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Make a difference: Choose artificial reefs over natural reefs to compensate for the environmental impacts of dive tourism

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HIGHLIGHTS

- Natural reefs are declining globally.
- Divers prefer to dive in natural rather than artificial reefs.
- Artificial reefs can divert pressure from natural reefs.
- Divers should consider diving artificial reefs over natural reefs to reduce their impact.
- Better education about artificial reefs in sustainable dive tourism is urgently needed.

GRAPHICAL ABSTRACT

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ABSTRACT

In the marine environment, natural reef habitats are amongst the most threatened by human activities. Although reef-based ecotourism can benefit local economies, dive tourism can damage sensitive habitats. One solution to managing conflicts between the economic value of diving and its ecological threats is the deployment of artificial reefs near popular dive sites. We surveyed recreational divers to assess divers' use, preference, and perceptions of diving artificial versus natural sites. We found that more divers prefer to dive in natural than artificial habitats, with associated biodiversity the most popular reason for preferring natural habitats, and appreciating shipwrecks the most popular reason for preferring artificial ones. Despite our sample population being highly educated and experienced, predominantly European divers, only 49 % of them perceived artificial reefs as important or somewhat important for diverting pressure from sensitive natural habitats. Similarly, only 13 % of respondents exhibited preference to avoid coral reefs to protect them. These results highlight the fact that more needs to be done to educate divers about the potential importance of artificial habitats in diverting divers from natural reefs. We suggest encouraging divers to switch out a proportion of their dives in vulnerable natural sites for artificial reefs. This is not only true for coral reefs, but should be applied to other natural reef habitats that are popular with divers such as kelp forests, sponge gardens and serpulid and coralligenous reefs. We hope that this study will provide a platform to stimulate a diver-led discussion and campaign for increased uptake of artificial reef use, resulting in reduced impacts on natural reefs.

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1. Introduction

Human activities are driving the irrevocable destruction of natural ecosystems globally. In the marine environment, natural biogenic reef habitats are amongst the most threatened with 85 % of oyster reefs (Beck et al., 2011), 38 % of kelp forests (Krumhansl et al., 2016) and >60 % of coral reefs (Eddy et al., 2021) being lost globally or in a degraded state. Long-term forecasts for the viability of tropical coral reefs are particularly dire. Recently, severe thermal stress events have caused over 70 % of the world's reefs to suffer consecutive or prolonged bleaching events resulting in widespread losses of living corals (Eakin et al., 2019), with warnings that temperature increases of 1–1.5 °C are likely to be catastrophic (Dixon et al., 2022). Many other biogenic habitats (e.g., worm and coralligenous reefs) are classed as 'Data Deficient' by the IUCN Red List of Habitats (Bertocci et al., 2017; Firth et al., 2021; Gubbay et al., 2017) hampering estimations of loss as well as conservation and restoration efforts. The projected loss rate of biogenic reefs is expected to increase in the future (Barbier et al., 2011; Lotze et al., 2006; Waycott et al., 2009). Conversely, the establishment of artificial reefs is on the rise globally. Bugnot et al. (2021) estimated that not only was the physical footprint of built structures in the marine environment at least 32,000 km^2 worldwide in 2018 (~11 %, 3600 km^2 classed specifically as 'artificial reef'), but that this was projected to reach 39,400 km^2 by 2028 (23 % increase). In recognition of the potential multifunctionality of artificial reefs for ecosystem service provision (Chen et al., 2013; Firth et al., 2016; Bartholomew et al., 2022), there are now global efforts to rehabilitate and reconcile critical ecosystem functions using nature-based solutions, greening of grey infrastructure and artificial reef programmes (Chee et al., 2021; Cohen-Shacham et al., 2016; Morris et al., 2019).

Ecotourism is becoming an increasingly popular and destructive force globally (Gil et al., 2015; Hall, 2016; Uyarra et al., 2009). Reef-based ecotourism can substantially benefit local economies, generating an estimated US$39 billion annually both directly (e.g. SCUBA diving) and indirectly (e.g. providing sandy beaches) (Spalding et al., 2017). Whilst diving is widely considered to be a form of ecotourism (Arcos-Aguilar et al., 2021; Meyer et al., 2009), it has long been known that the damage caused by recreational divers (Giglio et al., 2020; Hawkins et al., 1999; Krieger and Chadwick, 2013; Lamb et al., 2014), and the associated damage caused by anchoring (Giglio et al., 2017; Mason et al., 2023), and chemical and noise pollution (McCloskey et al., 2023; Nedelec et al., 2022) has myriad negative impacts on coral reefs. Importantly, diver experience level is a major factor in the likelihood of significant coral damage from impact. In a South African study, inexperienced divers damaged coral on 1 in 6 dives, moderately experienced divers 1 in 14, and very experienced divers 1 in 123 dives; worryingly, underwater photographers caused damage on 9 out of 10 dives (Walters and Samways, 2001). Solutions include educational dive briefings, issuing environmental compliance standards to dive operators (e.g., United Nations Environment Programme (UNEP) Green Fins Programme), limiting the numbers of divers, and even the complete exclusion of divers from some locations. Whilst the former two solutions have shown to have some positive effects on diver behaviour (Roche et al., 2016; Toyoshima and Nadaoka, 2015), the latter two may have negative economic consequences, not only for the dive operators, but for local businesses that support the dive tourism industry (Jameson et al., 2007; van Treeck and Schuhmacher, 1999). Furthermore, the latter two solutions may divert local communities from tourism-based economies, to extraction-based economies such as fishing and coral extraction (Shani et al., 2012).

