



**HAL**  
open science

## Drivers of nutrient intakes from fisheries in French Polynesia

Mark Hamilton, Eva Maire, Charlotte Monteil, Vainehu Vane, Nicholas Graham, Victor Brun, James Robinson, Joachim Claudet, Valeriano Parravicini, Christina Hicks

► **To cite this version:**

Mark Hamilton, Eva Maire, Charlotte Monteil, Vainehu Vane, Nicholas Graham, et al.. Drivers of nutrient intakes from fisheries in French Polynesia. *Ecosystems and People*, 2024, 20 (1), pp.2351385. 10.1080/26395916.2024.2351385 . hal-04588178

**HAL Id: hal-04588178**


**<https://hal.science/hal-04588178>**

Submitted on 26 May 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Drivers of nutrient intakes from fisheries in French Polynesia


Mark Hamilton<sup>1</sup>, Eva Maire<sup>1</sup>, Charlotte Monteil<sup>1</sup>, Vainehu Vane<sup>2</sup>, Nicholas A.J. Graham<sup>1</sup>,  
Victor Brun<sup>3</sup>, James P.W. Robinson<sup>1</sup>, Joachim Claudet<sup>3</sup>, Valeriano Parravicini<sup>4</sup>, Christina C. Hicks<sup>1</sup>

<sup>1</sup> Lancaster Environment Centre, Lancaster University, Lancaster, UK

<sup>2</sup> Moana Environnement, Uturoa, French Polynesia

<sup>3</sup> National Center for Scientific Research, PSL Université Paris, CRIOBE, CNRS-EPHE-UPVD, Maison de l'Océan, 195 rue Saint-Jacques 75005 Paris, France

<sup>4</sup> PSL Université Paris, CRIOBE, EPHE-CNRS-UPVD, 58 Avenue Paul Alduy, 66000 Perpignan, France

 Email: mark.hamilton@lancaster.ac.uk; Twitter: @Mark\_H\_22

## ORCiDs:

Mark Hamilton: 0000-0003-1618-8549

Eva Maire: 0000-0002-1032-3394

Nicholas A.J. Graham: 0000-0002-0304-7467

Victor Brun: 0000-0002-3137-3841

James P.W. Robinson: 0000-0002-7614-1112

Joachim Claudet: 0000-0001-6295-1061

Valeriano Parravicini: 0000-0002-3408-1625

Christina C. Hicks: 0000-0002-7399-4603

20 **Abstract**

21 Small-scale fisheries provide nutrients to hundreds of millions of people worldwide, with yields  
22 dependent on the condition of marine habitats such as coral reefs. Small-scale fisheries are a  
23 particularly important food source in societies with nutrient deficiencies and where unhealthy food  
24 alternatives are widely available. Using data from coral reef surveys around two islands in French  
25 Polynesia (Moorea and Raiatea), we show how the availability of nutrients to fisheries changed in  
26 relation to the condition of coral habitat. Fish biomass and nutrient availability were highest when  
27 coral cover was low around both islands, driven predominantly by abundant herbivorous reef fish. We  
28 also investigated the importance of fish in people's diets, to determine if fish consumption was  
29 aligned with available fisheries resources on local reefs and if nutrient intakes from fish could be  
30 explained by people's socioeconomic background. People ate a higher diversity of reef fish in  
31 Raiatea, however nutrient intakes from fish were higher in Moorea. Most people ate more fish than  
32 meat on both islands, however fish consumption declined over generations. People from fishing  
33 households had higher nutrient intakes from reef and pelagic fish, and people from farming  
34 households had higher intakes from reef fish. Preference for eating reef fish over pelagic fish in diets  
35 was also associated with higher total nutrient intakes. Promoting traditional diets rich in fish could be  
36 key to meeting people's nutritional needs in French Polynesia while reducing diet-related health  
37 issues linked to the overconsumption of fat.

38 **Key words:** small-scale fisheries; coral reefs; marine resources; nutrition; Moorea; Raiatea

## 39 **Introduction**

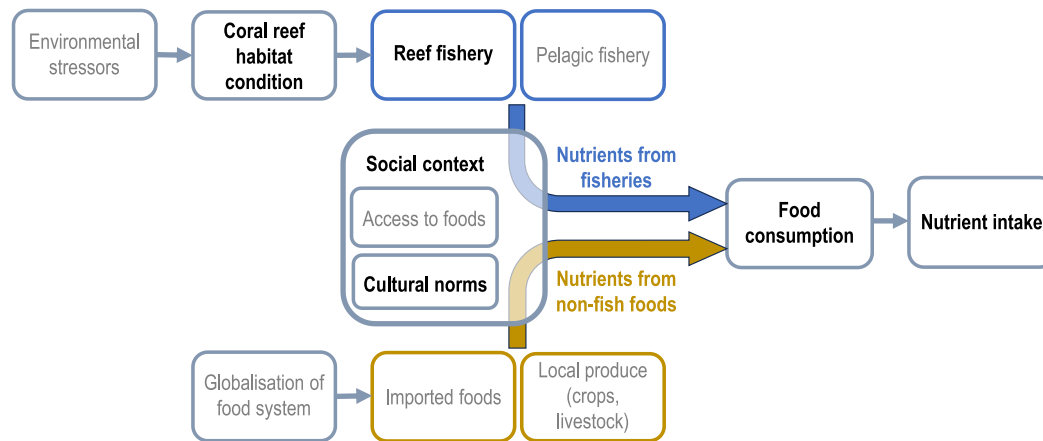
40 Small-scale fisheries support a wide diversity of fish accessible in many countries across the tropics  
41 (Belton and Thilsted, 2014) and often provide an affordable animal-based source of protein and key  
42 micronutrients that are lacking in people's diets (Kawarazuka and Béné, 2011; Hicks et al, 2019).  
43 Tropical fisheries vary in their vulnerability to environmental stressors, such as climate change, as  
44 well as in the nutrient density of yields (Maire et al, 2021). Therefore, tropical fisheries have the  
45 potential to remain an important source of human nutrition as environmental conditions alter (Hicks et  
46 al, 2021; Robinson et al, 2022a), although changes in the availability of fisheries resources may lead  
47 to changes in people's fish consumption patterns.

48 Marine fisheries are sensitive to the condition of key habitats of targeted fish populations (Brown et  
49 al, 2019), for example the condition of coral habitat influences the productivity, availability and long-  
50 term sustainability of reef fisheries (Cruz-Trinidad et al, 2014; Morais et al, 2020a). Currently, there is  
51 little understanding of how reef habitat condition impacts the provisioning of nutritious seafood  
52 through fisheries (Hicks et al, 2021). Existing literature show variable responses of fishery catches to  
53 changes in coral reef condition. For example, an increased abundance of herbivorous fish following  
54 coral mortality maintained small-scale fisheries yields on some degraded reefs in Seychelles  
55 (Robinson et al, 2019), while reef fisheries in the Pacific are expected to become less productive as  
56 coral cover is progressively lost (Bell et al, 2013). The impacts of reef habitat condition on the  
57 composition and size of fisheries catches may therefore influence the food provisioning services  
58 provided by coral reefs (Woodhead et al, 2019). Decreases in fish catches would be expected to  
59 reduce fish consumption, increasing risks of nutrient deficiencies in tropical coastal communities  
60 (Golden et al, 2016). Reef-associated fish have relatively high concentrations of zinc and vitamin A,  
61 while small pelagic (open-ocean) species have high calcium and omega-3 fatty acid concentrations  
62 (Robinson et al, 2022b), therefore changes in seafood composition, for example through projected  
63 catch increases of pelagic fisheries (Bell et al, 2013), would alter people's nutrient intakes from fish.

64 People's dietary choices are influenced by many factors beyond availability, including culture, price,  
65 demographics, and convenience (Tilman and Clark, 2014). For example, increasing availability of  
66 imported "Western" foods across the coastal tropics, driven by the globalisation of food trade systems  
67 (Thow et al, 2011), has facilitated dietary transitions away from traditional diets of nutritious local  
68 fish and plants, towards energy-dense and high-fat foods (Hughes and Marks, 2009). The nutritional  
69 implications of moving away from traditional diets are a public health concern, as diets may become  
70 deficient in essential nutrients, leading to micronutrient deficiencies, or contain excess nutrients  
71 contributing to health conditions such as obesity and diabetes (Hughes and Marks, 2009; Sahal Estimé  
72 et al, 2014; Stevens et al, 2022). For example, in the Peruvian Amazon, replacing wild caught  
73 freshwater fish with chicken and farmed fish reduced intakes of essential fatty acids and iron,  
74 nutrients that were already deficient in people's diets (Heilpern et al, 2021). If there is a shift away

75 from traditional fish-based diets towards modern diets with high fat content, it is important that people  
76 balance local produce and imported foods in a way that minimises diet-related ill-health (Parry et al,  
77 2010). Nutrition and diet-related health issues are unequally distributed within societies (Friel and  
78 Baker, 2009), therefore it is imperative to determine which groups of people may be most at risk from  
79 eating fewer traditional foods.

80 Here we focus on French Polynesia as a case study to examine linkages between ecological conditions  
81 (coral reef habitat and fisheries resources), socioeconomic factors, and people's diets (Fig. 1).  
82 Specifically, our research objectives are to 1) assess the availability of nutrients from reef fish in  
83 relation to changes in coral reef habitat condition, and 2) investigate the importance of reef and  
84 pelagic fish for people's nutrient intakes in relation to their socioeconomic background.



85

86 **Figure 1:** Conceptual diagram of links between coral reefs, fisheries, food supply, and dietary nutrition.  
87 Environmental stressors (e.g. climate change, crown-of-thorns sea star outbreaks) affect coral reef habitat  
88 condition, which in turn affects reef fisheries catches. People's nutrient intakes are determined by their  
89 consumption of foods from reef and pelagic fisheries (blue) and other sources (orange). Food consumption is  
90 influenced by social context, including culture and access to foods. Variables in grey text were not measured in  
91 the current study (e.g. availability of reef fishery resources was estimated, but pelagic resources were not).

