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Livelihood diversity and fishing skill during COVID-19 lockdowns in French Polynesia

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Small-scale fisheries provide seafood for billions of people and are one of the largest employers in many coastal communities. Those households engaged in these fisheries who maintain diverse income sources are generally thought to be better prepared to cope with social or ecological perturbations such as the crises presented by the COVID-19 pandemic. One outcome of the COVID-19 crisis was the collapse of international tourism after many nations instituted strict border controls to slow the virus's spread, severely impacting coastal communities that depend on tourism-related employment. This research assessed the effects of COVID-19-induced collapse of tourism on small-scale coral reef fishers and households in Moorea, French Polynesia. Ninety-five households were surveyed about their livelihoods, fishing, demographics, and income-generating occupations before and after the lockdown. Shifts in fish biomass were evaluated using time series data collected through underwater visual surveys, and roadside fish vendors were surveyed to assess fish sales. Results showed that after tourism employment evaporated more Moorea households began fishing to boost their incomes and food security. However, the increase in fishing pressure showed no appreciable decline in the biomass of fishable species. The households responsible for the increased fishing activities were those who were working in the tourism economy prior to the pandemic and subsequently lost their jobs. Households that combined fishing with construction or other stable sectors showed greater abilities to cope, while those combining fishing with tourism were heavily impacted. Importantly, results showed that those households devoted solely to fishing managed the crisis adeptly due to their superior fishing skills and ecological knowledge. This pattern suggests that not all forms of household livelihood diversification confer equal advantages and that

resource-dependent households are not necessarily intrinsically less resilient. More generally, it is argued that we should be cautious when promoting livelihood diversification as a blanket solution to decrease household vulnerability, and that ecological knowledge diversity is underappreciated.

KEYWORDS

COVID-19, small-scale fisheries, livelihood diversity, coral reefs, French Polynesia, fishing skill

1 Introduction

The COVID-19 virus caused an extraordinary socio-ecological disruption. Notwithstanding the human suffering caused by the pandemic, it presented an unprecedented case to examine the complex dynamics of social-ecological systems as the scope and pace of human activities radically shifted. Nations around the world instituted lockdowns restricting human mobility at an unprecedented scale to quell the spread of the virus. In early April 2020, 4.4 billion people, over half of the world's population, were under some form of instituted confinement (Bates et al., 2020). In addition to internal controls on movement, many nations also imposed strict border controls, causing international tourism to plummet. In the Pacific region, visitors were allowed to enter only after they underwent rigorous testing and quarantining. Some countries, such as New Zealand and the Solomon Islands, remained closed to international visitors for nearly two years, while others like French Polynesia reopened just a few months after the arrival of the virus (Campbell and Connell, 2021). The divergent approaches to border closures can be attributed to several factors such as national public health strategies, geopolitical considerations, and especially dependence on tourism.

Early reports about the impacts of the COVID lockdowns suggested that the dramatic slowdown in human activities had a silver lining—anthropogenic pressure on some ecosystems had rapidly declined. Carbon dioxide emissions plummeted as did air, water, and noise pollution, with potential benefits for wildlife and people (Rutz et al., 2020). In contrast, other findings revealed that the crushing economic blow of lockdowns was forcing poorer communities to rely more heavily on their surrounding ecosystems for food and livelihoods, resulting in more intense harvesting of plant and animal life and increasing poverty (Sumner et al., 2020). In India, highly threatened pangolins appear to have been harvested more intensely when COVID-19 restrictions were instituted (Aditya et al., 2021). As for island and coastal communities that depend heavily on tourism, some researchers predicted that they would experience an increase in fishing activity as households previously employed in tourism were forced into fisheries (Bennett et al., 2020; Stokes et al., 2020; Gaiser et al., 2022).

Recent research documenting the effects of COVID-19 on commercially oriented small-scale coral reef fisheries has shown

that households in many regions reduced their fishing in response to a collapse in international and local seafood markets (Knight et al., 2020; Ferrer et al., 2021; Love et al., 2021; Mangubhai et al., 2021; Alam et al., 2022; Macusi et al., 2022; Love et al., 2024). In Sulawesi, Indonesia, the number of active fishers and fish traders in coastal communities declined after national restrictions on travel were imposed (Campbell et al., 2021). Since most fish caught were sold for income, households in these communities coped with the sudden decrease in demand for fish by limiting their fishing activities and only fishing for household consumption. An ecological study carried out in southeast India corroborated this pattern of decreasing fishing activity and showed an overall increase in fish density at the study sites compared to pre-pandemic measurements (Edward et al., 2021; Lecchini et al., 2021). In Malaysia, fisher's incomes declined by 50% during the lockdowns, and rural fishers far from commercial centers were hit hardest (Menhat et al., 2021). These cases all involved commercially oriented small-scale fisheries rather than subsistence- or recreationally-oriented ones, yet there are indications that different types of fisheries responded in unique ways to the pandemic lockdowns (Campbell and Connell, 2021). In Palau, commercial fishers were more likely to report a decrease in their fishing effort than subsistence-oriented fishers (Ferguson et al., 2022). However, to our knowledge, no studies have been conducted in small-scale fisheries where the local economy was heavily dependent on tourism, contexts where there may be countervailing drivers of fishing effort such as less demand for fish by tourists while also reduced livelihood opportunities associated with tourism.

It is widely argued in the small-scale fisheries literature that households who maintain flexible and diverse livelihood strategies are best prepared to manage economic shocks such as the COVID-19 lockdowns, as they are thought to be capable of switching between different livelihoods in times of socio-ecological stress (Adger, 2006; Nelson et al., 2007; Pomeroy et al., 2017; Cinner et al., 2018; Thiault et al., 2021). Those households who can move in and out of the fishery or between different occupations are expected to adapt to new ecological or economic conditions most readily (Smit and Wandel, 2006). This view is based on the assumption that households with multiple livelihood options can lower their risk of failure or mitigate stress by distributing their incomes across various sources (Ellis, 1998). In addition, fishing communities with low livelihood diversity may in some circumstances be more

likely to overfish local waters and have inadequate resource management strategies to deal with common pool resources (Cinner et al., 2009). Higher levels of fish biomass, for example, have been documented near coastal communities where livelihoods are less dependent on resource extraction.

Yet the reality of many households in coastal or island communities is that many have low levels of livelihood diversity and depend solely on fishing. For these reasons fishing communities are presumably vulnerable to shocks and often portrayed as the “poorest of the poor” who are resource-dependent and reliant on “the occupation of last resort” (Bailey and Jentoft, 1990; Béné, 2003). Their relative lack of livelihood diversity is attributed to low levels of flexibility and the inability to shift out of the fishery as conditions change. As a result, many fisheries management initiatives seek to diversify the livelihoods of small-scale fishing communities so that they are less dependent on the local ecosystem and, presumably, more capable of managing social-ecological shocks (SPC, 2015; Roscher et al., 2022).

Some scholars, however, argue that dependence on local ecosystems for food and livelihoods among Pacific Island communities’ cultivates extensive ecological knowledge that enhances, rather than undermines, their capacity to navigate challenges such as climate change, economic instability (Lauer, 2017; McMillen et al., 2017), or significant disruptions like tsunamis (McMillen et al., 2014; Sterling et al., 2017; Lauer, 2023). Studies have shown that Pacific Island communities have a long history of managing significant environmental shifts even though they have limited livelihood options (McNamara et al., 2022).