One common solution to managing the conflict between the economic value of diving and its ecological threats is the deployment of purposely-sunk artificial reefs near popular dive sites (Belhassen et al., 2017; Kirkbride-Smith et al., 2013; Oh et al., 2008). These types of structures range in scale and material type from tyres, concrete, culverts, scaffolding, statues and other artworks, to cars, subway trains, planes, tanks, boats and ships (Dowling and Nichol, 2001; Seaman and Jensen, 2000; Shani et al., 2012; Stolk et al., 2007). As 'real' shipwrecks make such popular dive sites (Ditton et al., 2002; Leeworthy et al., 2006; Shani et al., 2012), many 'artificial reef wrecks' are purposely sunk to serve as training locations for novice divers (Edney and Spennemann, 2014; Tynyakov et al., 2017). Şensurat-Genç et al. (2022) found that divers prefer diving on historical shipwrecks which sank in wars or accidents, and not on ships intentionally sunk as attractions. Following the deployment of a decommissioned ship (largest ever at the time) as an artificial reef dive site in Florida, Leeworthy et al. (2006) tracked a 3.7 % overall increase in local dive charter business, which bolstered local income by $961,800 and created 68 new jobs. As business grew, pressure on surrounding natural reefs was reduced; the total number of artificial reef users grew by 118.1 %, whereas total users on natural reefs declined by 13.7 %. Whilst this is likely to be an extreme example, it does demonstrate what success could look like if managed properly.

Other types of artificial reefs can be purposely placed to divert pressure from vulnerable dive sites (sometimes unsuccessfully, Oliveira et al., 2015), particularly if they offer themed or challenging technical dive experiences (Edney and Spennemann, 2014; Kirkbride-Smith et al., 2013). Established in the National Marine Park of Cancún, Mexico in 2009, Museo Subaquatico De Arte (MUSA) is one of the most elaborate examples of such a multifunctional undersea attraction. The underwater museum contains over 400 sculptures created by British sculptor Jason deCaires Taylor. The site aims to protect the natural heritage through 'otherworldly diversion', serving as a tourist attraction and conservation front distracting divers, snorkellers and glass-bottom boats away from the Meso-American Reef (Picken, 2016; Taylor et al., 2014). Following the success of MUSA, Taylor has deployed sixteen such projects across ten countries globally (Taylor, 2023).

Whilst it appears that some divers do appreciate the importance of artificial reefs for training purposes (Belhassen et al., 2017) and for diverting pressure away from vulnerable natural reefs (Oh et al., 2008; Osenberg et al., 2002; Shani et al., 2012) and shipwreck sites (Edney and Spennemann, 2014), arguably the majority are not aware of such benefits. Artificial reefs are also widely considered to be inferior to natural reefs (Pitcher and Seaman Jr, 2000; Şensurat-Genç et al., 2022). In general, divers have a preference for diving natural sites over artificial ones (Kirkbride-Smith et al., 2013; Oh et al., 2008), with some considering artificial reefs "glorified fishing holes, and tourist traps" (Bennington 2005, cited in Oh et al., 2008), whilst others consider them ocean dumping (Firth et al., 2020; van Treeck and Schuhmacher, 1999). The preference is likely to depend on whether the diver is a resident or a visitor, particularly if they are on a 'once in a lifetime trip'. For instance, a diver who has spent $1000s to travel across the world may simply want to dive the most beautiful, 'pristine' or interesting dive sites that a location has to offer and have no interest in diving artificial reefs, whereas an inexperienced visitor or local diver may just be happy to get in the water. Furthermore, this preference may be exacerbated by age or experience level, with older, more experienced divers seeking technical challenges (Edney and Spennemann, 2014). Castelló y Tickell et al. (2019) suggest that instead of considering artificial reefs inferior to natural reefs, the unique ecosystem services artificial reefs offer need to be defined and highlighted to divers. In the current global biodiversity and climate crisis, more can and should be done to alter perceptions of artificial reefs and enhance diving on artificial reefs as part of responsible dive tourism (Castelló y Tickell et al., 2019; Fletcher, 2019).