## 92 **Materials and methods**

### 93 *Study area*

94 This study focuses on two islands, Moorea and Raiatea, within the Society Archipelago, French  
95 Polynesia (Fig. S1). Moorea is the second most inhabited island in French Polynesia after Tahiti, with  
96 a population of 17, 463, while Raiatea has a population of 12, 291 (Institute of Statistics of French  
97 Polynesia, 2017). Obesity is an urgent health concern in French Polynesia, with 68% of men and 67%  
98 of women estimated to be overweight or obese in 2008 (Daigre et al, 2012). French Polynesia has

99 become dependent on Western imports of high-calorie foods since the 1980s, such as chicken which  
100 has a particularly high fat content when fried (World Health Organisation (WHO), 2003). Food  
101 imported into French Polynesia is mainly sourced from Europe, and the volume of unhealthy imported  
102 foods has increased over time (Andrew et al, 2022).

103 Small-scale fisheries in French Polynesia use traps, hook and line, gillnets and spearguns to catch  
104 reef-associated and pelagic fish, of which a large proportion is consumed locally (Chauvet and Galzin,  
105 1996; Leenhardt et al, 2016). Reef and pelagic fish are sold at the roadside in Moorea, which provides  
106 an income for fishing families and a local supply of fish for islanders (Nassiri et al, 2021). A large  
107 proportion of fish caught around Raiatea is sold at a large market (Uturoa) at the north of the island  
108 (Chauvet and Galzin, 1996). It is also common for islanders to order fish directly from fishers  
109 (Leenhardt et al, 2016).

#### 110 *Ecological data*

111 Live coral cover on reefs around Moorea and Raiatea was reduced to almost zero by 2010 after  
112 crown-of-thorns sea star (*Acanthaster planci*; “taramea” in Tahitian) outbreaks, before being further  
113 impacted by a cyclone and coral bleaching (Pérez-Rosales et al, 2021). We used underwater visual  
114 census (UVC) surveys to collect data on live coral cover (photo-quadrats) and abundances and sizes  
115 of reef fishes (belt transects) (details of transect methodology are in supplementary material). Surveys  
116 were conducted every second year, in even years (2010-2020) at one site in Raiatea and two sites in  
117 Moorea, and in odd years (2011-2019) at another site in Moorea (Fig S1).

118 We classified fish species into three trophic groups: “herbivore” (including detritivores and  
119 microvores), “mobile invertivore” (including microinvertivores and macroinvertivores) and  
120 “piscivore” (Parravicini et al, 2020) (Table S1). Fish weights were summed per trophic group to  
121 estimate the total biomass per transect in kilograms per hectare. We calculated mean biomass and  
122 standard error across transects per site in each year.

#### 123 *Socioeconomic and dietary surveys*

124 We developed a semi-structured survey to gather socioeconomic (Table S2) and dietary data in  
125 Moorea and Raiatea. The semi-structured interview was piloted in both islands, alongside informal  
126 discussions, to create a final version that incorporated island-specific context while still allowing  
127 comparisons to be made between islands. In total, 183 household interviews were conducted in  
128 Raiatea, between June and September 2019 and 96 in Moorea in September 2019. We followed a  
129 purposive snowball sampling approach (Ayhan, 2011) stratified across administrative districts,  
130 targeting fishing and non-fishing households (Table S2). Initially, a few influential people in a district  
131 were identified for interview, and subsequent interviews were then based on their recommendations  
132 and introductions. Sample sizes satisfied our chosen 95% confidence level given the population of

133 each island (with 10% margin of error as we only sampled one person per household, even though  
134 households often contained multiple people). Approximately two thirds of respondents on each island  
135 were women as they were most commonly at home during the day to answer questions (pers. obs.).  
136 Interviews were conducted in either French or Tahitian with a translator (English version of the  
137 questionnaire available in online supplementary material).

138 We collected dietary data on the frequency of consumption of various food groups (based on the  
139 Global Individual Food consumption data Tool, GIFT; Food and Agriculture Organisation (FAO),  
140 2022; Table S3) and the types of fish people ate. Options for the frequency of consumption were:  
141 “never”, “1-2 times per month”, “3-4 times per month”, “1-2 times per week”, “3-5 times per week”  
142 and “6 or more times per week”. All responses were standardised by converting to number of times  
143 per week. Some food categories were grouped together prior to analyses using a similar approach to  
144 Kennedy et al (2011), for example “nuts/seeds” and “legumes” were separate questionnaire responses  
145 but were combined to give a total consumption frequency (Table S3).

146 The types of fish eaten were identified to species level where possible, otherwise to taxonomic family  
147 level. Fish names given in Tahitian were matched to scientific taxa based on local knowledge and  
148 FishBase (Table S1). Frequency of consumption was not collected for each type of fish, only for fish  
149 in general. Respondents were also asked about their fish consumption in comparison to their meat  
150 consumption and their fish and meat consumption in comparison to previous generations  
151 (parents/grandparents).

#### 152 *Nutrient content of fish*

153 Fish nutrient estimates were obtained from the Nutrient Analysis Tool in FishBase  
154 ([www.fishbase.org](http://www.fishbase.org), Froese and Pauly, 2022), developed by Hicks et al (2019). We used nutrient  
155 prediction updates from August 2022. Nutrient concentrations in a 100 g portion of muscle tissue  
156 were estimated for five nutrients (calcium, Ca; iron, Fe; zinc, Zn; vitamin A, Vit A; omega-3 fatty  
157 acids (eicosapentaenoic acid (EPA) + docosahexaenoic acid (DHA)), O3) that are highly concentrated  
158 and bioavailable in fish and lacking in diets across the tropics (Beal et al, 2017; Ferguson et al, 2019;  
159 Golden et al, 2021). Nutrient content data were extracted for each species observed in reef surveys  
160 and for species mentioned by respondents during interviews. When fish were not identified to species  
161 level, or when nutrient estimates were not available for a particular species, genus or family level  
162 estimates were used by taking medians across species belonging to the same taxonomic grouping also  
163 found in French Polynesia (according to FishBase).

164 Nutrient concentrations (100 g<sup>-1</sup>) per individual fish were scaled up to reef survey biomass estimates  
165 to represent the total quantity of each nutrient per hectare (i.e. potential nutrient yield for fisheries).  
166 Only fish  $\geq 15$  cm in total length were included to represent the nutrients within fish deemed large

167 enough to be captured by fisheries (i.e. the minimum fishable size; Rassweiler et al, 2020). Values  
168 were then summed per functional group in each transect and then the mean calculated across transects  
169 at each survey site.

170 We then estimated the mean nutrient concentration of a 100 g fish portion for each respondent, by  
171 averaging nutrient concentrations across all fish species they provided during interviews. Nutrient  
172 estimates per person were then expressed as the percentage contribution to each daily recommended  
173 nutrient intake (RNI) or equivalent for adult women (Ca = 1000 mg, Fe = 19.6 mg, Zn = 4.9 mg, Vit  
174 A = 270 µg; WHO/FAO, 2004) (O3 = 250 mg; European Food Safety Authority, 2010) (Table S4).

#### 175 *Calculating nutrient density and intakes*

176 We assessed the nutritional quality of different food groups by calculating the nutrient density based  
177 on our five nutrients (Drewnowski, 2009). Nutrient density was defined as the sum of percentage  
178 contributions to RNIs for all five nutrients in a 100 g portion of food, with the maximum possible  
179 value for each nutrient capped at 100%, or a maximum of 500% when all five nutrients are fully  
180 meeting dietary needs. The nutrient contents of 100 g food portions were obtained from Pacific Island  
181 food composition tables (FAO, 2004) by taking a median across all food items within a food group for  
182 each nutrient. Specific food items were removed from the composition tables if they were not eaten in  
183 the form given, for example raw flour or raw plant-based foods that were toxic unless cooked prior to  
184 consumption (see online supplementary material for details). The total fat content of 100 g food  
185 portions was also obtained from food composition tables and expressed as a percentage of the  
186 maximum recommended daily fat allowance (65 g; Drewnowski, 2009).

187 We represented each respondent's average diet by calculating the total nutrient density across all food  
188 groups, weighted by frequency of consumption for each food group,  $i$ , up to the total number of food  
189 groups eaten by a respondent,  $n$  (Equation 1).

$$190 \quad ND_{weighted} = \frac{\sum(NutrientDensity \times ConsumptionFrequency)_{i...n}}{\sum ConsumptionFrequency_{i...n}}$$

191 [1]

192 These weighted nutrient density scores represented the nutritional value of each person's diet, based  
193 on the content of our five nutrients. As frequency of fish consumption was across all species eaten per  
194 respondent, we estimated separate weighted nutrient densities for reef and pelagic fish by equally  
195 splitting consumption frequency.

196 In addition to nutrient density of diets, we then estimated people's nutrient intake using information  
197 on typical portion sizes from the food composition tables (FAO, 2004), as these data were not  
198 collected during interviews. We rescaled the nutrient content in 100 g of each food item to estimated



199 portion sizes. Medians across food items were then used to represent the nutrients in a typical portion  
200 for each food group. Nutrient values were multiplied by the frequency each food group was consumed  
201 in a week and divided by seven to give a daily estimate of nutrient intake per respondent. It should be  
202 noted that foods eaten more than once per day were not captured in our questionnaire, for example the  
203 most frequent response for consumption for any food was “every day”, without indicating whether a  
204 particular food was eaten multiple times a day or not. As such, our nutrient intake estimates are not  
205 intended to be a complete daily profile of people’s nutrition, but rather a representation of which  
206 foods people tended to eat on a regular basis, allowing comparisons to be made between people eating  
207 more or less of various foods.