Here we engage in this debate by focusing on the island of Moorea, French Polynesia (FP), a context that provides a unique case to examine the relationship between tourism employment, livelihood diversity, and fishing during the COVID-19 crisis. Since 2014, we have conducted social and ecological studies of the coral reef fishery on Moorea where tourism provides the bulk of local formal employment (Rassweiler et al., 2020; Holbrook et al., 2022; Lauer et al., 2022; Rassweiler et al., 2022; Cook et al., 2024; Rassweiler and Wall, 2024). Fishing remains central to social and economic life and the island’s highly active coral-reef fishery involves a complex mix of commercial, subsistence, and culturally motivated fishing (Leenhardt et al., 2016). When, in April 2020, the FP government imposed strict internal controls on movement and closed the borders to international travel, tourism employment plummeted. We explored the social-ecological effects of the COVID-19 pandemic in the context of household vulnerability and resilience, with a focus on the possible unintended consequences of livelihood diversification for small-scale coral reef fishers and households in Moorea.

2 Materials and methods

2.1 Conceptual framework

It is generally assumed that some households will have more ability to anticipate and respond to changes like the COVID-19-

induced lockdown that occurred in Moorea and to cope with and recover from its consequences more quickly. This capacity is typically defined as a household’s “adaptability”, “coping ability”, or “adaptive capacity”, concepts that all converge around the idea that certain processes enable households to “better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity” (Smit and Wandel, 2006). Fishing-dependent communities in lower- and middle-income countries have been characterized as suffering from low levels of adaptive capacity due to their lack of diversified livelihood opportunities (Allison and Ellis, 2001; Gillett et al., 2008). As a result, livelihood diversification interventions have progressively gained momentum among international development experts and fisheries managers (FAO, 2015). Livelihood diversification projects, including tourism development initiatives (Añasco et al., 2021) are thought to potentially produce more resilient coastal communities by providing alternative or supplemental income opportunities and reducing pressure on fish stocks (Pomeroy et al., 2017). Thus, livelihood diversification, through tourism or other means, is generally accepted and promoted to achieve more sustainable fishery practices and to boost the adaptive capacity of coastal communities when coping with social-ecological perturbations (Allison and Ellis, 2001).

We use three complementary approaches to document how households adapted their fishing practices and livelihoods in response to the COVID-19 disruptions and how these changes may have affected local coral reef fish populations. First, semi-structured and open-ended household interviews were used to understand changes in household livelihood strategies, shifts in fishing effort, and perceptions about overall community responses to the lockdown. We hypothesized that there would be an increase in fishing activity as tourism-related employment was cut off. Second, we analyzed ecological data to evaluate trends in fishable resources. We predicted that increases in fishing effort could result in overharvesting and thus declines in food fish biomass on Moorea’s reefs. Finally, we conducted surveys of fish sales to document any changes in fishing activities and fish sales during the pandemic crisis, and how the catch differed between established fishers and those with less experience fishing for income generating purposes (i.e., who entered the fishery during the lockdown). We expected that total catch would increase, but the quality of the catch (e.g., fish size, catch per unit effort) might decline as the increase in total effort led to more competition for the available resources. Taken together, these lines of evidence provide unique insight into the relationship between livelihood diversity and fishing skill among Moorea’s coastal communities during the COVID-19 disruptions.

2.2 Study site and the coral reef fishery

Moorea is a triangular, high island with an extensive lagoon, a barrier reef, steep mountains, and two narrow, deep bays. With a land area of about 134 square km, the island is part of the Windward Group of the Society Islands, one of five major archipelagos in FP. Moorea is also the second most populous island in FP with around 18,000 inhabitants. Politically FP is considered an overseas collectivity

of France and is granted autonomy in many of its activities although economically the country is heavily dependent on France. Tourism is by far the largest sector of the FP economy, constituting 85% of total value added (CIA, 2020). Moorea's proximity to the only international airport located on Tahiti provides the island with a steady stream of tourists, with tourism providing 27% of Moorea's formal employment (ISPF, 2020). Prior to the pandemic, there were three major international chain hotels on Moorea (Intercontinental, Hilton, Sofitel), and one local resort franchise, Manava. In total these hotels offered over 450 luxury rooms.

Administratively the island is divided into five *communes associées* (districts) with most of the hotels located in the districts of Papetoai and Paopao on the north coast (Figure 1). These districts are more economically dependent on tourism than the rest of the island and are the most populated. The southwest district of Haapiti, in contrast, is the least populated and its tourism industry is limited to guesthouses and short-term rental properties.

Our previous research has documented a vibrant coral reef fishery on Moorea (Leenhardt et al., 2016; Rassweiler et al., 2020; Hunter and Lauer, 2021; Nassiri et al., 2021). Engagement in the fishery is widespread and over three-quarters of households have an active member who fishes at least once a week. However, only a small fraction of households rely solely on fishing as their main source of income. Local demand for fresh reef fish is high on the island with over 75% of households consuming fresh reef fish at least three times per week. There is a small-scale pelagic fishery, but these species constitute a small fraction of the local diet and are generally less desired for eating. With high local consumption of reef fish, almost no reef fish are exported off the island. Rather than a strictly commercial or subsistence fishery, the motivations for households to engage in fishing crosscut these categories, with many families fishing not just to supply seafood

for their household but also because of strong preferences for eating fresh reef fish rather than seafood or other animal products that are frozen or tinned. For Polynesians fresh reef fish is an essential food for proper *mā'a Tahiti* or *mā'a mā'ohi* (feasts) that are held during important celebrations such as weddings and church gatherings. Many Polynesians fish for the sheer enjoyment it provides as an ocean-focused activity, and this is reinforced by the fact that fishing is central to sustaining Polynesian identity and pride.

Our previous studies revealed that the catch on Moorea is dominated by five taxa: *pahoro/pā'ati/uhu* (Scarids; parrotfish), *'īhi* (*Myrpristis* spp.; soldierfish), *vete* (*Mulloidichthys* spp.; goatfish), *mā'ava/pā'auara* (*Siganus* spp.; rabbitfish), and *tara'o/roi* (*Epinephelus* spp.; grouper) (Rassweiler et al., 2020). There is not a centralized fish market and thus a significant portion of the catch is sold on strings, known in Tahitian as *tui*, where fish are strung through the belly and mouth usually with a rope made of *pūrau* (*Hibiscus tiliaceus*) bark and then hung from stanchions that are placed along the side of the island's ring road. *Tui* are usually sold at a standard price (e.g., 2000 CFP per *tui*) and thus the number of fish per *tui* varies according to the size of the fish and the desirability of the species (Nassiri et al., 2021). Typically, the larger the fish, the fewer are hung on a *tui*. Some highly prized fish such as unicornfish (*Naso unicornis*) are often sold – when they are large enough – on a *tui* containing a single fish. In contrast, soldierfish (*Holocentridae*), a fish that rarely grows larger than 25 cm, are sold in *tui* containing 15 to 20 fish for the same price. The vast majority of fish that are sold are caught by speargun, although other main gears include hook and line, and gill nets. There is also some gleaning of clams, sea urchins, lobsters, crabs, and mantis shrimp. Spearfishing on SCUBA or a hookah system is illegal in FP so spear fishers free dive from the surface. Expert fishers not only sell their catch on the