The overarching goal of this study was to assess divers' use, preference and perceptions of diving on artificial reefs and natural dive sites. Using an online questionnaire, we gathered information on the environmental attributes and motivational factors that contribute to diver enjoyment. We hypothesised that the majority of divers would have a preference for natural dive sites over artificial reefs, but that shipwrecks and deliberately sunken vessels would be rated more highly than other types of artificial reefs. We also explored divers' perceptions of what constitutes an artificial reef. We hypothesised that the majority of people would not be aware of the importance of artificial reefs for diverting pressure from natural locations. Our results are discussed within the context of SCUBA diving management in regions where reef conservation is important.

2. Methods

2.1. Questionnaire development and data collection

To obtain a broad sample of responses, a questionnaire was developed in English using Google Forms (Appendix 1). An initial pilot study was carried out ($n = 30$) in 2019 to test understanding and refine questions for inclusivity and clarity. The final survey used a mixed methods approach of 21 closed and open questions. The survey was distributed between May and August 2020 using social media and through the authors' professional and personal networks, resulting in 679 complete responses.

Part 1 of the survey collected respondent demographics (age, gender identity, nationality, occupation, location, education). The remainder of the questionnaire was designed to profile respondents' dive histories (qualifications, number of dives, etc.) and their use, perceptions, and preferences for diving on artificial and natural habitats. A series of 5-point Likert scale questions and checklists were included as well as six free-response questions which gave divers the opportunity to explain responses in more depth.

For the purpose of this survey an **artificial habitat** was defined on the survey as "any man-made structure located in the marine environment for a range of purposes (i.e., diver recreation, jetties or bridges, breakwaters for coastal defence, fisheries enhancement, oil extraction, divert disturbance or fishing pressure away from natural habitats, shipwrecks)". Similarly, the survey defined a **natural habitat** as "a naturally occurring feature (e.g. coral reefs, seagrass beds, kelp forests, sandy bottom, etc.)". These definitions were included in Part 2 of the survey and were not meant to be exhaustive but to give some clear examples of each type of habitat to aid respondents in answering the questionnaire. We used the term 'artificial habitat' as opposed to artificial reef in the survey to represent a direct comparison with natural habitats and to avoid introducing jargon.

2.2. Ethics statement

All divers completed the survey themselves and gave their permission to use the results. Individuals were not identifiable from the data provided. The survey described in this paper was reviewed and approved by the University of Plymouth Science and Engineering Research Ethics Committee.

2.3. Data analysis

To improve comparison of diver experience with the literature (Fitzsimmons, 2008; Kirkbride-Smith et al., 2013), divers were categorised according to number of logged dives (novice ≤ 100 logged dives; experienced ≥ 100 logged dives).

Quantitative data were analysed in R v4.1.0 using the Tidyverse collection of packages (R Core Team, 2019; Wickham et al., 2019). Data were not normally distributed, so non-parametric testing was used. One-sample Wilcoxon tests were used to determine if the responses to some questions differed from the midpoint (proportion of dives in natural habitats (midpoint = 0.5, an equal number of dives in artificial and natural habitats)) and alternate uses of artificial habits ((midpoint = 3, neither unimportant nor important)). Spearman's rank correlation was used to examine correlation between continuous variables, and Kruskal-Wallis testing, followed by Bonferroni post hoc p adjustment, was used to identify differences in continuous non-parametric variables. The 'multicomp' function from the RVAideMemoire package was used to identify differences in categorical count data via Chi square and Fisher's exact tests, as appropriate, with the Bonferroni correction for post hoc testing. Likert data were analysed using the 'Likert' function from the Likert package in R. Generalised linear modelling was used to identify predictors (age, gender, education level, where the diver lives, total number of dives, dive experience) of the binomial habitat preference response variable (prefers to dive in artificial habitats or prefers to dive in natural habitats). Model selection started with a full model including the one response variable (habitat preference) and the predictor variables. Using the 'dredge' function in the MuMIn package, Akaike Information Criterion (AIC) was then used to eliminate non-significant variables one by one to identify the model with the lowest AIC.

Qualitative data were analysed using NVIVO 12. Open questions were coded and common themes extracted and their frequencies of occurrence examined.

3. Results

3.1. Respondent profile and diving experience

Questionnaires ($n = 679$) were completed and returned from divers living in countries ($n = 61$) across all habitable continents. Of the 679 respondents, the majority of divers were from Europe (73 %). Other responses came from North/South/Central America and Caribbean countries (14 %) and Asia/Indo-Pacific countries (7 %). The remaining respondents (6 %) were located in Africa, the Middle East, and Australia/New Zealand/Oceania. This geographic distribution likely reflects the authors' social networks.