### 208 *Statistical analyses*

209 All analyses were run in R (version 4.2.2; R Core Team, 2022). We investigated the association between  
210 the nutrient density of fish consumed and socioeconomic backgrounds of respondents by conducting a  
211 redundancy analysis (RDA) for each island using the “*easyCODA*” package (Greenacre, 2018).  
212 Response variables were the percentage contributions to RNI for each of five nutrients and the total  
213 nutrient density estimate of each respondent’s diet. Explanatory variables were gender (male or female),  
214 age, education level (at least high school level or lower), wealth, ability to speak at least one Polynesian  
215 language (yes or no), fisher or farmer households (both, fisher only, farmer only or neither), preference  
216 for reef or pelagic fish (based on the number of fish families eaten), how often takeaway food was eaten,  
217 and how often traditional Tahitian dishes (“Maa Tahiti”) were eaten.

218 Wealth was determined using a principal component analysis (PCA) that included details of each  
219 respondent’s home ownership (own house, renting or lodger), financial difficulties (yes or no) and  
220 vehicle ownership. Each respondent was given a vehicle score, calculated by multiplying each item by  
221 a score that reflected its value (bicycles = 0.1, pirogues (small boats) = 0.2, motorcycles = 0.5, cars and  
222 motorboats = 1) and summing scores for all vehicles owned. Some households may have had shared  
223 access to certain items, for example pirogues (pers. obs.), however this was not accounted for in our  
224 analysis. Values from PCA axis 1 explained 39% of variation in the data and were used as a wealth  
225 indicator in analyses, with higher values indicating higher wealth (Fig. S2). All numerical explanatory  
226 variables in the redundancy analyses (age, wealth, fish preference, takeaway food and Maa Tahiti  
227 frequencies) were scaled, with mean = 0 and standard deviation = 1, to allow the effects of variables to  
228 be examined relative to one another.

229 Variance explained by each variable, the global significance of the model, and the significance of axes  
230 and terms in the model were examined for each redundancy analysis. Variance inflation factors for  
231 model terms were assessed using the “*vegan*” package (Oksanen et al, 2022) to ensure that none had a  
232 value >2.

233 Generalised linear models (GLM) were used to investigate the effects of various socioeconomic  
234 variables on nutrient intakes. Separate models were used to analyse nutrient intakes from entire diets,  
235 reef fish only and pelagic fish only (Equation 2, for  $i$  questionnaire respondents), all with Gaussian  
236 distributions.

$$\begin{aligned} 237 \quad \text{Nutrient.Intake}_i &\sim \alpha + \text{gender}_i + \beta_1 \times \text{age}_i + \text{education}_i + \text{language}_i + \text{fishing.farming}_i \\ 238 \quad &+ \beta_2 \times \text{wealth}_i + \beta_3 \times \text{takeaway.food}_i + \beta_4 \times \text{Maa.Tahiti}_i \\ 239 \quad &+ \beta_5 \times \text{fish.preference}_i + \text{island}_i \end{aligned}$$

240 [2]

241 Model assumptions of each GLM were verified using the protocol described by Zuur and Ieno (2016),  
242 by plotting residuals against fitted values and each covariate in the model. Residuals were assessed to  
243 confirm there were no temporal or spatial dependencies.

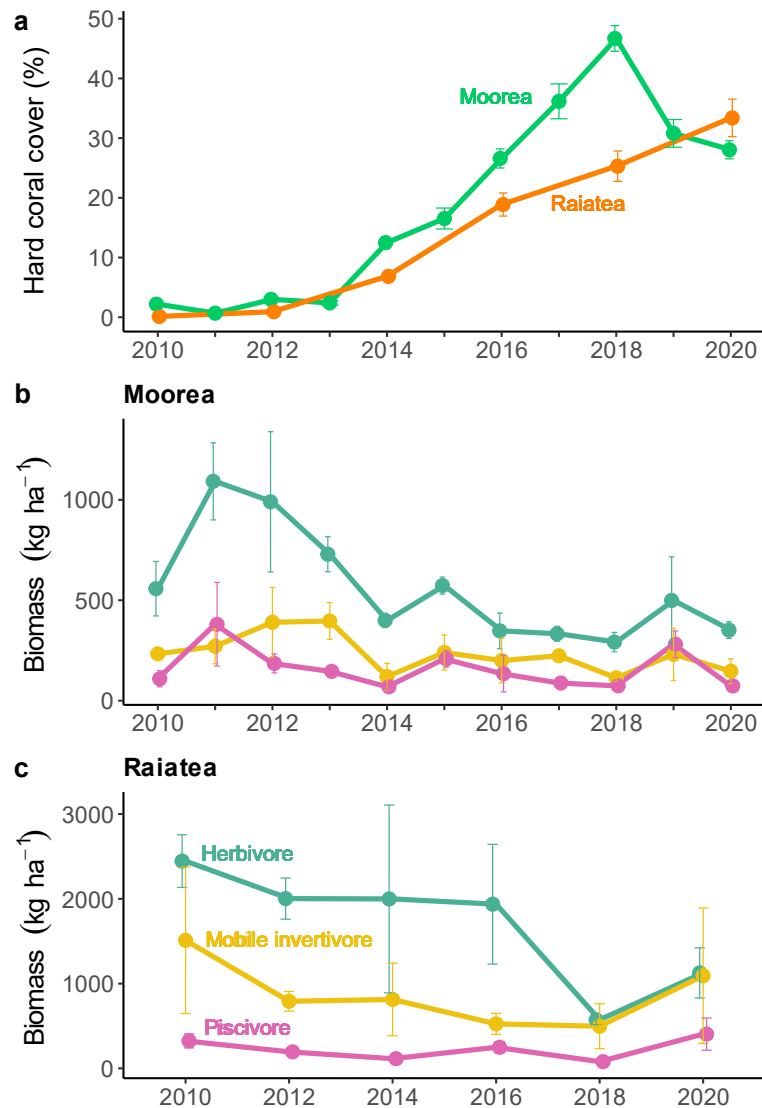
244

## 245 **Results**

### 246 *Availability of reef fish biomass and nutrients to fisheries*

247 Coral cover increased from ~0-33% between 2010 and 2020 in Raiatea and, in Moorea, from 2-47%  
248 between 2010 and 2018 before declining to 28% by 2020 (Fig. 2 a). Over this period of coral  
249 recovery, reef fish biomass generally decreased (Fig. 2). In Moorea, biomass of all trophic groups  
250 decreased from 2010 to 2020 (by 37% for both herbivores and invertivores, 33% for piscivores) (Fig 2  
251 b). A 54% decrease in herbivore biomass occurred in Raiatea from 2010 to 2020 ( $2444.9 \pm 310.4$  to  
252  $1126.0 \pm 296.2$  kg ha<sup>-1</sup>), while invertivore and piscivore biomass gradually declined from 2010 to 2018  
253 before rising for all trophic groups from 2018 to 2020 (Fig. 2 c). Fish biomass was higher in Raiatea  
254 than Moorea, particularly for herbivores and mobile invertivores.

255 Nutrient availability from reef fish was similar to biomass trends for most nutrients and was also  
256 higher in Raiatea than Moorea (Fig. S3). Availability of all five nutrients from mobile invertivores  
257 and piscivores were at similarly low levels in Moorea over the time series, however in Raiatea,  
258 nutrient quantities from invertivores were higher than piscivores. Vitamin A availability from  
259 invertivores in Raiatea was particularly high (and variable) in 2010 and 2020 compared to other  
260 trophic groups (Fig. S3).



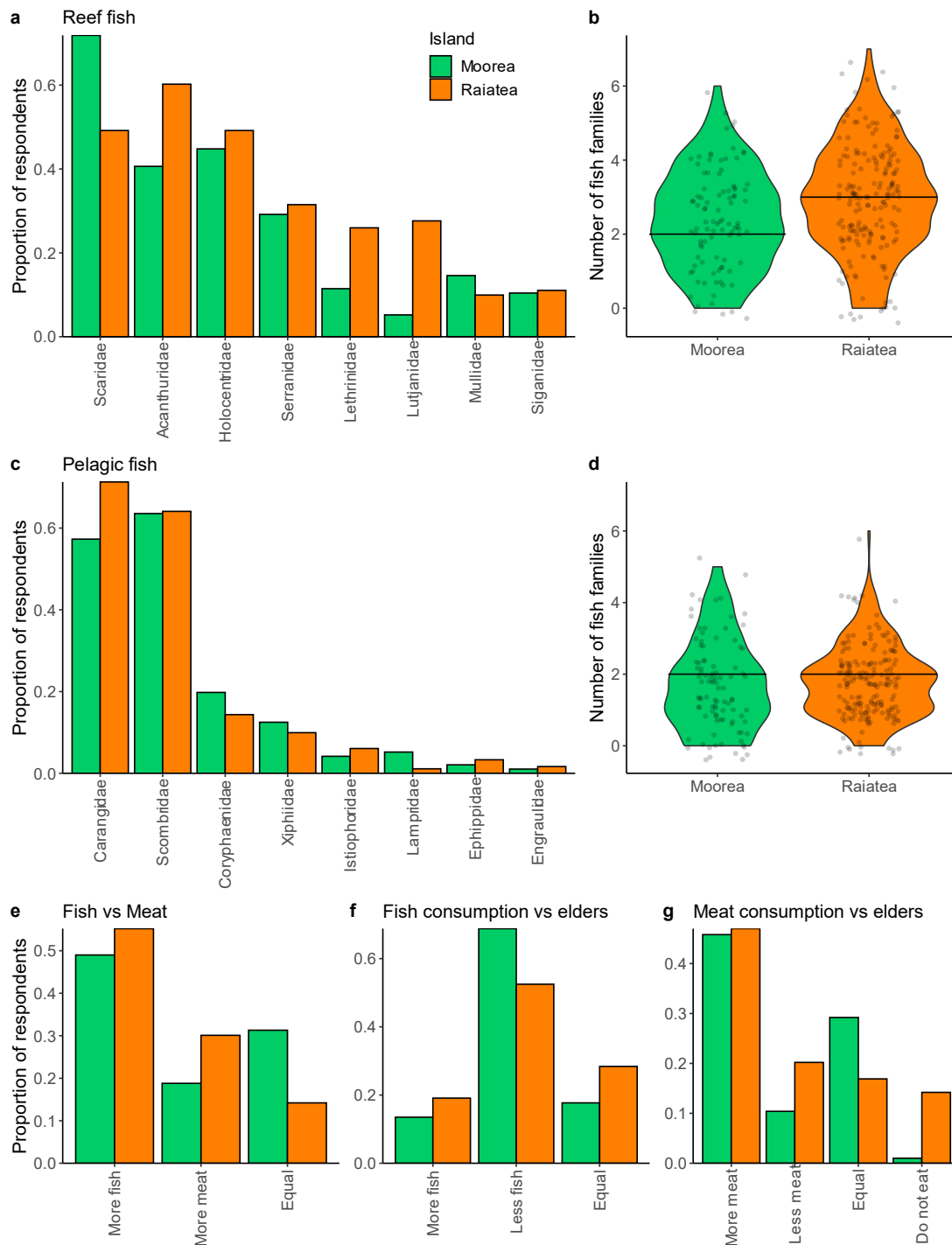
261

262 **Figure 2:** Trends of hard coral cover (a) and fish biomass on reefs in Moorea (b) and Raiatea (c) from 2010 to  
 263 2020. Biomass trends are for three trophic groups of reef fish (herbivore, mobile invertivore and piscivore).  
 264 Only fish above the minimum fishable size ( $\geq 15$  cm) with the potential to contribute to human nutrition were  
 265 included. Errors bars are the standard error of the mean across transects. Note y-axis scales for biomass differ  
 266 between islands (b and c).

