seahorses readily colonize artificial substrata (Simpson et al., 2019), despite strong species-specific habitat preferences (Zhang & Vincent, 2018). Whether the microhabitats that cryptobenthic fishes settle on are provided by the FARMS structures themselves or sessile epifauna and algae that accumulate on the PVC structures remains to be determined. In this context, excessive overgrowth may also hinder colonization as sessile organisms

TABLE 2 Dominant species obtained from FARMS and complementary sampling methods across the five locations in which more than three FARMS were deployed.

Location	Species	Relative abundance
Hawai'i	*Asterropteryx semipunctata*	55.5%
	Priolepis farcimen	15.2%
	Bathygobius sp.	10.5%
Saudi Arabia	*Eviota guttata*	34.2%
	Pseudanthias squamipinnis	13.2%
	Pleurosicya mossambica	7.8%
Brazil	*Bathygobius soporator*	88.0%
	Hypleurochilus fissicornis	4.4%
	Hippocampus reidi	3.3%
	Dormitator maculatus	3.3%
Texas: FARMS	*Gobiosoma bosc*	42.7%
	Gobiosoma robustum	34.1%
	Gobiesox strumosus	15.4%
Texas: OSUs	*Gobiosoma robustum*	32.4%
	Gobiosoma bosc	16.0%
	Eucinostomus sp.	15.7%
Panama: FARMS	*Coryphopterus personatus*	61.9%
	Phaeoptyx sp.	22.2%
	Coryphopterus eidolon	6.4%
Panama: outcrops	*Coryphopterus personatus*	71.8%
	Coryphopterus eidolon	4.0%
	Phaeoptyx sp.	3.6%

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may overgrow and block access to available refuges. Experiments that examine cryptobenthic fish communities on FARMS that are sampled repeatedly and either cleared of all epifauna (treatment) or left undisturbed (control) may shed light on the importance of fouling communities on the FARMS.

Although our results suggests that FARMS can be a useful, standardized sampling approach to determine patterns of diversity and community composition, it is necessary also to consider the overall regional inventories obtained from the deployments. For FARMS deployed in Hawai'i, we only obtained eight species, most of which had previously been collected during roving collections (Parenti et al., 2020). Thus, the γ-diversity obtained from 26 FARMS falls well short of the 192 species collected in Kane'ohe Bay using small rotenone stations (Greenfield, 2003). Of the 19 goby species reported by Greenfield (2003), FARMS captured just over a quarter (26.3%), although the temporal effort employed by Greenfield (2003) is likely to have substantially outweighed our FARMS deployment. In the Red Sea, γ-diversity was the highest among the locations in this study (23 species), but a regional inventory of cryptobenthic fishes obtained from rotenone stations in the southern and central Red Sea (238 species) vastly exceeded this number (Coker et al., 2018). While this inventory extends beyond the geographic area covered by FARMS and again involved higher temporal effort than the FARMS deployment and retrieval, it appears that collections using ichthyocide or anaesthetic stations—where feasible—are a more efficient strategy to produce thorough taxonomic inventories of cryptobenthic fishes. This may be partially ameliorated through longer FARMS deployment periods to obtain a more mature community. The FARMS that were deployed for the longest period (one year in Panama) exhibited the highest species richness across the five shallow case studies, suggesting that longer deployment times may yield more mature, diverse communities of cryptobenthics. We suggest a minimum submergence time of 6 months, ideally leaving the units for one year.

Overall, FARMS are a simple, standardized, broadly accessible and cost-effective technique on a per unit basis to obtain locally representative cryptobenthic fish assemblages based on live specimens, especially in habitats where SCUBA-based anaesthetic or ichthyocide stations are impossible or permits to destructively sample fishes are unobtainable. This includes highly turbid, deep, inaccessible, or governmentally restricted habitats, which are some of the least explored habitats. The utility of FARMS for these habitats is highlighted by the deployment of only three FARMS in Curaçao, and the capture of a specimen of *Psilotris laurae* in the FARMS deployed at 146 m. Despite extensive roving submersible-based collections performed across the slope of Curaçao between 2011 and 2022, no other specimens of *P. laurae* had been observed or collected (Baldwin et al., 2018; Tornabene et al., 2016). This suggests that deploying FARMS in undersampled habitats such as deep reefs may yield a additional taxonomic records that help us gain a better understanding of cryptobenthic fish diversity and distribution patterns, while also yielding critically important specimens and tissue samples that can support emerging molecular survey methods (de Santana et al., 2021; Gold et al., 2021).

AUTHOR CONTRIBUTIONS

Simon J. Brandl conceived the project, executed fieldwork in Panama, analysed the data and wrote the first draft. Lee A. Weigt, Jordan M. Casey, J. Emmett Duffy and Carole C. Baldwin contributed to the design of the FARMS units. Lynne R. Parenti, Lee A. Weigt, Diane E. Pitassy and Mary Hagedorn led the data collection in Hawai'i. Darren J. Coker and Michael L. Berumen led the data collection in Saudi Arabia. Christopher J. Patrick and Edward J. Buskey led the data collection in Texas. Matheus H. Luchese, Maikon Di Domenico and Marcelo Soeth led the data collection in Brazil. Carole C. Baldwin led the data collection in Curaçao. Jordan M. Casey and Zachary M. Topor contributed to data collection in Panama. All co-authors contributed to editing the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Data are available via the Dryad Digital Repository Brandl et al. (2023) (https://doi.org/10.5061/dryad.cjsxksnb0); download

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ORCID

Simon J. Brandl https://orcid.org/0000-0002-6649-2496
Jordan M. Casey https://orcid.org/0000-0002-2434-7207

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Cryptobenthic fish communities from FARMS deployed in Kane'ohe Bay, Oahu, Hawai'i. (a) nMDS ordination, where sites are delineated by colors and polygons. Species are overlaid from the origin of the ordination. (b and c) site-specific differences in abundance and species richness. Violin plots reflect posterior distributions based on 500 draws from Bayesian models, while dots represent the raw data (jittered horizontally). Black lines in the violins mark the 2.5%, 50%, and 97.5% quantiles.

Figure S2. Cryptobenthic fish communities from FARMS deployed on coral reefs in the Red Sea, Thuwal, Saudi Arabia. (a) nMDS ordination, where different shelf positions are delineated by colors and polygons. Species are overlaid from the origin of the ordination. (b and c) site-specific differences in abundance and species richness. Violin plots reflect posterior distributions based on 500 draws from Bayesian models, while dots represent the raw data (jittered horizontally). Black lines in the violins mark the 2.5%, 50%, and 97.5% quantiles. Note that the four FARMS without fishes were omitted from the ordination.

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Figure S3. Cryptobenthic fish communities obtained from FARMS deployed in the Paranaguá Estuarine Complex (PEC) in Brazil. (a) PCoA ordination, where different habitats are delineated by greyscales and polygons. Species are overlaid as loadings from the origin of the ordination. (b and c) site-specific differences in abundance and species richness. Violin plots reflect posterior distributions based on 500 draws from Bayesian models, while dots represent the raw data (jittered horizontally). Black lines in the violins mark the 2.5%, 50%, and 97.5% quantiles of the distributions.**Supplemental Video S1.** (FarmsAssembly_TimeLapse.m4v) Time-lapse video showing the complete assembly of a FARMS unit.

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