Significantly more respondents identified as men (56 %) than women (43 %) ($\chi^2(1) = 12.558, p = 0.0004$). Respondents covered a wide range of ages, with the most populous category between 18 and 29 years old (30 %), followed by 23 % between 30 and 39 years, with 16 % in their forties, 18 % in their fifties, and 13 % over 60 years old. Respondents were highly educated, with 74 % having at least a university-level education, 10.6 % had a secondary/high school education, and 13.5 % had obtained a certificate or diploma.

This survey targeted recreational SCUBA divers of all experience and qualification levels, and revealed respondents were well-trained and experienced divers: 91 % of respondents were qualified to at least advanced diver level (Diver Level 2 - Autonomous Diver, ISO 24801-2 with a 30 m endorsement e.g. PADI Advanced Open Water) and 9 % of respondents (204 individuals) held a basic open water qualification (Diver Level 2 - Autonomous Diver, ISO 24801-2, e.g., PADI Open Water). Of certified divers, 26 % were qualified as a dive instructor (Instructor Level 2 – ISO 24802-2), and 20 % qualified as a dive master, dive leader, or guide (Diver Level 3 - Autonomous Dive Leader, ISO 24801-3), and 4 % were commercial diver certified (Supporting Online Material (SOM) Fig. 1a). Two individuals (<1 % of respondents) were not certified for diving. To further assess each respondent's level of diving experience, they were asked to indicate total number of logged dives (SOM Fig. 1b). Respondents logged a total of 516,650 dives (range 2–18,569 dives), indicating a wide range of diving experience. The average number of logged dives was 760 (SD = ±1434) but the median number of dives was 260, revealing a distribution skewed towards divers logging 500 or fewer dives. Approximately 30 % of respondents were novices (<100 logged dives) and ~70 % experienced (>100 logged dives); 17 % of respondents had logged over 1000 dives.

3.2. Habitat use and preference

When queried about the number of dives respondents had logged a significantly higher proportion of dives in natural (78 %) than artificial (22 %) habitats (one-sample Wilcoxon test: $V = 9645.5$, p-value < 0.0001; Fig. 1). When respondents were separated into novice and experienced divers, a similar pattern remained with 81 % of novice and 76 % of experienced divers' dives logged in natural habitats. A very weak but significant correlation was found between total number of dives

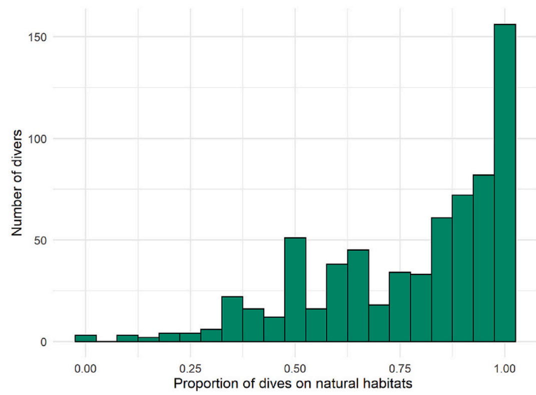

Fig. 1. Proportion of dives on natural habitats across all respondents.

logged and the proportion of dives logged in either habitat type (for proportion of dives in natural habitats: Spearman's rho = −0.111; p = 0.004).

To find out if habitat use aligns with habitat preference, we then asked respondents in which type of habitat they prefer to dive. Significantly more divers (62 %) indicated that they prefer to dive in natural habitats, whilst 7 % preferred diving in artificial habitats, and 31 % had no preference ($\chi^2(2) = 319.55$, $p < 0.0001$). Habitat use was found to reflect habitat preference, with divers who preferred natural habitats having the highest mean percentage of dives logged in natural habitats (84.3 %), and divers preferring artificial habitats having the highest mean percentage of dives logged in artificial habitats (53.8 %). The percentage of dives on natural habitats was significantly different between divers who prefer natural habitats, those that prefer artificial habitats, and those with no preference (Kruskal Wallis H(2) = 130.61, $P < 0.0001$).

We then investigated if preference for natural or artificial habitats is related to dive experience (indicated by number of logged dives), age, gender, education level, or country of diver residence. A generalised linear model indicated that gender, age, and dive experience level were the best predictors of habitat preference, with older, women-identifying divers, with less dive experience most likely to prefer natural habitats (Table 1). The model's explanatory power, however, is very weak (Tjur's $R^2 = 0.020$).

When asked why respondents preferred artificial or natural habitats, or had no preference, the highest-ranked theme occurring across all three habitat preferences focused on biodiversity, naming associated biodiversity as the reason for preferring natural habitats (40 %), artificial habitats (33 %), or having no preference (28 %) (Fig. 2). When asked to elaborate in free text, aside from biodiversity, the key themes mentioned by divers who prefer to dive on artificial habitats were shipwrecks (46 %), the combination of human and nature (22 %), and historic interest (20 %), whilst responses from divers preferring natural habitats focused on naturalness (nature in a natural setting) (31 %) and aesthetics (9 %), indicating different motivations behind preference choice of the two groups of divers. The delivery of an interesting, exciting, or challenging experience was a key theme across all divers (no preference = 32 %, artificial habitats = 17 %, natural habitats = 10 %).