267 *Fish consumption and nutrient intakes*

268 The reef fish families eaten by most respondents were herbivores on both islands; Scaridae in Moorea  
 269 (72% of respondents) and Acanthuridae in Raiatea (60% of respondents) (Fig. 3 a). With the  
 270 exceptions of Scaridae and Mullidae, all reef fish families were eaten by a higher proportion of  
 271 respondents in Raiatea compared to Moorea. Three reef fish families were typically eaten in Raiatea,  
 272 compared to two in Moorea (Fig. 3 b). The pelagic fish families eaten by most respondents were  
 273 Scombridae in Moorea (64% of respondents) and Carangidae in Raiatea (71% of respondents) (Fig. 3  
 274 c). The proportion of respondents eating each pelagic family was more similar between islands than

275 for reef fish, although a lower proportion of people ate carangids in Moorea (57%; Fig. 3 c). The  
 276 median number of pelagic families consumed was two on both islands (Fig. 3 d).



277  
 278 **Figure 3:** Proportion of respondents who ate the top eight reef (a) and pelagic (c) fish families, as stated during  
 279 interviews in Moorea (green,  $n = 96$ ) and Raiatea (orange,  $n = 181$ , two respondents who did not eat fish were  
 280 not included). The total number of fish families consumed by each respondent is shown for reef (b) and pelagic  
 281 (d) fish, with medians represented as solid horizontal lines. A comparison of fish to meat consumption per  
 282 respondent (e), as well as perceptions of fish (f) and meat (g) consumption compared to their elders are also  
 283 shown.

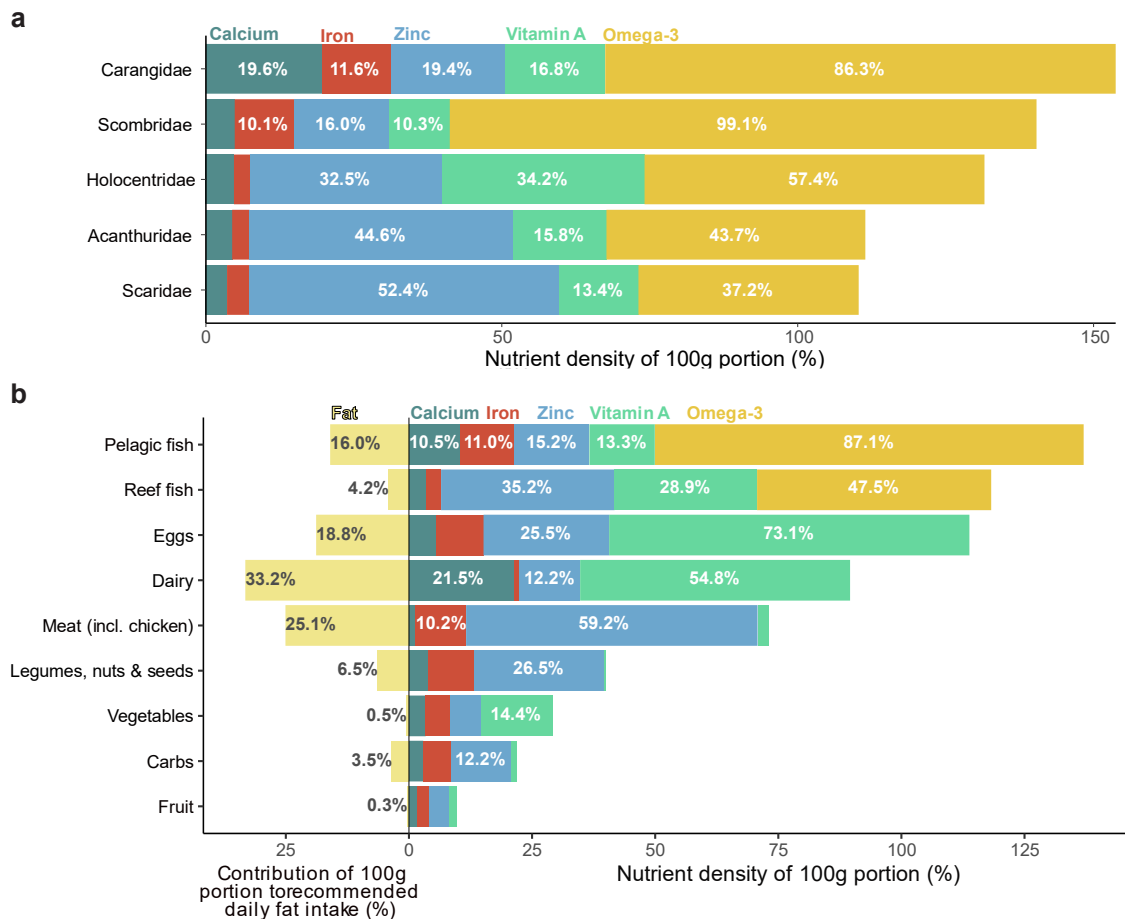
284 On both islands, around half of respondents said they ate more fish than meat (Moorea = 50%, Raiatea  
285 = 55%) (Fig. 3 e). The second most popular response in Moorea was eating equal amounts of fish and  
286 meat (31%), while in Raiatea it was eating more meat (30%). Although most people ate more fish  
287 than meat, the majority of people on both islands said they ate less fish (Moorea = 69%, Raiatea =  
288 53%) and more meat (Moorea = 46%, Raiatea = 47%) compared to previous generations (Fig. 3 f, g).  
289 A higher proportion of people in Raiatea (28%) said their fish consumption was equal to their elders  
290 (18% in Moorea), while a higher proportion in Moorea (29%) said their meat consumption was equal  
291 to their elders (17% in Raiatea). 14% of respondents in Raiatea did not eat meat, as they were  
292 pescatarian (compared to only 1% in Moorea) (Fig. 3 g).

293 Out of the top five fish families eaten (reef: Holocentridae, Scaridae and Acanthuridae; pelagic:  
294 Carangidae and Scombridae), Carangidae was the most nutrient dense (153% in total across all five  
295 nutrients; Fig. 4 a). Both pelagic fish families had the highest concentrations of omega-3 (Carangidae:  
296 86% of RNI, Scombridae: 99%) and iron (Carangidae: 12%, Scombridae: 10%) compared to reef fish  
297 families. Calcium concentrations were variable between pelagic families, with Carangidae having the  
298 highest (20%), whereas Scombridae was more similar to reef families (<5%). Reef families had  
299 higher zinc concentrations, particularly Scaridae (52%) and Acanthuridae (45%). Vitamin A  
300 concentrations were variable among reef and pelagic families and highest in Holocentridae (34%)  
301 (Fig. 4 a).

302 Pelagic fish was the most nutrient dense of all food groups for these five nutrients (137%) and reef  
303 fish was second (118%) after eggs and dairy (Fig. 4 b). The five most nutrient dense food groups were  
304 all animal-based, though there was considerable variation in the concentration of each nutrient  
305 between food groups. Dairy foods had the highest calcium contribution (22% of RNI) but the lowest  
306 iron contribution (1%), whereas iron-rich foods were pelagic fish (11%) and meat (including chicken  
307 and tinned meat, 10%). Meat had the highest zinc contribution (59%) followed by reef fish (35%), and  
308 foods with high vitamin A content were eggs (73%), dairy (55%) and reef fish (29%) (Fig. 4 b).

309 As with nutrient density, the food groups with the highest fat content were from animal sources, with  
310 dairy being the highest (33% of the recommended daily total fat intake in 100 g) (Fig. 4 b). Pelagic  
311 fish had more fat content (16%) than reef fish (4%) and compared to other animal-based food groups,  
312 reef and pelagic fish were relatively nutrient-dense and low in fat (Fig. 4 b).