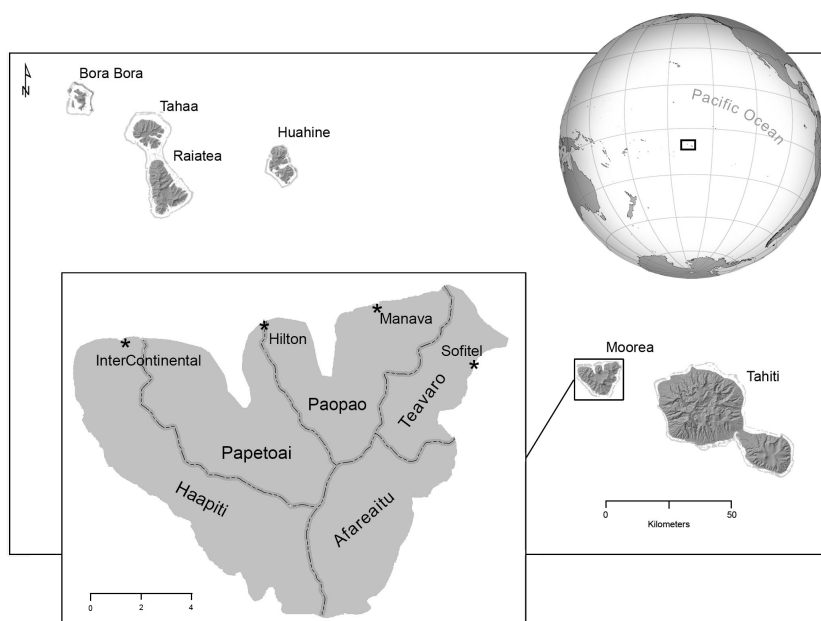


FIGURE 1

Moorea's location in the south Pacific and within French Polynesia. The inset shows the five districts and locations of the island's four largest hotels.

roadside but also maintain relationships with clients. In many cases the clients will contract the fisher to acquire fish or the fisher will contact clients after they have returned from a fishing outing. Moreover, expert fishers tend to target fish that are more sought after and difficult to catch and thus rely on detailed ecological knowledge of the lagoon and the behavior of fish.

2.3 The COVID-19 crisis

The first policy action taken in FP to prevent the spread of COVID-19 was on March 11th, 2020 when the Territorial government canceled all cruise ship traffic. Just one day later, on March 12th, the first positive COVID-19 case in the entire Pacific Islands region was identified in Papeete, Tahiti. Nine days later the Territorial government closed its border to international travelers, and two days after that a country-wide *confinement* (lockdown) was instituted that lasted just over one month. Similar to France, FP's lockdown was very strict. Residents were only allowed to leave their dwellings if they worked outside of the household in essential businesses or needed to buy essential supplies, attend a medical appointment, or care for a sick relative and those who left their houses were required to complete an *Attestation de Déplacement Dérrogatoire*. All businesses, including the hotels on Moorea as well as schools and restaurants, were shuttered except for those deemed essential such as grocery stores and pharmacies. In Moorea, the municipal government encouraged people to shop in their local district and to purchase fish and vegetables directly from local producers. During the first weeks, there was much uncertainty concerning regulations pertaining to fishing. Officially all lagoon activities were forbidden except if fishing represented the household's only source of income. Moreover, the legality of fish selling on the roadside, the usual venue, was unclear.

Compared to other countries in the region the human toll of the pandemic in FP was heavy in terms of the COVID-19 death rate (232 deaths per 100,000 as of September 2022 (WHO, 2022)). The impact on the FP tourism industry was also severe. Overseas visitors dropped from an annual figure of 236,642 in 2019 to roughly 80,000 for both 2020 and 2021 (ISPF, 2021). At the end of May 2020, the largest hotel in Moorea, the Intercontinental, closed indefinitely, leaving 280 persons jobless. It was not until July 2020 that international flights resumed, and the country opened back up for international tourism, albeit with arriving travelers required to undergo a rigorous testing protocol. This inconvenience suppressed tourism for several months after the pandemic.

2.4 Semi-structured and open-ended household interviews

During the COVID-19 crisis one of the authors (Wencélius), along with two local collaborators, was resident on the island and thus able to conduct socially distanced social science research from May 2020 (immediately after the first confinement was lifted) to June 2021. During this period, they conducted 95 household interviews in all five districts of the island to characterize any

shifts in household livelihoods in the wake of the lockdowns and hotel closures. The first cohort of households interviewed was a subset of individuals who participated in the fish sales survey described below ($N = 54$). All of those encountered during the roadside survey were men, which presents a significant gender bias in our sample. However, this is unsurprising since in French Polynesia and on Moorea in particular, fishing as a cash generating occupation is predominantly, if not exclusively, a male activity. Through snowball sampling, 41 fishers who we had never met during roadside fish sales survey were also included to account for a greater diversity of practices in terms of the following: a) livelihoods (e.g., including households who do not solely rely on selling fish for their livelihood), b) their main motivation for fishing (e.g., fishers who do not sell their fish for income), and c) gender. Even though we sought to include more female fishers in this second round of interviews, our sample was still biased towards men, with only five female interviewees out of 41 second-round interviews.

Households, as a unit of investigation, were defined based on shared-residence, thus it includes all individuals sharing the same dwelling. In households including more than one active and regular fisher (6 households out of 95) we selected the interviewee based on availability (not necessarily the senior fisher).

In the interviews, we asked a range of questions about household livelihoods, dependence on fishing, income-generating occupations before and after the lockdowns, and basic demographics as well as more extended open-ended questions with willing interviewees about community responses to the crisis. To assess the effect of lockdowns on households with different levels of dependence on the fishery we qualified them by income-generating occupations. Of the households interviewed, 44.2% were engaged in a single occupation, and 55.8% were involved in multiple activities including reef fishing. The income-generating occupations of all household members were accounted for through our category of "mixed occupation". For example, a household where the senior male sells his fish, his wife has no income-generating occupation, and the daughter works in a hotel was qualified as a mixed occupation household (fishing & tourism). We defined "occupation" as fishing, tourism-related activities (hotel and restaurant workers, tour guides, tourism-oriented craftsmanship), other non-fishing or non-tourism-related occupations (civil servants, teachers, food processing, store clerks, security agents, local clientele restaurant workers, farmers), construction (kept separate as it represented the most frequent alternate occupation), and retirees.

We also explored the range of possible economic impacts of the lockdown measures. To do so we differentiated three timeframes: pre-lockdown, the lockdown (from March 21st to April 29th, 2020), and post-lockdown. We asked respondents to compare their pre-lockdown fishing activities with their activities during the lockdown and post-lockdown. We also asked fishers to compare their pre-lockdown fish sales (if they had any) with any sales activity they engaged in during lockdown. Because interviews were carried out over a six-month period, those fishers interviewed months after the lockdown were asked to retrospectively assess their behavior. We also asked fishers about the behavior of other fishers from their

district during the lockdown and to evaluate whether they observed fewer or more people engaging in fishing activities during the lockdown. Roughly half of the interviews included open-ended questions, broadening our understanding of the lockdown's effects.