Table 1
Binomial generalised linear model (GLM) describing predictors of habitat preference, selected via stepwise AIC-based selection process.

Model formula	df	Predictor	Estimate	Std error	Z	*P* value
DivePref ~ gender + age + dive experience	459	Intercept	2.09	0.77	2.70	0.007
		Gender	0.49	0.34	1.42	0.156
		Age	0.31	0.14	2.22	0.026
		Dive experience	−0.64	0.26	−2.50	0.013

Divers preferring natural habitats had the widest variety of reasons for doing so, but also had the most respondents.

To better understand where divers prefer to dive, participants were asked to rank in which order of preference they would most like to dive a variety of representative dive sites (Fig. 3). Across all divers surveyed, 70 % of respondents selected natural habitats (either coral reef or kelp forest) as their first choice; 51 % chose coral reef as their first choice, with 34 % selecting kelp forest as their second choice. 36 % chose a sunken ship as their third choice and 60 % selected the site with an indeterminate metal structure as their least preferred dive site. A significant relationship was found between habitat preference and preferred first choice dive site (Fishers exact test, $p < 0.0001$), with 61 % of those preferring to dive in natural habitats selecting the coral reef site as their first choice and 67 % of divers preferring artificial habitats selecting the ship as first choice. The top dive sites for divers with no preference for artificial or natural habitats were the coral reef (39 %) followed by the ship (36 %) and kelp forest (15 %); in other words, 54 % of divers who did not indicate a preference selected a natural habitat as their preferred choice of dive site. In contrast, the indeterminate metal structure was the least preferred (4th choice) by all groups of divers.

The majority of both novice (56 %) and experienced (50 %) divers selected the coral reef as their first choice, with a total of 66 % of experienced divers and 80.6 % of novice divers selecting the natural habitats (kelp or coral) as their first choice. A significant relationship was found between first choice dive site and gender with 79 % of women and 63 % of men selecting the natural habitats as their first choice site ($\chi^2(3) = 11.712$, $p = 0.008$). Diver age was not related to first choice site selection (Fisher's exact test, $p > 0.05$), but most respondents across all age groups preferred the coral reef, and the fewest selected the indeterminate metal structure as their first choice. In summary, all groups based on gender, experience, or age selected the indeterminate metal structure as their least preferred choice of dive site, except for divers who prefer artificial habitats who selected it as their second preference.

When probed for the reason for selecting their preferred dive site, common themes emerged across preferred sites (Fig. 4a). Associated biodiversity/wildlife featured as a reason for selecting all sites, and was the most-selected reason for the coral reef (51 %) and the kelp forest (29 %), and was followed closely by the naturalness delivered by these habitats (coral reef: 27 %; kelp forest: 16 %). For the indeterminate metal structure and the ship, an interesting/exciting/challenging experience (ship: 33 %, structure: 30 %) and exploration/adventure opportunity (structure: 13 %, ship: 10 %) featured. The second reason for selecting the ship as first choice, after delivery of an interesting/exciting/challenging experience, was an enjoyment of wreck diving (31 %), whilst the novelty offered by the metal structure was the second more popular reason for selecting that site (23 %). When asked why respondents selected their least-preferred dive site (Fig. 4b), a lack of biodiversity/wildlife featured as a reason across all sites, including the natural habitats (structure: 16 %, ship: 12 %, kelp forest: 5 %, coral reef: 6 %). The most popular reason for choosing the ship and metal structure as the least-preferred site was that these sites were perceived as not interesting, exciting, or challenging (metal structure: 29 %, ship: 20 %). The coral reef (11 %) and kelp forest (7 %) were also perceived as not interesting, exciting, or challenging by some respondents. The number one reason for selecting the kelp forest as the least-preferred dive site was the associated diving conditions (17 %), whilst the most popular reason for choosing the coral reef as the least-preferred site was the vulnerability of that habitat (13 %).