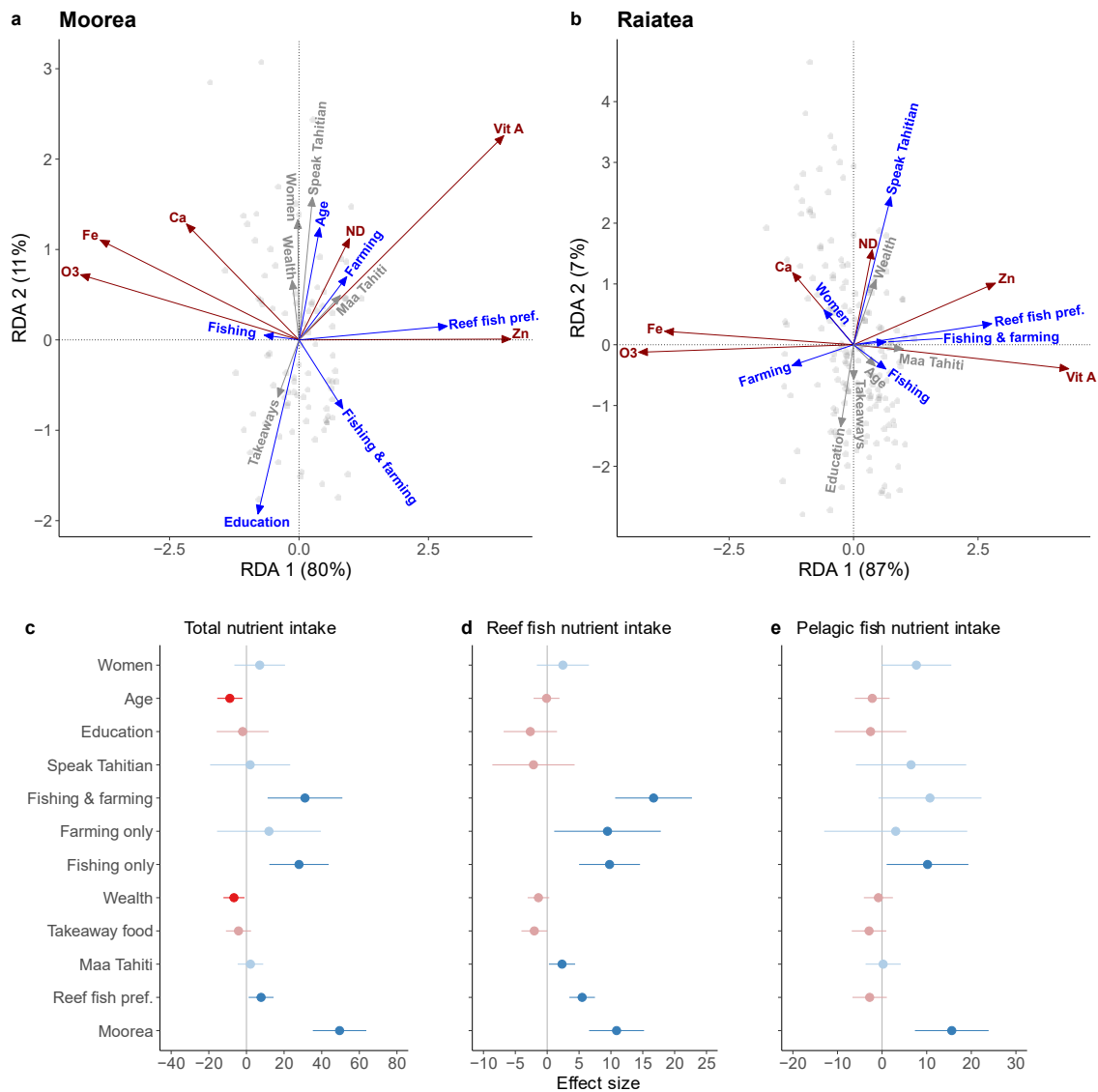
313 People on Moorea generally ate each food group more frequently compared to Raiatea (Fig. S4). Fish  
314 was one of the food groups with the largest difference in frequency of consumption between Moorea  
315 (median = 4.0) and Raiatea (median = 1.5). Most food groups were commonly eaten every day in  
316 Moorea, however on Raiatea, few people stated they ate any food group every day (Fig. S4).



317

318 **Figure 4:** Nutrient densities of 100 g portions of the top five fish families eaten (a) and of food groups (b),  
 319 calculated as the sum of contributions to daily recommended nutrient intakes (RNI) across five nutrients  
 320 (calcium, iron, zinc, vitamin A, and omega-3 fatty acids). The contributions of 100 g portions to the maximum  
 321 recommended daily fat intake (65 g, Drewnowski, 2009) are also shown for each food group (b, left). Values for  
 322 fish families (a) are means of all fish species in each family mentioned by respondents during interviews.  
 323 Nutrient estimates for reef and pelagic fish groups (b) are means of all fish species eaten by respondents.  
 324 Omega-3 fatty acids (eicosapentaenoic acid (EPA) + docosahexaenoic acid (DHA)) were assumed to only be  
 325 present in fish. Nutrient contents of food portions were obtained from Pacific Island food composition tables  
 326 (FAO, 2004), except fish which were obtained from the Nutrient Analysis Tool in FishBase (Froese and Pauly,  
 327 2022).

328 Redundancy analyses of the relationships between respondents' characteristics and nutrient density of  
 329 their diets revealed what type of people tended to get more of certain nutrients from fish. Preference  
 330 for reef fish had the strongest effect on the nutrients people received from fish on both islands  
 331 (Moorea:  $F = 31.9$ ,  $p = 0.001$ ; Raiatea:  $F = 28.7$ ,  $p = 0.001$ ) (Fig. 5 a and b). People who preferred to  
 332 eat reef fish had higher intakes of zinc and vitamin A and, conversely, those who ate more pelagic  
 333 families had higher intakes of calcium, iron, and omega-3, consistent with the nutrient concentrations  
 334 for those fish groups (Fig. 4 b).



335

336

**Figure 5:** Analyses of socioeconomic effects and dietary habits on the nutrients in people's diets. Redundancy

337

analyses for Moorea (a) and Raiatea (b) show associations between people's background (blue and grey arrows)

338

and the nutrient density (ND) of five nutrients received from fish, as well as the ND across all food groups in

339

their diet (red arrows). Explanatory variables with a significance level of  $p < 0.1$  are shown in blue, others are

340

shown in grey. Axis percentages are the variance explained by the data (note different axis scales for RDA 2

341

between islands). Generalised linear model estimates for the effect of socioeconomic factors on nutrient intakes are

342

shown for total dietary intakes (c), and from reef (d) and pelagic (e) fish only, with confidence intervals ( $1.96 \times$

343

standard error). Significant terms ( $p \leq 0.05$ ) are shown in solid colour and non-significant terms are faded.

344

Nutrient estimates for fish species were obtained from the Nutrient Analysis Tool in FishBase (Froese and

345

Pauly, 2022).

346

On Moorea, older people and those from farming (but not fishing) households had diets that consisted

347

of more nutritious foods, although effects were small (age:  $F = 2.4, p = 0.074$ ), while those with a

348

higher level of education had less nutritious diets ( $F = 5.7, p = 0.005$ ) (Fig. 5 a). People from

349

households involved in fishing and farming got fewer nutrients associated with pelagic species

350 (calcium, iron, omega-3) and were more aligned with nutrients from reef fish (zinc and vitamin A)  
351 (fishing and/or farming:  $F = 3.5, p = 0.002$ ). On Raiatea, those who spoke Tahitian had more nutrient-  
352 dense diets ( $F = 5.1, p = 0.003$ ) and women to a lesser extent ( $F = 2.2, p = 0.066$ ) (Fig. 5 b). People  
353 from fishing households (including those who also farmed) got more nutrients associated with reef  
354 fish, while people from farming only households got more nutrients from pelagic fish (fishing and/or  
355 farming:  $F = 4.3, p = 0.001$ ).

356 We fitted models to estimate the relative strength of the drivers identified in redundancy analysis on  
357 people's nutrient intakes. People from fishing households and people in Moorea had higher total  
358 nutrient intakes (fishing: effect size =  $27.9 \pm 8.0$  standard error,  $t = 3.5, p < 0.001$ ; Moorea:  $49.5 \pm 7.3, t$   
359  $= 6.8, p < 0.001$ ), as well as nutrient intakes from reef (fishing:  $9.8 \pm 2.4, t = 4.0, p < 0.001$ ; Moorea:  
360  $10.9 \pm 2.2, t = 5.0, p < 0.001$ ) and pelagic fish (fishing:  $10.2 \pm 4.7, t = 2.2, p = 0.030$ ; Moorea:  $15.6$   
361  $\pm 4.2, t = 3.7, p < 0.001$ ) (Fig. 5 c, d and e). However, for people from fishing households that were  
362 also involved in farming, this was not significant for nutrient intakes from pelagic fish (total nutrient  
363 intake:  $31.1 \pm 10.1, t = 3.1, p = 0.002$ ; reef fish:  $16.7 \pm 3.1, t = 5.4, p < 0.001$ ) (Fig. 5 e). People from  
364 farming households with no involvement in fishing also had higher nutrient intakes from reef fish ( $9.5$   
365  $\pm 4.3, t = 2.2, p = 0.027$ ). People who preferred to eat reef fish had higher nutrient intakes from reef  
366 fish, which could be expected, however they also had higher total nutrient intakes in their diets ( $7.8$   
367  $\pm 3.4, t = 2.3, p = 0.022$ ). Older people and wealthier people had slightly lower total nutrient intakes  
368 (age:  $-8.8 \pm 3.4, t = -2.6, p = 0.010$ ; wealth:  $-6.6 \pm 2.9, t = -2.3, p = 0.021$ ) (Fig. 5 a). Eating Maa Tahiti  
369 more often was associated with slightly higher nutrient intakes from reef fish ( $2.3 \pm 1.0, t = 2.2, p =$   
370  $0.027$ ). Women had higher nutrient intakes, while education and eating more takeaway food had  
371 negative effects on nutrient intakes, however these effects were weak and non-significant (Fig. 5 c, d  
372 and e).

## 373 Discussion

374 We investigated the resources available to coral reef fisheries and the importance of fish in islander  
375 diets through a nutrition lens. Nutrient availability to reef fisheries was highest when live coral cover  
376 was low, mainly due to the high biomass of herbivorous fishes, suggesting that nutrient provisioning  
377 services can be maintained on these reefs despite periods of habitat degradation. We found that fish  
378 was a key component of people's diets on both islands (despite differences in available reef fish  
379 biomass), although there was evidence that the amount of fish people were eating had decreased over  
380 time while meat consumption had increased. Socioeconomics were a major driver of fish  
381 consumption, for example people from fishing and farming households had higher nutrient intakes  
382 from fish. Collectively, our results suggest local food cultures and norms may be stronger drivers of  
383 nutrition from fisheries, relative to ecological factors on coral reefs.