2.5 Assessment of trends in fishable resources

We used ecological time series data collected by the Moorea Coral Reef Long Term Ecological Research (MCR LTER) project to assess any effects of the lockdown on catchable food fish populations (Brooks, 2022). The data we analyzed were derived from yearly underwater visual fish counts and body size estimates conducted by MCR LTER scientists on SCUBA. Visual fish counts involve trained divers observing and recording fish species along set transects. One limitation of this sampling method affecting its reliability and accuracy is that it does not take into consideration fish behavioral responses to divers. In fisheries like Moorea where spearfishing is common fish may become more wary and elusive, altering their behavior and making them harder to spot. This can lead to an underestimation of fish populations in the survey. However, our experience in Moorea is that fish avoidance/flight responses are much stronger to snorkelers than to SCUBA divers, as all spearfishing is done on snorkel. As noted above, MCR fish data are collected by SCUBA divers, so we expect the data to be far less influenced by fish avoidance behavior compared to data collected by snorkelers.

The underwater visual counts are conducted each year along permanent band transects at six sites around Moorea, with three major reef habitats (fore reef, back reef, and fringing reef) sampled at each site. Divers count fish using a moving window approach resulting in unbiased estimates of density per area of reef. Biomass was calculated by combining fish counts and sizes with established length-weight relationships for each species of fish harvested in the fishery (see Brooks and Adam, 2019). The time series has been collected since 2006, enabling changes in biomass to be quantified along with patterns of variability among years.

To assess changes in biomass of fished resources, we filtered the MCR LTER dataset to include data from the back reef and fringing reef habitats (the habitats within the lagoon where most fishing takes place) and to only include individual fish greater than 15 cm total length (TL) to represent fishable biomass as fishers generally do not catch fish smaller than 15 cm (Rassweiler et al., 2020). By focusing on larger fish, we are evaluating depletion of fish on the reef, not multigenerational effects, as fish born in 2020 would generally have been below fishable size in 2021. Data from both habitats at each site were combined to obtain a mean value. We calculated the mean biomass of selected fish taxa within each site across all years (2006 - 2021), focusing on the four taxa mostly commonly sold on the roadside in Moorea: *Scaridae* (parrotfish), *Holocentridae* (squirrelfish), *Mullidae* (goatfish), and *Siganidae* (rabbitfish). Due to non-normality of the biomass values, we calculated the median of the site-specific anomalies for each year to detect whether there were island-wide changes in biomass relative to each site's mean value.

2.6 Surveys of fish sales

To assess the impact of the lockdown on the catch, we carried out roadside surveys of fish sales by surveying vendors along Moorea's single coastal road, which is where all public (i.e., not contract based sales) fish sales occur. To sample the entire road, we divided it into three roughly equal length sections (running along the east, north, and west coasts, respectively) and assigned a researcher to each district. Every Sunday morning – from May 3rd, 2020 to June 13th, 2021 – starting at 05:00, each researcher drove their transect and stopped at each vendor encountered along the roadside. With the permission of the fish vendor, photographs of their *tui* were taken (including a hanging scale bar for accurate fish sizing) and if willing, vendors were asked series of standardized questions. Over the year-long fish vendor survey we documented 290 fish sale events involving 96 different fishers. Given that Sunday mornings represent the peak of weekly reef fish sales our survey provides a good estimate, yet undoubtedly incomplete, of the total population of fishers who market part or all their catch¹. Indeed, through our island-wide and year-round survey we certainly missed some fishers who never sell on Sunday mornings (e.g. other days of the weeks and/or during the afternoon).

For each event, a closed-ended questionnaire was administered that covered details about the vendor's fishing outing, or the outing of the fisher who caught the fish being sold (date, time, number of fishers involved, type of fishing technique, and vessel used), and about their marketed catch (the price of each *tui*, as well as the number and species composition of the *tui* already sold which were not captured in the photos). Photos of the vendor's catch were subsequently analyzed, and fish were identified to the finest taxonomic level possible, and the total length of each fish was estimated.

For this paper we only analyzed the catch of fish vendors who were also interviewed in our household interviews (N = 54 vendors out of a total of 96) and for whom we have detailed information on their fishing practices and selling behaviors before and after the pandemic. We categorized those who told us they started to sell fish only after the March-April 2020 lockdown as Newcomers (N = 12), and the group who declared selling fish before the pandemic as Old timers (N = 42) (Table 1). Individuals categorized as Newcomers were not new to fishing per se, rather they were unexperienced with fishing as a cash-generating occupation. As noted above, fishing is widespread on Moorea although only a small portion of the population fishes as an income generating activity. These data on Newcomers vs. Old timers offered the opportunity to compare the fishing skill of these two groups of fishers. For the analysis we defined fishing skill in terms of three interrelated components: a) quantity of the catch (absolute quantity and monetary value); b) size of fish caught; and c) the species composition of the catch.

1 In French Polynesia there is no mandatory fishing license to market fish products by the roadside. Consequently, there are no available figures on the total population of 'commercial' fishers.

TABLE 1 The number of Newcomer and Old timer vendors encountered on the roadside and the quantity of fish in their catch that was sized.

	N Roadside Vendors			N Rdsd Events		N Sized Fish
	Total	No sizing [†] available	Sizing available	Total	Sizing Available	
Newcomer	12	0	12	44	40	1936
Old timer	42	4	38	170	95	5163
Unsurveyed [‡]	42	5	37	76	61	2078

[†] Roadside vendors who were not interviewed in the household survey on COVID-related impacts.

[‡] Sizing refers to fish sizes estimated from photographs of *tui* sold by the roadside.

We estimated catch quantity by analyzing the absolute number of fish caught, the total number of *tui* offered for sale, and the amount of income a vendor could generate from their *tui*. To reflect varying levels of fishing effort (lone fisher vs. a group of fishers) the income generated by each seller was divided by the number of fishers involved in catching the fish, hence the metric captures what each participating fisher earned from the sale (rather than the bulk income generated). We estimated differences in fish size by taxonomic group (at the family level, except for Acanthuridae which were broken down at the sub-family between Acanthurinae and Nasinae as the latter form a distinct and locally recognized and prized group of fish). For each of these metrics (number of fish caught, number of sold *tui*, generated income and fish sizes) we performed independent sample Wilcoxon tests (to account for non-normal size distributions) to test for significant differences across groups of fishers and Cohen's d to test for effect sizes. We also examined differences in catch composition at the family level (except for Acanthuridae) using a chi-square test.

3 Results

3.1 Vulnerability of households to the COVID-19 disruption

We found that households engaged in the tourism sector (whether as single- or mixed-occupations) were those most affected by the pandemic-induced disruptions (Table 2). The household interviews revealed that non-tourism-dependent households suffered little impact, with only 11% of these households indicating that they were economically stressed by COVID-19 restrictions. All households (100%) that both fished and held jobs in the tourism sector reported economic hardship. In contrast just twenty-five percent of households that relied solely on fishing as their livelihood reported experiencing economic hardship during the lockdown. These fishing-focused households attributed their hardship to reduced fishing activity and lower fish sales, stemming from widespread uncertainty and confusion over newly

TABLE 2 Occupational portfolios of Moorea's households, the percentage of households reporting economic hardship due to lockdown, and trends in sales and fishing intensity.