3.3. *Perceptions of artificial habitats*

To better understand what motivates divers to dive on artificial habitats we asked participants to rate the importance of artificial habitats for a variety of uses (Fig. 5). Responses revealed a number of clear roles for artificial habitats with most respondents rating artificial habitats as somewhat important or important when they have desirable

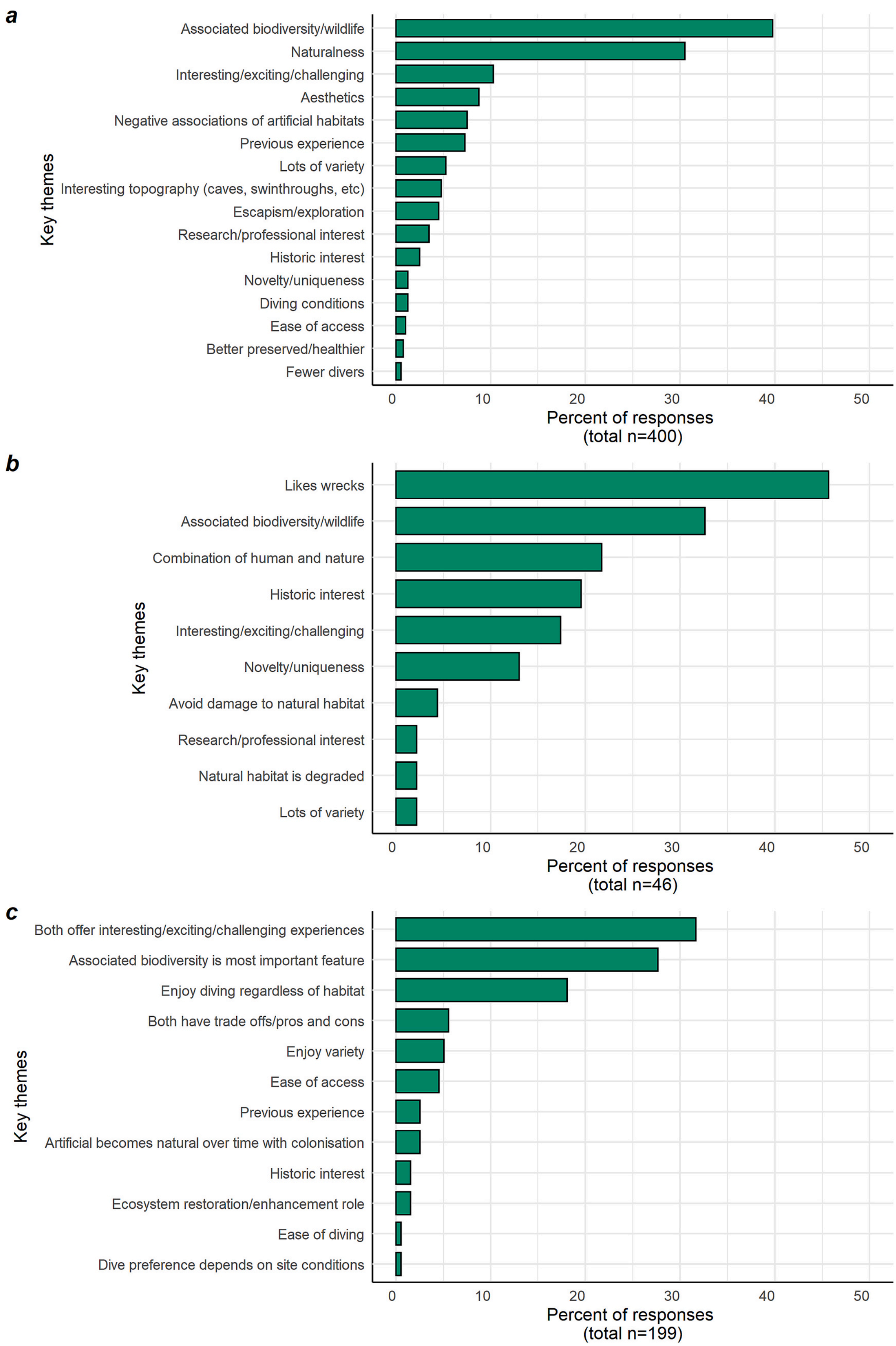

Fig. 2. Percentage of respondents who prefer to dive in natural habitats (a), artificial habitats (b), and who have no preference for which habitat they dive (c) to the question "What was the reason for selecting your habitat preference?". Percentages were calculated based on total number of responses for each habitat preference (not on the total number of survey respondents). The number of respondents therefore varied depending on how many participants prefer to dive in each habitat (or have no preference).