384 High herbivorous fish biomass when live coral cover was low underpinned large contributions of  
385 nutrients from reefs. Herbivorous fishes important to fisheries, such as parrotfish, often increase in  
386 biomass and productivity following reductions in live coral due to greater benthic algal and detrital  
387 food sources (Rogers et al, 2018; Morais et al, 2020b; Rassweiler et al, 2020). In Moorea, the initial  
388 increase in herbivore biomass following a prolonged crown-of-thorns sea star outbreak and a cyclone  
389 facilitated the recovery of hard corals through the removal of competitive algae, leading to altered  
390 compositions of reef fish assemblages as corals recovered (Lamy et al, 2016). Herbivore biomass (and  
391 nutrients) also increased in Moorea in 2019 (Figs 2 and S3) after coral cover was reduced once more  
392 following a coral bleaching event (Speare et al, 2022). We highlight the nutritional benefits that low  
393 trophic-level fishes (e.g. herbivores) provide to small-scale fisheries on low-coral cover reefs, which  
394 will likely continue to be important for food provisioning if reefs become degraded again in future.  
395 Comparatively low reef fish biomass in Moorea could potentially be linked to higher fishing pressure  
396 in response to high fish consumption and thus market demand for reef fish, particularly as larger fish  
397 are preferentially targeted by spearfishers (Rassweiler et al, 2020). Fish biomass trends can help  
398 inform if the fish consumption patterns on Moorea and Raiatea may be sustained and continue to  
399 provide essential nutrients, given the level of reef resources available. Our results suggest careful  
400 management may be necessary when fisheries become more dependent on low trophic-level fishes to  
401 maintain a plentiful supply of nutrients from these species, particularly when coral cover is relatively  
402 high.

403 As multiple reef and pelagic fishes were important components of diets, it is likely that many  
404 islanders receive nutritional benefits from reef and pelagic fisheries. For example, people in fishing  
405 households had high nutrient intakes from both fish groups (Fig. 5) and would have had high zinc and  
406 vitamin A intakes from reef fish, and iron, calcium, and omega-3 intakes from pelagic fish. This could  
407 explain why less wealthy people (for example from lower income households, such as fishers and  
408 farmers) had slightly higher nutrient intakes, if their diets contained plenty of locally produced foods,  
409 such as fish and vegetables they harvested themselves. For example, it is common for fishers to keep a  
410 share of their catch to eat within their household (Kawarazuka and Béné, 2010). The popularity of  
411 carangid and scombrid fishes on both islands (Fig. 3 c) suggests islanders received health benefits  
412 associated with eating pelagic fish rich in omega-3, calcium and iron. Adequate omega-3 intakes can  
413 help to prevent obesity-related health issues, which are particularly prevalent in French Polynesia  
414 (Inamo et al, 2011), and so pelagic fish could be hugely beneficial to those who regularly eat them, for  
415 example fishing households and Mooreans (Fig. 5). Fish is available at many roadside points around  
416 Moorea, whereas in Raiatea, fish and other foods tend to be sold at a large market in the north of the  
417 island (pers. obs.), which would have influenced people's access to fish and could explain the higher  
418 frequency of fish consumption in Moorea.

419 Although fisheries in French Polynesia were important for supporting people's nutritional needs, we  
420 also found evidence that fish consumption may have decreased from one generation to the next, along  
421 with an increase in meat consumption. Meat is nutrient-dense and could provide people with higher  
422 zinc intakes compared to reef fish, but with the added cost of having a higher fat content (Fig. 5 b).  
423 Globalisation of French Polynesia's food system may have contributed to the loss of some traditional  
424 food cultures (Hughes and Lawrence, 2005), with an increase in Western, industrialised food imports,  
425 particularly processed meat high in saturated fat and foods with high amounts of added sugar (Brewer  
426 et al, 2023). The increasing reliance on imported food in French Polynesia has corresponded to the  
427 high proportion of overweight and obese adults (Hawley & McGarvey, 2015), therefore promoting  
428 traditional Polynesian diets and reducing reliance on imported foods could help to address these diet-  
429 related health issues (DiBello et al, 2009; Thow et al, 2011). As omega-3 can counteract the negative  
430 health effects of saturated fat found in red meat and many other Western foods (Shahidi and  
431 Ambigaipalan, 2018), locally caught fish (especially pelagics) may be a particularly important food  
432 source alongside meat for those with a high reliance on imported foods.

433 The varying effects of people's socioeconomic attributes on their consumption habits indicates social  
434 norms, habit, and identity can have a large influence on their nutrition (Baumhofer et al, 2020). We  
435 found that aspects of Polynesian culture, such as regularly eating Maa Tahiti, and speaking Tahitian in  
436 Raiatea, had positive effects on nutrition, suggesting traditional customs may be associated with  
437 health benefits. Lower total nutrient intakes in the elderly could be of concern, however this has  
438 previously been observed in French Polynesia as food intakes decrease with age (WHO, 2003).  
439 Although there were no strong effects, our results indicate women may have had more nutritious diets  
440 and had higher nutrient intakes compared to men, which is typical worldwide (Miller et al, 2022).  
441 Therefore, efforts to promote nutritious diets in French Polynesian men could result in health benefits.  
442 The causes of the large differences in nutrient intakes between people in Moorea and Raiatea are  
443 presumably due to Mooreans generally consuming foods more frequently. It is unclear from our  
444 results whether this is an indication of overconsumption in Moorea or of limited nutrient intakes in  
445 Raiatea. This island effect on nutrition may stem from differences in food culture and may warrant  
446 further investigation.

## 447 **Conclusion**

448 Our study highlights the importance of nutrient-dense reef and pelagic fish from local fisheries to  
449 societies in French Polynesia. The nutrient provisioning services provided by coral reef ecosystems  
450 can be maintained when the condition of coral habitat is reduced. Despite the globalisation and  
451 industrialisation of the food system increasing reliance on imported food, it was apparent that  
452 traditional diets rich in nutritious fish had persisted in French Polynesia. While more research is  
453 needed into specific drivers of people's food acquisition and consumption habits, our study highlights

454 which demographics benefited most from fisheries-derived nutrition and reveals those where potential  
455 improvements to nutrition could be made. Time series of social data alongside ecological data would  
456 be immensely valuable for similar studies in the future to more closely connect reef ecosystems and  
457 their influence on human nutrition, particularly as islander diets transition over time.

## 458 **Acknowledgements**

459 MH was funded by a studentship from the NERC Envision Doctoral Training Partnership  
460 (NE/S007423/1). EM and JPWR were funded by Early Career Fellowships from the Leverhulme  
461 Trust. NAJG was funded by a Royal Society University Research Fellowship (URF\R(201029) and a  
462 Philip Leverhulme Prize. JC was funded by Biodiversa (METRODIVER and MOVE) and Fondation  
463 de France (MultiNet). CCH was funded by an ERC Starting Grant and Philip Leverhulme Prize.  
464 Fieldwork was funded by the Fondation de France (Nutrition). Interviewers in French Polynesia were  
465 CM, VV, Juliette Languille and Vahinerii Tautoo. We thank the Service National d'Observation  
466 CORAIL from CRIOBE for providing data on reef fish biomass and coral cover. Lisa Boström-  
467 Einarsson assisted with R code to produce Figure S1. This study was conducted with approval of the  
468 Faculty of Science and Technology Research Ethics Committee, Lancaster University (ref:  
469 FST18040). We thank two anonymous reviewers for their constructive comments which improved our  
470 manuscript.

## 471 **Declaration of interests**

472 On behalf of all authors, the corresponding author reports there are no competing interests to declare.

## 473 **Data availability**

474 Data and R code used in analyses and to produce figures can be found in the following repository on  
475 GitHub: <https://github.com/Mark-H-22/FP-fish-diets/>

## 476 **References**

- 477 Andrew, N.L., Allison, E.H., Brewer, T., Connell, J., Eriksson, H., Eurich, J.G., Farmery, A., Gephart,  
478 J.A., Golden, C.D., Herrero, M., Mapusua, K., Seto, K.L., Sharp, M.K., Thornton, P., Thow, A.M.,  
479 Tutuo, J., 2022. Continuity and change in the contemporary Pacific food system. *Global Food*  
480 *Security* 32, 100608. <https://doi.org/10.1016/j.gfs.2021.100608>
- 481 Ayhan, H.Ö., 2011. Non-probability sampling survey methods, in *International Encyclopedia of*  
482 *Statistical Science*, ed M. Lovric (Berlin: Springer). doi: 10.1007/978-3-642-04898-2\_41

483 Baumhofer, N.K., Panapasa, S.V., Cook, E.F., Roberto, C.A., Williams, D.R., 2020.  
484 Sociodemographic factors influencing island foods consumption in the Pacific Islander Health  
485 Study. *Ethnicity & Health* 25, 305–321. <https://doi.org/10.1080/13557858.2017.1418300>

486 Beal, T., Massiot, E., Arsenault, J.E., Smith, M.R., Hijmans, R.J., 2017. Global trends in dietary  
487 micronutrient supplies and estimated prevalence of inadequate intakes. *PLOS ONE* 12, e0175554.  
488 <https://doi.org/10.1371/journal.pone.0175554>

489 Bell, J.D., Ganachaud, A., Gehrke, P.C., Griffiths, S.P., Hobday, A.J., Hoegh-Guldberg, O., Johnson,  
490 J.E., Le Borgne, R., Lehodey, P., Lough, J.M., Matear, R.J., Pickering, T.D., Pratchett, M.S.,  
491 Gupta, A.S., Senina, I., Waycott, M., 2013. Mixed responses of tropical Pacific fisheries and  
492 aquaculture to climate change. *Nature Clim Change* 3, 591–599.  
493 <https://doi.org/10.1038/nclimate1838>

494 Belton, B., Thilsted, S.H., 2014. Fisheries in transition: Food and nutrition security implications for  
495 the global South. *Global Food Security* 3, 59–66. <https://doi.org/10.1016/j.gfs.2013.10.001>