Occupation	N (%)	Econ. Impacted by lockdown	Fish sales during lockdown compared to pre-lockdown				Fishing intensity (in reference to the pre-lockdown period)					
							During lockdown			Post-lockdown		
			No sales	Less	Same	More	Less	Same	More	Less	Same	More
Single occupation												
tourism	25 (26,3%)	96%	24%	0%	0%	76%	32%	8%	60%	4%	20%	76%
other	9 (9,5%)	11%	23%	0%	33%	44%	11%	11%	78%	0%	78%	22%
fishing	8 (8,4%)	25%	0%	25%	62%	13%	25%	50%	25%	0%	100%	0%
Mixed occupations w/fishing												
fishing & tourism	6 (6,3%)	100%	0%	17%	83%	0%	17%	50%	33%	0%	100%	0%
fishing & construction	19 (20%)	5%	0%	11%	78%	11%	11%	63%	26%	0%	89%	11%
fishing & other	20 (21,1%)	10%	0%	25%	70%	5%	40%	55%	5%	10%	90%	0%
fishing & retired	8 (8,4%)	0%	0%	25%	75%	0%	25%	75%	0%	0%	100%	0%

imposed fishing regulations. These households incorrectly assumed that that all fishing was banned when stay-at-home measures were first implemented even though fishing for income remained legal. This was also the principal reason that some households across all occupations reported fishing less during the confinement period. In addition to the confusion around fishing regulations, there was also widespread fear and anxiety during the first wave about the possibility of contracting the virus. Nevertheless, 75% of households who relied solely on fishing reported little economic hardship and continued to venture outside of the household and fish for income.

Our interviews indicated that there was a push into the fishery during and after the lockdown by people who had little experience fishing for income generating purposes prior to the pandemic. These households may have fished occasionally for recreation or subsistence purposes, but they lacked the ecological knowledge and diving skills necessary to effectively fish for income. Of households engaged solely in tourism, 60% reported fishing more during the lockdown and 76% reported fishing more after the lockdown (Table 2). In addition, of households engaged in formal single occupations that were neither tourism- nor fishing-related ("other" category), 78% reported fishing more during the lockdown and 22% after. Moreover, people employed in the tourism sector who entered the fishery during the lockdown seemed to progressively fish more during the post-lockdown period as they needed the income to survive. After the stay-at-home measures were lifted on April 29th, the country was still closed to foreign travelers until July 15th, 2020, when international flights resumed and visitors were no longer required to complete a quarantine period. Nevertheless, tourism-oriented activities were very slow to resume. Those households engaged in occupations other than tourism were able to return to work more rapidly after the end of stay-at-home measures and thus did not need the income and fished less often in the post-lockdown period.

When we asked household members if they observed more or fewer people going out fishing during and after the lockdown, 45% of respondents indicated that they did not have a clear understanding of the trends, 24% mentioned they saw more fishers during and after the lockdown, 26% mentioned they had seen fewer fishers during and after lockdown, and 4% indicated that they did not perceive any change.

Results based on the geographic distribution of respondents suggested some different patterns across the island (Table 3). Indeed, 62% (13 of 21) of respondents residing on the north coast and who provided an answer mentioned observing more fishers

during and right after the lockdown, compared to just 32% (6 of 19) for those living on the east coast. Only 29% (6 of 21) of those on the north coast who provided an answer mentioned observing less fishing, compared to 68% (13 of 19) for the east coast. On the west coast, there was no discernable pattern. That respondents from the north coast observed more fishing activity during and after the lockdown is not surprising considering that three of the four major hotels are located on the north coast (Figure 1) and as a result, there are more opportunities (and dependence) on tourism-related occupations on this coast than for those who reside elsewhere on the island. Results concerning respondents' perceptions of overall trends of increased or decreased fishing activity (Table 3) corroborate results from respondents' own behavior (Table 2) regarding a push into the fishery by people who had been working in the tourism industry prior to the pandemic.

3.2 Trends in fishable biomass

Although our household interviews indicated that many on the island perceived an increase in fishing activity, ecological data revealed no consistent pattern of change in the biomass of targeted species after the imposition of COVID-19 stay-at-home measures (Figure 2). Although there was a decrease in the median biomass in certain taxa between 2019 and 2020, such as the *Siganidae* (Figure 2D), these values are both small in magnitude and within the range of normal inter-annual variability observed in the time-series data for each taxon (e.g., the increase in mean biomass anomaly from 2018 to 2019 was larger than the decrease from 2019 to 2020). The results of our analysis challenged our expectation that the fishery would experience a surge in fishing effort that would be reflected in declining fish abundance on the reef as local tourism employment collapsed. Even though our household surveys suggested that more households were entering the fishery, based on these ecological data, there was no support for an appreciable decline in fishable biomass.

3.3 Fishing skill

Our more open-ended, in-depth interviews provided clues as to why there was no change in fishable biomass on the reef even though household interviews suggested fishing effort may have intensified. Many of the more experienced fishers asserted that the new fishers who entered the fishery during and after the lockdown were generally less skilled and experienced and thus not as effective at catching fish. As one man stated: "*Many new people have started fishing to try to earn money. But it doesn't go at all. These are people who know nothing....*" Other experienced fishers noted that only skilled fishers know when and where to fish, targeting species of the right size and age while more casual fishers, unfamiliar with these subtleties, indiscriminately catch fish, often of the wrong size or species, indicating a lack of selective judgment. Experienced fishers also suggested that proficient fishing requires an understanding of different techniques, such as night

TABLE 3 Responses to the survey question "Did you observe more, the same, or fewer people fishing during and after the lockdown" by household members on Moorea.

	Total	No Answer	More	Same	Less
North	34	13	13	2	6
West	20	8	4	2	6
East	41	22	6	0	13

Given is the number of responses made by residents on the North, West and East sides of the island.

"North" is the north shore, "West" is west shore, and "East" is the east shore.