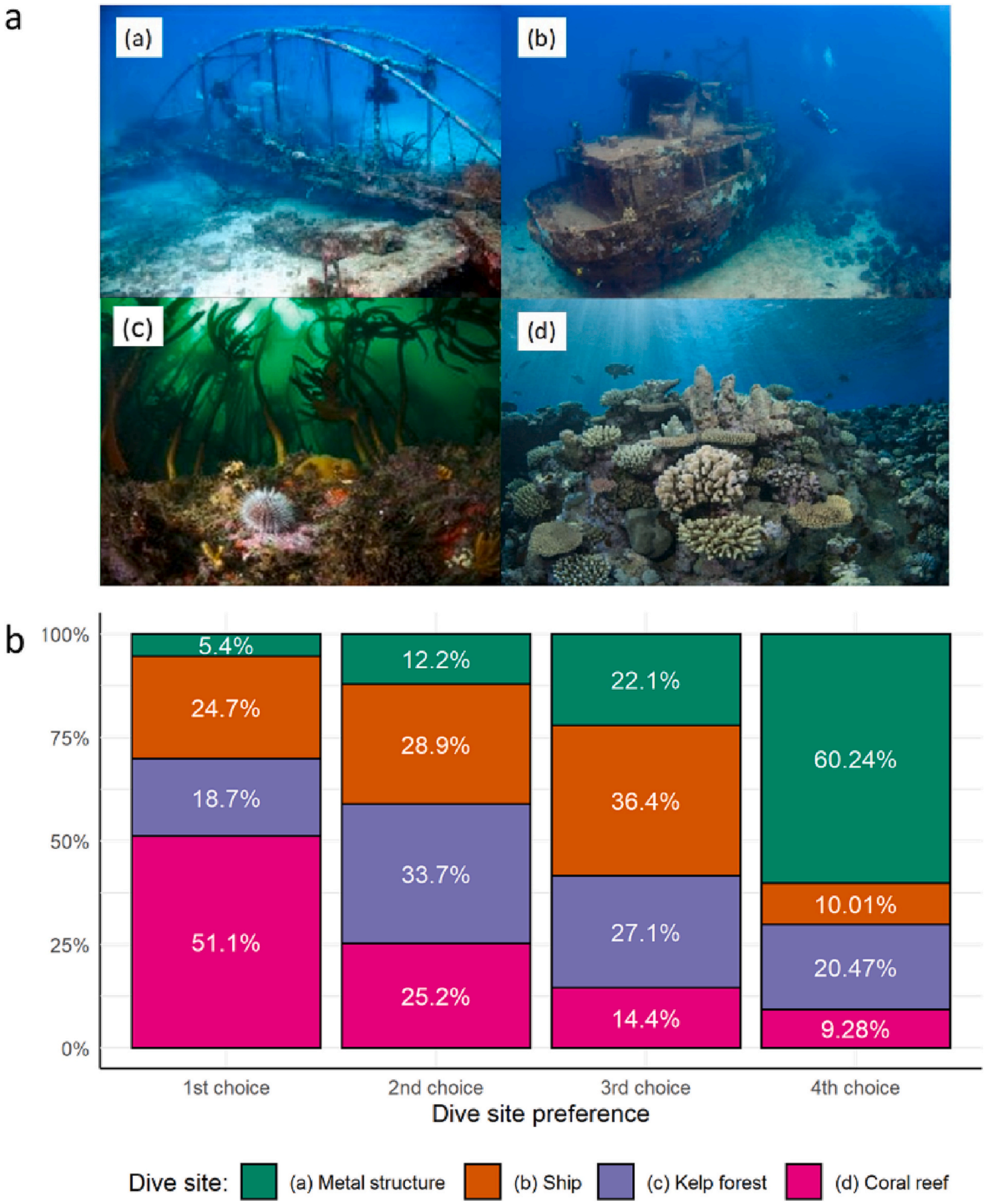

Fig. 3. Divers were asked to rank the sites in (a) in order of preference for diving (b).

associated marine life (87 %), contain heritage/cultural/historical value (86 %), when natural habitats are non-desirable/degraded (79 %), or when artificial habitats, have novelty value (72 %) or provide technical challenge (63 %). The perceived importance of artificial habitats for diverting divers away from natural habitats and for being more convenient/cheaper to dive than natural habitats were ranked much lower than the other uses (49 % and 43 % respectively). We hypothesised that the majority of people would not be aware of the importance of artificial reefs for diverting pressure from natural locations. Whilst only 49 % of respondents rated artificial habitats as somewhat important or important for diverting divers away from natural habitats, 84 % of survey participants responded 'yes' when asked the direct question "Do you think artificial habitats can be used to divert divers from natural habitats in order to preserve/protect natural habitats?". This contrast in responses highlights the discrepancy between responses received from asking a leading question and the more nuanced information gleaned from using a Likert scale. Here, we place more emphasis on the responses to the Likert scale rather than the direct question.