496 Brewer, T.D., Andrew, N.L., Abbott, D., Detenamo, R., Faaola, E.N., Gounder, P.V., Lal, N., Lui, K.,  
497 Ravuvu, A., Sapalolang, D., Sharp, M.K., Sulu, R.J., Suvulo, S., Tamate, J.M.M.M., Thow, A.M.,  
498 Wells, A.T., 2023. The role of trade in pacific food security and nutrition. *Global Food Security*  
499 36, 100670. <https://doi.org/10.1016/j.gfs.2022.100670>

500 Brown, C.J., Broadley, A., Adame, M.F., Branch, T.A., Turschwell, M.P., Connolly, R.M., 2019. The  
501 assessment of fishery status depends on fish habitats. *Fish and Fisheries* 20, 1–14.  
502 <https://doi.org/10.1111/faf.12318>

503 Chauvet, C., Galzin, R., 1996. The lagoon fisheries of French Polynesia. Naga, the ICLARM  
504 Quarterly. URL: [http://worldfish.catalog.cgiar.org/naga/na\\_2244.pdf](http://worldfish.catalog.cgiar.org/naga/na_2244.pdf)

505 Cruz-Trinidad, A., Aliño, P.M., Geronimo, R.C., Cabral, R.B., 2014. Linking Food Security with  
506 Coral Reefs and Fisheries in the Coral Triangle. *Coastal Management* 42, 160–182.  
507 <https://doi.org/10.1080/08920753.2014.877761>

508 Daigre, J.-L., Atallah, A., Boissin, J.-L., Jean-Baptiste, G., Kangambega, P., Chevalier, H., Balkau,  
509 B., Smadja, D., Inamo, J., 2012. The prevalence of overweight and obesity, and distribution of  
510 waist circumference, in adults and children in the French Overseas Territories: The PODIUM  
511 survey. *Diabetes & Metabolism* 38, 404–411. <https://doi.org/10.1016/j.diabet.2012.03.008>

512 DiBello, J.R., McGarvey, S.T., Kraft, P., Goldberg, R., Campos, H., Qusted, C., Laumoli, T.S.,  
513 Baylin, A., 2009. Dietary Patterns are Associated with Metabolic Syndrome in Adult Samoans.  
514 *The Journal of Nutrition* 139, 1933–1943. <https://doi.org/10.3945/jn.109.107888>

515 Drewnowski, A., 2009. Defining Nutrient Density: Development and Validation of the Nutrient Rich  
516 Foods Index. *Journal of the American College of Nutrition* 28, 421S–426S.  
517 <https://doi.org/10.1080/07315724.2009.10718106>

518 European Food Safety Authority (EFSA), 2010. Scientific Opinion on Dietary Reference Values for  
519 fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans  
520 fatty acids, and cholesterol. *EFSA Journal* 8, 1461. <https://doi.org/10.2903/j.efsa.2010.1461>

521 Ferguson, E.L., Watson, L., Berger, J., Chea, M., Chittchang, U., Fahmida, U., Khov, K.,  
522 Kounnavong, S., Le, B.M., Rojroongwasinkul, N., Santika, O., Sok, S., Sok, D., Do, T.T., Thi,  
523 L.T., Vonglokhom, M., Wieringa, F., Wasantwisut, E., Winichagoon, P., 2019. Realistic Food-  
524 Based Approaches Alone May Not Ensure Dietary Adequacy for Women and Young Children in  
525 South-East Asia. *Matern Child Health J* 23, 55–66. <https://doi.org/10.1007/s10995-018-2638-3>

- 526 Food and Agriculture Organisation, 1988. Requirements of Vitamin A, Iron, Folate, and Vitamin B12:  
527 Report of a Joint FAO/WHO Expert Consultation. FAO Food and Nutrition Series. Vol. 23, Rome.
- 528 Food and Agriculture Organisation, 2004. The Pacific Islands food composition tables, Second  
529 edition. Rome, Italy. <https://www.fao.org/4/y5432e/y5432e00.htm>
- 530 Food and Agriculture Organisation, 2022. FAO/WHO Global Individual Food consumption data Tool  
531 (GIFT): methodological document. <https://www.fao.org/3/cb8809en/cb8809en.pdf>
- 532 Friel, S., Baker, P.I., 2009. Equity, Food Security and Health Equity in the Asia Pacific Region. Asia  
533 Pacific Journal of Clinical Nutrition 18 (4), 620–632.
- 534 Froese, R., 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis  
535 and recommendations. Journal of Applied Ichthyology 22, 241–253.  
536 <https://doi.org/10.1111/j.1439-0426.2006.00805.x>
- 537 Froese, R., D. Pauly. Editors. 2022. FishBase. World Wide Web electronic publication.  
538 [www.fishbase.org](http://www.fishbase.org), version (08/2022).
- 539 Golden, C.D., Allison, E.H., Cheung, W.W.L., Dey, M.M., Halpern, B.S., McCauley, D.J., Smith, M.,  
540 Vaitla, B., Zeller, D., Myers, S.S., 2016. Nutrition: Fall in fish catch threatens human health.  
541 Nature 534, 317–320. <https://doi.org/10.1038/534317a>
- 542 Golden, C.D., Koehn, J.Z., Shepon, A., Passarelli, S., Free, C.M., Viana, D.F., Matthey, H., Eurich,  
543 J.G., Gephart, J.A., Fluet-Chouinard, E., Nyboer, E.A., Lynch, A.J., Kjelleovold, M., Bromage, S.,  
544 Charlebois, P., Barange, M., Vannuccini, S., Cao, L., Kleisner, K.M., Rimm, E.B., Danaei, G.,  
545 DeSisto, C., Kelahan, H., Fiorella, K.J., Little, D.C., Allison, E.H., Fanzo, J., Thilsted, S.H., 2021.  
546 Aquatic foods to nourish nations. Nature 598, 315–320. [https://doi.org/10.1038/s41586-021-](https://doi.org/10.1038/s41586-021-03917-1)  
547 [03917-1](https://doi.org/10.1038/s41586-021-03917-1)
- 548 Greenacre, M. (2018). Compositional Data Analysis in Practice. Chapman & Hall, CRC Press.
- 549 Hawley, N.L., McGarvey, S.T., 2015. Obesity and Diabetes in Pacific Islanders: The Current Burden  
550 and the Need for Urgent Action. Curr Diab Rep 15, 29. <https://doi.org/10.1007/s11892-015-0594-5>
- 551 Heilpern, S.A., Fiorella, K., Cañas, C., Flecker, A.S., Moya, L., Naeem, S., Sethi, S.A., Uriarte, M.,  
552 DeFries, R., 2021. Substitution of inland fisheries with aquaculture and chicken undermines  
553 human nutrition in the Peruvian Amazon. Nat Food 2, 192–197. [https://doi.org/10.1038/s43016-](https://doi.org/10.1038/s43016-021-00242-8)  
554 [021-00242-8](https://doi.org/10.1038/s43016-021-00242-8)
- 555 Hicks, C.C., Cohen, P.J., Graham, N.A.J., Nash, K.L., Allison, E.H., D’Lima, C., Mills, D.J., Roscher,  
556 M., Thilsted, S.H., Thorne-Lyman, A.L., MacNeil, M.A., 2019. Harnessing global fisheries to  
557 tackle micronutrient deficiencies. Nature 574, 95–98. <https://doi.org/10.1038/s41586-019-1592-6>
- 558 Hicks, C.C., Graham, N.A.J., Maire, E., Robinson, J.P.W., 2021. Secure local aquatic food systems in  
559 the face of declining coral reefs. One Earth 4, 1214–1216.  
560 <https://doi.org/10.1016/j.oneear.2021.08.023>
- 561 Hughes, R.G., Lawrence, M.A., 2005. Globalisation, food and health in Pacific Island countries. Asia  
562 Pac J Clin Nutr 2005; 14 (4):298-306
- 563 Hughes, R.G., Marks, G.C., 2009. Against the Tide of Change: Diet and Health in the Pacific Islands.  
564 Journal of the American Dietetic Association 109, 1700–1703.  
565 <https://doi.org/10.1016/j.jada.2009.07.015>
- 566 Inamo, J., Daigre, J.-L., Boissin, J.-L., Kangambega, P., Larifla, L., Chevallier, H., Balkau, B.,  
567 Smadja, D., Atallah, A., 2011. High blood pressure and obesity: disparities among four French

568 Overseas Territories. *Journal of Hypertension* 29, 1494.  
569 <https://doi.org/10.1097/HJH.0b013e328348fd95>

570 Institute of Statistics of French Polynesia, 2017. URL: <https://www.ispf.pf/chiffres> (accessed 11  
571 August 2022).