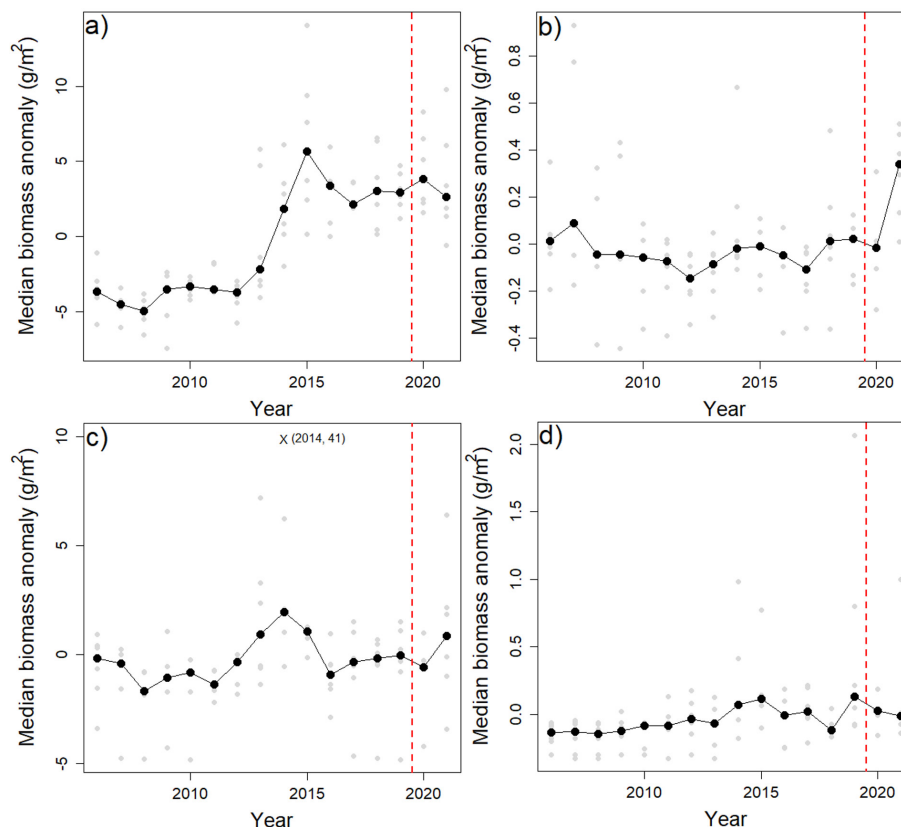


FIGURE 2

Median biomass anomalies (median difference in biomass of each site in a given year relative to the site-specific mean across all years) plotted over time for (A) *Scaridae* (parrotfish), (B) *Holocentridae* (squirrelfish), (C) *Mullidae* (goatfish), and (D) *Siganidae* (rabbitfish), the taxa most commonly sold on the roadside in Moorea (Table 4). The red dashed line indicates the approximate time COVID-19 lockdowns occurred in the time series. Gray points show the biomass at each site in each year. The "X" in panel c indicates an extreme outlier (a value of 41 in 2014) which was not plotted to scale to allow better depiction of the trends in the median. Note the variation in Y-axis scales.

fishing, which casual fishers approach with misplaced ease, underestimating the demands of the task. Not only were these issues of experience, skill, and judgment mentioned in the interviews but also a number of skilled fishers emphasized the adaptability of skilled fishers relative to more casual fishers. One fisherman, for example, stated: “You know fishermen who make a living from fishing are versatile, they always know how to get by, they adapt. On the other hand, there are many people who regret not being able to harvest the sea. They find themselves out of work and do not know how to get food from the sea. It’s a problem of our country, we import everything, we eat fries instead of taro. We eat chicken instead of fish.”

3.4 Skill and roadside fish sales

Our in-depth household interviews raised two issues that we explored further by analyzing roadside fish sales data. First, there was the observation that less skilled fishers were entering the fishery and that they were unable to catch adequately sized fish, and second, that the less skilled fishers were unable to earn an adequate income from fishing. Both narratives suggest that

patterns of catch should differ between Newcomers who only fished casually if at all before the pandemic, and Old timers who fished regularly before the disruptions.

Based on our surveys of fish sales there was no significant difference observed in the absolute number of fish caught by Newcomers and Old timers (Table 4). However, there was a significant difference between the average number of *tui* sold per event by Old timers (mean = 12.1, SD = 6.7) in comparison to Newcomers (mean = 8.0, SD = 5.0) and consequently in the average amount of income generated per event and per fisher (mean = 10880 CFP, SD = 7888 for Old timers vs. 6525 CFP, SD = 3332 for Newcomers). This can be interpreted as the consequence of an old timer’s ability to compose more *tui* – and generate more income – while catching an approximately equivalent number of fish in comparison to Newcomers.

The fact that Old timers were able to compose more *tui* with the same number of fish than Newcomers indicates that Old timers were catching more valuable fish, generally targeting larger-sized fish and, more particularly, fish that have a higher value for consumers. Consistent with this, our results suggest a slight trend for Old timers to sell larger fish. On average, four out of the five most frequently sold fish taxa (*Scaridae*, *Holocentridae*, *Mullidae*,

TABLE 4 Comparison of catches of Newcomers and Old timers, in terms of quantity and value, and taxonomic composition and fish size for the most targeted fish families.

	Skill components										Catch composition
	Quantity			Size							
Variables	N fish per event	N tui per event	Income by event	Scaridae (31% catch)	Holocentridae (26% catch)	Mullidae (12% catch)	Siganidae (8% catch)	Serranidae (6% catch)	N fish per taxonomic group per category of fisher		
Newcomer (mean - SD)	47.9 (sd=30.6)	8.0 (sd=5.0)	6525 (sd=3332)	22.9 (sd=4.7)	19.6 (sd=2.9)	24.4 (sd=4.9)	19.9 (sd=2.9)	20.8 (sd=4.2)	-		
Old timer (mean - SD)	56.1 (sd=44.1)	12.1 (sd=6.7)	10880 (sd=7888)	22.7 (sd=4.7)	20.2 (sd=3)	25.6 (sd=4.9)	20.5 (sd=3.5)	21.9 (sd=4.3)	-		
Test type	Wilcoxon	Wilcoxon	Wilcoxon	Wilcoxon	Wilcoxon	Wilcoxon	Wilcoxon	Wilcoxon	chi-square		
Test parameter	1914	2470	2498	385338	387680	63648.5	19695.5	14783	623.21 (df=9)		
Test significance	NS	<0.001***	<0.001***	NS	<0.001***	<0.001***	<0.05*	<0.001***	<0.001***		
Effect size	NA	0.297 (moderate)	0.309 (moderate)	NA	0.07 (small)	0.12 (small)	0.08 (small)	0.16 (small)	NA		

*statistically significant test, p-value < 0.05, ** statistically significant test, p-value <0.01, *** statistically significant test, p-value <0.001 NS, Non-significant test, NA, Non Applicable.

Siganidae, and *Serranidae* – 83% of the documented catch) were slightly larger in size in the catch of the Old timers (Table 4). We do note, however, that effect sizes are rather small (results from Cohen’s D) in terms of differences in size between groups.

With respect to the composition of the catch, we observed significant differences between Old timers and Newcomers. Results from a chi-square test on the number of fish sold by both groups for the 10 most represented taxonomic groups (Figure 3) – which represent 96% of the catch – reveal distinct patterns in the type of targeted fish. Chi-square residuals (indicating for each taxonomic group the magnitude of the difference between observed quantities of fish between groups and expected quantities under the null hypothesis) suggest that Newcomers had a stronger tendency to select species such as *Holocentridae* (soldierfish and squirrelfish) and *Serranidae* (groupers).

Fishers who had recently entered the fishery caught a smaller proportion of highly prized fish (and fish that have greater monetary value) – such as unicornfish (*Naso* spp.) and rabbitfish (*Siganus* spp.) The contribution of *Naso* spp. to the catch as represented in the results of the chi-square is only moderate (3rd highest residual value), which is probably due to the relatively small proportion of those species in the total amount of fish identified by the roadside (3% of the sized and unsized fish). The absolute figures, however, are more revealing. Of the 150 observed *Naso* spp. all were caught by Old timers, and none were observed in the *tui* sold by Newcomers. These results probably underrepresent this trend because customers frequently contract expert fishers to catch the highly prized *Naso* spp. known as *ume* in Tahitian, and these fish never make it to the roadside stands. Lastly, we found some differences in gear use. In particular, outings where at least part of the catch was harvested using line fishing represented a much higher proportion of outings for Newcomers (34%) than for Old timers (10%). By contrast, night spearfishing, which requires both higher investment in gear and effort and more in-depth knowledge of the marine environment, occurred in the bulk of outings for both groups (72% of outings for Newcomers and 75% of outings for Old timers).