572 Kawarazuka, N., Béné, C., 2010. Linking small-scale fisheries and aquaculture to household  
573 nutritional security: an overview. *Food Sec.* 2, 343–357.  
574 <https://doi.org/10.1007/s12571-010-0079-y>

575 Kawarazuka, N., Béné, C., 2011. The potential role of small fish species in improving micronutrient  
576 deficiencies in developing countries: building evidence. *Public Health Nutrition* 14, 1927–1938.  
577 <https://doi.org/10.1017/S1368980011000814>

578 Kennedy, P.G., Ballard, T., Dop, M., 2011. Guidelines for measuring household and individual  
579 dietary diversity. Nutrition and Consumer Protection Division, FAO, FANTA, Rome, Italy 2011

580 Lamy, T., Galzin, R., Kulbicki, M., Lison de Loma, T., Claudet, J., 2016. Three decades of recurrent  
581 declines and recoveries in corals belie ongoing change in fish assemblages. *Coral Reefs* 35, 293–  
582 302. <https://doi.org/10.1007/s00338-015-1371-2>

583 Leenhardt, P., Lauer, M., Madi Moussa, R., Holbrook, S.J., Rassweiler, A., Schmitt, R.J., Claudet, J.,  
584 2016. Complexities and Uncertainties in Transitioning Small-Scale Coral Reef Fisheries. *Frontiers*  
585 *in Marine Science* 3, 70. <https://doi.org/10.3389/fmars.2016.00070>

586 Maire, E., Graham, N.A.J., MacNeil, M.A., Lam, V.W.Y., Robinson, J.P.W., Cheung, W.W.L.,  
587 Hicks, C.C., 2021. Micronutrient supply from global marine fisheries under climate change and  
588 overfishing. *Current Biology* 31, 4132–4138.e3. <https://doi.org/10.1016/j.cub.2021.06.067>

589 Miller, V., Webb, P., Cudhea, F., Shi, P., Zhang, J., Reedy, J., Erndt-Marino, J., Coates, J.,  
590 Mozaffarian, D., 2022. Global dietary quality in 185 countries from 1990 to 2018 show wide  
591 differences by nation, age, education, and urbanicity. *Nat Food* 3, 694–702.  
592 <https://doi.org/10.1038/s43016-022-00594-9>

593 Morais, R.A., Connolly, S.R., Bellwood, D.R., 2020a. Human exploitation shapes productivity–  
594 biomass relationships on coral reefs. *Global Change Biology* 26, 1295–1305.  
595 <https://doi.org/10.1111/gcb.14941>

596 Morais, R.A., Depczynski, M., Fulton, C., Marnane, M., Narvaez, P., Huertas, V., Brandl, S.J.,  
597 Bellwood, D.R., 2020b. Severe coral loss shifts energetic dynamics on a coral reef. *Functional*  
598 *Ecology* 34, 1507–1518. <https://doi.org/10.1111/1365-2435.13568>

599 assiri, A., Thébaud, O., Holbrook, S.J., Lauer, M., Rassweiler, A., Schmitt, R.J., Claudet, J., 2021.  
600 Hedonic evaluation of coral reef fish prices on a direct sale market. *Marine Policy* 129, 104525.  
601 <https://doi.org/10.1016/j.marpol.2021.104525>

602 Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens  
603 M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M,  
604 De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill  
605 M, Lahti L, McGlenn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J,  
606 2022. *vegan*: Community Ecology Package. R package version 2.6-4, [https://CRAN.R-](https://CRAN.R-project.org/package=vegan)  
607 [project.org/package=vegan](https://CRAN.R-project.org/package=vegan)

608 Parravicini, V., Casey, J.M., Schiettekatte, N.M.D., Brandl, S.J., Pozas-Schacre, C., Carlot, J., Edgar,  
609 G.J., Graham, N.A.J., Harmelin-Vivien, M., Kulbicki, M., Strona, G., Stuart-Smith, R.D., 2020.

610 Delineating reef fish trophic guilds with global gut content data synthesis and phylogeny. *PLOS*  
611 *Biology* 18, e3000702. <https://doi.org/10.1371/journal.pbio.3000702>

612 Parry, J., 2010. Conference calls for urgent action on food security in Pacific. *BMJ* 340, c2321.  
613 <https://doi.org/10.1136/bmj.c2321>

614 Pérez-Rosales, G., Brandl, S.J., Chancerelle, Y., Siu, G., Martinez, E., Parravicini, V., Hédouin, L.,  
615 2021. Documenting decadal disturbance dynamics reveals archipelago-specific recovery and  
616 compositional change on Polynesian reefs. *Marine Pollution Bulletin* 170, 112659.  
617 <https://doi.org/10.1016/j.marpolbul.2021.112659>

618 R Core Team (2022). R: A language and environment for statistical computing. R Foundation for  
619 Statistical Computing, Vienna, Austria. URL: <https://www.R-project.org/>

620 Rassweiler, A., Lauer, M., Lester, S.E., Holbrook, S.J., Schmitt, R.J., Madi Moussa, R., Munsterman,  
621 K.S., Lenihan, H.S., Brooks, A.J., Wencélius, J., Claudet, J., 2020. Perceptions and responses of  
622 Pacific Island fishers to changing coral reefs. *Ambio* 49, 130–143. [https://doi.org/10.1007/s13280-](https://doi.org/10.1007/s13280-019-01154-5)  
623 [019-01154-5](https://doi.org/10.1007/s13280-019-01154-5)

624 Robinson, J.P.W., Wilson, S.K., Robinson, J., Gerry, C., Lucas, J., Assan, C., Govinden, R., Jennings,  
625 S., Graham, N.A.J., 2019. Productive instability of coral reef fisheries after climate-driven regime  
626 shifts. *Nat Ecol Evol* 3, 183–190. <https://doi.org/10.1038/s41559-018-0715-z>

627 Robinson, J.P.W., Maire, E., Bodin, N., Hempson, T.N., Graham, N.A.J., Wilson, S.K., MacNeil,  
628 M.A., Hicks, C.C., 2022a. Climate-induced increases in micronutrient availability for coral reef  
629 fisheries. *One Earth* 5, 98–108. <https://doi.org/10.1016/j.oneear.2021.12.005>

630 Robinson, J.P.W., Mills, D.J., Asiedu, G.A., Byrd, K., Mancha Cisneros, M. del M., Cohen, P.J.,  
631 Fiorella, K.J., Graham, N.A.J., MacNeil, M.A., Maire, E., Mbaru, E.K., Nico, G., Omukoto, J.O.,  
632 Simmance, F., Hicks, C.C., 2022b. Small pelagic fish supply abundant and affordable  
633 micronutrients to low- and middle-income countries. *Nat Food* 1–10.  
634 <https://doi.org/10.1038/s43016-022-00643-3>

635 Rogers, A., Blanchard, J.L., Mumby, P.J., 2018. Fisheries productivity under progressive coral reef  
636 degradation. *Journal of Applied Ecology* 55, 1041–1049. <https://doi.org/10.1111/1365-2664.13051>

637 Sahal Estimé, M., Lutz, B., Strobel, F., 2014. Trade as a structural driver of dietary risk factors for  
638 noncommunicable diseases in the Pacific: an analysis of household income and expenditure survey  
639 data. *Global Health* 10, 48. <https://doi.org/10.1186/1744-8603-10-48>

640 Shahidi, F., Ambigaipalan, P., 2018. Omega-3 Polyunsaturated Fatty Acids and Their Health Benefits.  
641 *Annual Review of Food Science and Technology* 9, 345–381. [https://doi.org/10.1146/annurev-](https://doi.org/10.1146/annurev-food-111317-095850)  
642 [food-111317-095850](https://doi.org/10.1146/annurev-food-111317-095850)

643 Speare, K.E., Adam, T.C., Winslow, E.M., Lenihan, H.S., Burkepile, D.E., 2022. Size-dependent  
644 mortality of corals during marine heatwave erodes recovery capacity of a coral reef. *Global*  
645 *Change Biology* 28, 1342–1358. <https://doi.org/10.1111/gcb.16000>

646 Stevens, G.A., Beal, T., Mbuya, M.N.N., Luo, H., Neufeld, L.M., Addo, O.Y., Adu-Afarwuah, S.,  
647 Alayón, S., Bhutta, Z., Brown, K.H., Jefferds, M.E., Engle-Stone, R., Fawzi, W., Hess, S.Y.,  
648 Johnston, R., Katz, J., Krasevec, J., McDonald, C.M., Mei, Z., Osendarp, S., Paciorek, C.J., Petry,  
649 N., Pfeiffer, C.M., Ramirez-Luzuriaga, M.J., Rogers, L.M., Rohner, F., Sethi, V., Suchdev, P.S.,  
650 Tessema, M., Villapando, S., Wieringa, F.T., Williams, A.M., Woldeyahannes, M., Young, M.F.,  
651 2022. Micronutrient deficiencies among preschool-aged children and women of reproductive age  
652 worldwide: a pooled analysis of individual-level data from population-representative surveys. *The*  
653 *Lancet Global Health* 10, e1590–e1599. [https://doi.org/10.1016/S2214-109X\(22\)00367-9](https://doi.org/10.1016/S2214-109X(22)00367-9)

- 654 Thow, A.M., Heywood, P., Schultz, J., Quested, C., Jan, S., Colagiuri, S., 2011. Trade and the  
655 Nutrition Transition: Strengthening Policy for Health in the Pacific. *Ecology of Food and Nutrition*  
656 50, 18–42. <https://doi.org/10.1080/03670244.2010.524104>
- 657 Tilman, D., Clark, M., 2014. Global diets link environmental sustainability and human health. *Nature*  
658 515, 518–522. <https://doi.org/10.1038/nature13959> Woodhead, A.J., Hicks, C.C., Norström, A.V.,  
659 Williams, G.J., Graham, N.A.J., 2019. Coral reef ecosystem services in the Anthropocene.  
660 *Functional Ecology* 33, 1023–1034. <https://doi.org/10.1111/1365-2435.13331>
- 661 Woodhead, A.J., Hicks, C.C., Norström, A.V., Williams, G.J., Graham, N.A.J., 2019. Coral reef  
662 ecosystem services in the Anthropocene. *Functional Ecology* 33, 1023–1034.  
663 <https://doi.org/10.1111/1365-2435.13331>
- 664 World Health Organisation, 2003. Diet, food supply and obesity in the Pacific. ISBN 92 9061 044 1,  
665 (NLM Classification: WA 695).  
666 [https://apps.who.int/iris/bitstream/handle/10665/206945/9290610441\\_eng](https://apps.who.int/iris/bitstream/handle/10665/206945/9290610441_eng)
- 667 World Health Organisation, Food and Agriculture Organisation of the United Nations (Eds.), 2004.  
668 Vitamin and mineral requirements in human nutrition, 2nd ed. WHO; FAO, Geneva: Rome.
- 669 Zuur, A.F., Ieno, E.N., 2016. A protocol for conducting and presenting results of regression-type  
670 analyses. *Methods in Ecology and Evolution* 7, 636–645. [https://doi.org/10.1111/2041-](https://doi.org/10.1111/2041-210X.12577)  
671 [210X.12577](https://doi.org/10.1111/2041-210X.12577)