4 Discussion

The COVID-19 pandemic tested humanity at every scale, from individuals to households to national and global governance systems and inserted an unsettling level of uncertainty and surprise into nearly everyone’s lives. As detailed in this case study, Moorea’s households experienced their own unique challenges and surprises. With the closing of borders and the resultant collapse of international tourism, one of the main sources of employment evaporated, forcing households to adapt to the shifting economic landscape. In this case study we were able to evaluate how the relationship between a household’s participation in the tourist economy and their fishing skill shaped their capacity to adapt to the COVID pandemic. More broadly, we gained insight into the extent to which livelihood diversification reduces the vulnerability of households who rely on small-scale fisheries.



FIGURE 3

Species compositions documented in the catch of Newcomers and Old timers. Residual values from chi-square test (623.21 (df = 9), p-value < 0.001) on vendor type (e.g., Newcomer, Old timer) by taxonomic groups (10 most targeted fish families). Taxonomic groups are presented by decreasing order of absolute chi-square residuals.

4.1 Fishing knowledge and skill

When employment in Moorea's tourist sector collapsed, those households most tied to tourism quickly entered the fishery to support household incomes and enhance food security. Moreover, these households who entered the fishery continued their fishing activities after the stay-at-home measures were lifted since FP's tourist economy was slow to recover. Despite the increase in the number of fishers in Moorea's lagoons, there was no detectable impact on food fish biomass. We acknowledge that some fish are known to avoid people, particularly in contexts with heavy spearfishing intensity (Feary et al., 2011), and that changes in patterns of human activity associated with COVID could have affected our ability to accurately conduct underwater fish surveys. However, the increase in fishing activity during the pandemic likely heightened the avoidance behavior of fish, while the decreased presence of tourists may have reduced habituation (Titus et al., 2015). These factors might have skewed our fish counts downward, as more fish may have evaded detection during underwater surveys. This potential undercounting of fish, due to increased fish avoidance and reduced habitation, reinforces our assessment that fish populations were not depleted during the pandemic since our underwater surveys quite possibly underestimated the fish populations during this period compared to pre-pandemic levels.

According to our in-depth interviews with fishers one possible reason that our biomass assessment did not detect any depletion of reef fish stocks is that those fishers who began fishing for income during and after the lockdown, a group we called Newcomers, lacked extensive fishing skill, experience, and ecological knowledge. This lack of fishing skill was apparent in the different life history traits of the fishes primarily captured by Newcomers compared to Old timers, traits that influence how vulnerable a species is to overfishing. For example, *Holocentridae* (soldierfish and squirrelfish), the taxon that was exceedingly over-represented in

the catch of Newcomers relative to highly skilled fishers, tend to be fast growing, short-lived species that are highly resilient to exploitation (Roberts and Hawkins, 2000). By contrast, the most valuable but most difficult to capture species, such as unicornfish (*Naso* spp.), tend to be slow growing, long-lived fishes, traits that make them much more vulnerable to fishing (Cook et al., 2024). Thus, to the extent there was additional fishing pressure triggered by the pandemic, it largely was focused on the segment of the fishable resources that was most able to absorb the added mortality. We note, however, that our analysis of Moorea's fishery is not exhaustive and many interrelated factors such as changes in fishing effort, fish population dynamics, shifts in catch per unit effort, market demands, and the fluctuating price of fish all interplay in complex ways.

We were able to quantify the relative difference in fishing skill between more casual fishers (e.g., Newcomers) who entered the fishery during the COVID-19 crisis to boost their incomes with professional fishers (Old timers) through our assessments of roadside fish sales. Old timers tended to sell on average more strings of fish (*tui*) and earn more per fishing event per fisher compared to less experienced fishers. Moreover, the composition of the Old timers' catch had a higher proportion of monetarily valuable and culinarily prized genera such as unicornfish (*Naso* spp.). To effectively harvest *Naso* species requires spear or net-fishing, techniques that necessitate more investment than other gears. Moreover, *Naso* species are widely regarded by Moorea fishers as the most difficult species to catch, especially larger specimens/individuals shot during the day. At night they are slightly easier to harvest since they sleep or lay motionless, but they usually take refuge in deeper areas of the lagoon and passes (> 10-15 m depth), a depth that requires a significant degree of free diving skill as well as an intimate familiarity with the lagoon environment. In contrast, Newcomers tended to catch more *Holocentridae* and *Serranidae*, taxa that are less challenging to

catch than *Naso* species and that can be caught with nylon line, hook, and bait (or lure), all of which require less monetary investment than spearfishing or net fishing. Holocentrids are also a relatively easy target when speared at night. They are nocturnal species that often leave their daytime hiding places and are readily stunned by the powerful LED waterproof lights of fishers, rendering them immobile and exposed in open water and easy spearfishing targets.

It is important to note that the distinction between a skilled and a less skilled fisher is not limited to the COVID-19 experience but rather is a highly salient dimension of how Tahitians conceptualize “fishing”. This is most explicitly expressed in the Tahitian language, which has two terms that refer to the activity: *rāvā'ai* and *tāi'a*. Highly skilled fishers are known as *ta'ata rāvā'ai*, a term that indicates a form of professionalism. The status of *ta'ata rāvā'ai*, however, is not simply earned by someone who gains exceptional proficiency in fishing. Instead, it is better understood as a way of being that is an attribute of certain extended family groups that are not only renowned for their fishing skill and their intergenerationally-maintained ecological knowledge about the marine environment but also owners of *tarena*, traditional calendars that mark the timing of spawning aggregations, the movements of certain fish, or other pertinent ecological knowledge about the fishery. These families, more than the average Tahitian family, sustain Polynesian modes of being by embracing cosmological connections with sea beings (*taura*) that serve as their protectors. More casual fishers, on the other hand, are called *ta'ata tāi'a* and lack not only fishing skill but also the broader cultural repertoire of *ta'ata rāvā'ai* (Wencélius et al., 2022). In everyday talk, fishers emphasize the difference between these two categories of fishers as much or more than the gear employed to fish (e.g., spearfishing, line fishing, net fishing, etc.).

4.2 Specialization and diversification

Our analysis challenges several assumptions about livelihood diversification, suggesting that in the case of the COVID-19 disruption on Moorea, those *ta'ata rāvā'ai* households who were dedicated to fishing coped well with the disruptions and yet had little livelihood diversification. While households solely reliant on tourism were profoundly affected, a predictable outcome given that tourism was the hardest-hit sector. Those who had taken up jobs prior to the pandemic in the lucrative tourism industry lacked the necessary fishing skills and knowledge. They were not able to develop and sustain a deep understanding of Moorea's coral reefs, an ecosystem that is characterized by complex, ever-shifting dynamics of the benthos (Adam et al., 2011; Holbrook et al., 2016, 2018, 2022) and the fishable resources (Adam et al., 2014; Han et al., 2016; Rassweiler et al., 2020). The ability of fishers to navigate these dynamics likely influences the collective effects of fishing, with important implications for the resilience of the reef ecosystem (Rassweiler et al., 2020; Lauer et al., 2022; Rassweiler et al., 2022; Cook et al., 2024).

Indeed, some studies have emphasized how many Pacific Island communities that rely on the local ecosystem for food and

livelihoods build up robust specialized ecological knowledge that confers adaptive capacity to manage perturbations such as climate change, economic or political crises, or major disturbances such as tsunamis (McMillen et al., 2014; Sterling et al., 2017; Lauer, 2023). Moreover, deep cosmological attachments to place like those of Moorea's expert *ta'ata rāvā'ai* fishers, that emerge through long-term habitation and dependence on local marine ecosystems, are acknowledged as an element that underpins good stewardship and management of marine resources (Hviding, 1996; Folke, 2004). “Diversity” in these contexts is characterized by the depth and different forms of knowledge about local ecosystems, the non-monetary motivated activities, and non-western worldviews and modes of being rather than the livelihood diversity represented by multiple cash-generating occupations. As noted by some scholars, knowledge diversity is a critical, yet underappreciated and undertheorized, in the vulnerability and resilience literature (Williams et al., 2015). Fishing communities in particular may be losing important intergenerationally transmitted knowledge as they adapt to changing socio-economic conditions (Tam et al., 2018).

4.3 Contextualizing livelihood diversification

Despite gains in understanding the relationship between social-ecological changes and a fishing household's capacity to respond to them, livelihood diversification tends to be portrayed in overly broad and beneficial terms (FFA, 2015; Roscher et al., 2022). The prevalent assumption that diverse income-generating strategies universally reduce vulnerability to a wide range of shocks, and that resource-dependent fisher folk are intrinsically vulnerable, assumes the known dynamics of a social-ecological system outweigh the unknown ones. Yet, social-ecological systems like small-scale fisheries are complex, adaptive systems that have intrinsic non-linear, and unpredictable aspects (Scoones, 1999). The idea that Moorea fishing households who specialize narrowly on fishing as their livelihood and steered clear of lucrative tourist employment were best equipped to cope with the COVID-19 economic shocks is testament to the complexity and difficulty of predicting the dynamics of small-scale fisheries. Although diversification has the potential to spread risk, the sector into which a household diversifies is crucial. As this study has shown, the type and context of diversification matter greatly and Moorea households with mixed livelihoods that included tourism were more vulnerable, not less during the COVID-19 disruptions.

The limits of livelihood diversification in reducing vulnerability are applicable beyond fisheries. For example, in agricultural communities farming households that diversify into non-farming sectors lose critical farming knowledge as well as labor which can reduce agricultural productivity and food security, making households more vulnerable to certain agricultural shocks (Béné et al., 2012). At the same time diversification pathways that stay *within* the fisheries sector such as the introduction of trochus (*Rochia nilotica*) in Samoa, might sustain or even enhance fishing skills and local ecological knowledge (Purcell et al., 2021).

Since diversification may not inherently lead to less vulnerability, livelihood diversification might be more fruitfully theorized in relation to specific perturbations or stressors. Conceptualizing perturbations and livelihood diversification in isolation or in simple, predictable cause-and-effect relationships, belies the complexity and interrelatedness of these processes. Indeed, the quality of diversification matters, and the effectiveness of diversification is context dependent. The nature of the shock—whether it affects global markets, local ecosystems, or specific industries—will shape whether diversification is helpful or harmful, or if specialization confers advantages. A transformative shock like the COVID-19 pandemic redefines and reshuffles what constitutes a vulnerability or a successful livelihood diversification strategy. Arguably, programs and policies that promote livelihood diversity as a panacea that invariably reduces vulnerability rest on normative assumptions about the benefits of economic growth and globalization, processes that have been identified by some as important drivers of our current ecological crises (Evans and Reid, 2014) and may contribute to the emergence and spread of novel viruses and zoonotic diseases like COVID-19 (Brancalion et al., 2020).

4.4 Policy implications, recommendations, and future research

The practical implications for managing uncertainty and contextualizing livelihood diversification involve a shift from top-down, expert-led policies towards reflexive and collaborative fisher-expert learning, so that a broader diversity of income strategies and knowledge may be identified in specific contexts (Lee, 1994; Callon et al., 2009 [2001]; Govan, 2011). Encouraging diversification should not be done indiscriminately but rather strategically. Communities and experts should approach diversification as conditional on the characteristics of the occupational sectors involved and the possible social-ecological shocks. A stepwise adaptive management approach, where problems are identified and interventions devised jointly by experts and stakeholder groups and then carried out, monitored, and adjusted, offers a promising strategy for living in an uncertain world (Armitage et al., 2009). In fact, local resource managers and stakeholders in Moorea have revised the marine resource management scheme known as the *Plan de Gestion de l'Espace Maritime* (PGEM) with adaptive management principles and have enlarged the policy-making process (Hunter et al., 2018; Wencélius et al., 2022). Rather than being excluded from the decision-making, expert *ta'ata rāvā'ai* fishers now play a more central role in management design and decisions in their respective districts. This certainly does not guarantee success and might be superficial (Nadasdy, 2007), but it does at least provide the potential to mitigate social marginalization and ecological destruction, and in the process forge other possible futures for coastal communities and their local ecologies.

To gain more understanding of these processes, future research could compare island economies with differing levels of reliance on

tourism and fisheries to understand their unique vulnerabilities and knowledge diversities. Additionally, studies could investigate the long-term impacts of pandemic-driven changes in fishing practices on ecological resilience and household livelihoods. Finally, further exploration is needed on ways to refine adaptive management strategies that support diversified knowledge bases and sustainable livelihoods for Pacific Island communities.

4.5 Limitations

This study faces several limitations. First, there is a notable gender bias in the sample of household heads, as most participants were men. This is, however, a reflection of the male-dominated nature of income-generating fishing activities on Moorea. Additionally, underwater visual surveys may have underestimated fish populations due to fish avoidance behaviors amplified by increased fishing activity. Finally, while household surveys indicated an increase in fishing effort, the ecological data did not show a corresponding decline in fish biomass, possibly due to the study's constraints in detecting subtle changes in the fishery over a short period.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://portal-s.edirepository.org/nis/mapbrowse?scope=knb-lter-mcr&identifier=4012&revision=4>.

Ethics statement

The studies involving humans were approved by San Diego State University Institutional Review Board (HS-2017-0179). The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because the research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context.

Author contributions

ML: Writing – original draft, Writing – review & editing, Formal analysis, Conceptualization. JW: Writing – original draft, Writing – review & editing, Conceptualization, Investigation, Methodology, Project administration. PD: Writing – review & editing, Conceptualization. SH: Writing – review & editing, Conceptualization, Funding acquisition. SL: Writing – review &

editing, Conceptualization. SM: Writing – original draft, Writing – review & editing, Conceptualization, Formal analysis. SN-M: Writing – review & editing, Conceptualization. AR: Writing – review & editing, Conceptualization, Funding acquisition. RS: Writing – review & editing, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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