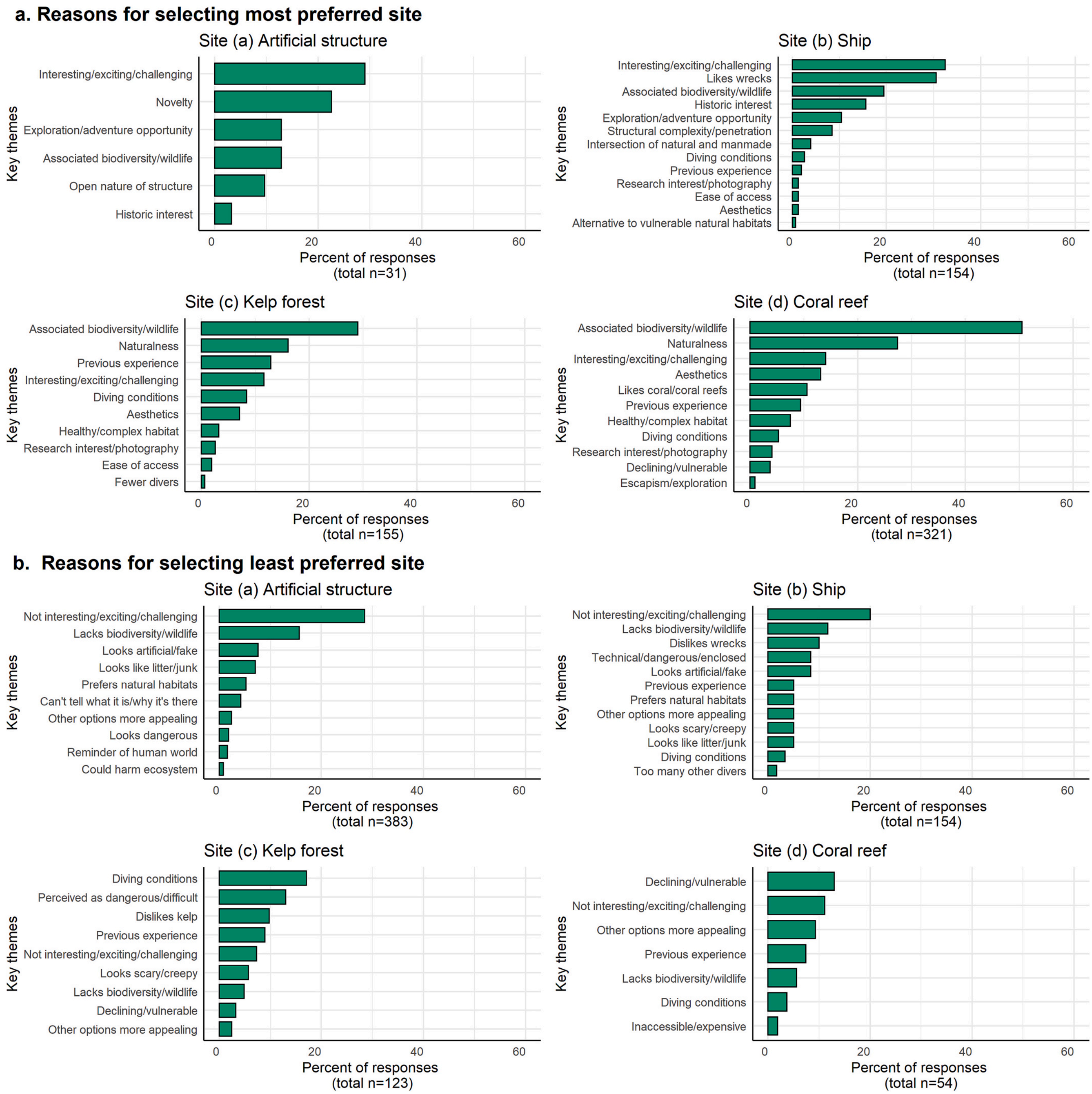

Fig. 4. (a) Reasons respondents selected their most and (b) least preferred choice of dive site from Fig. 3. Percentages were calculated based on total number of responses for divers who selected each site as their first or last choice (not on the total number of survey respondents). The number of respondents therefore varied depending on how many participants selected each site as their first or last choice. Note, not all respondents answered this question.

Diver experience (measured by number of dives) was correlated with perceived importance of some of the uses of artificial habitats as dive sites. Importantly, divers with more logged dives were less likely to perceive the role of artificial habitats in diverting divers away from natural habitats as important (Spearman's $R = -0.158$, $p < 0.0001$) and also less likely to perceive the novelty or unique experience value of artificial habitat dive sites as important (Spearman's $R = -0.077$, $p = 0.044$). No other significant relationships were found between diver experience level/number of logged dives and perceived importance of artificial habitats as dive sites for different uses.

Divers preferring to dive in natural habitats were less likely than those with no preference to think artificial reefs play an important role where natural habitats are non-desirable or degraded ($H(2) = 9.042$, $p = 0.01$). Where it is cheaper or more convenient to dive in artificial than natural habitats, divers with no habitat preference were more likely than those who prefer diving on natural habitats to think artificial habitats are important ($H(2) = 9.879$, $p = 0.007$). Divers who prefer artificial habitats were more likely than divers who prefer natural habitats and divers with no habitat preference to think artificial habitats are important when they have heritage, historical, or cultural value ($H(2) = 17.765$, $p < 0.0001$). Divers who prefer natural habitats were more likely than those with no habitat preference to think artificial habitats are important when the associated marine life is desirable ($H(2) = 13.867$, $p < 0.001$). Finally, divers preferring artificial habitats were

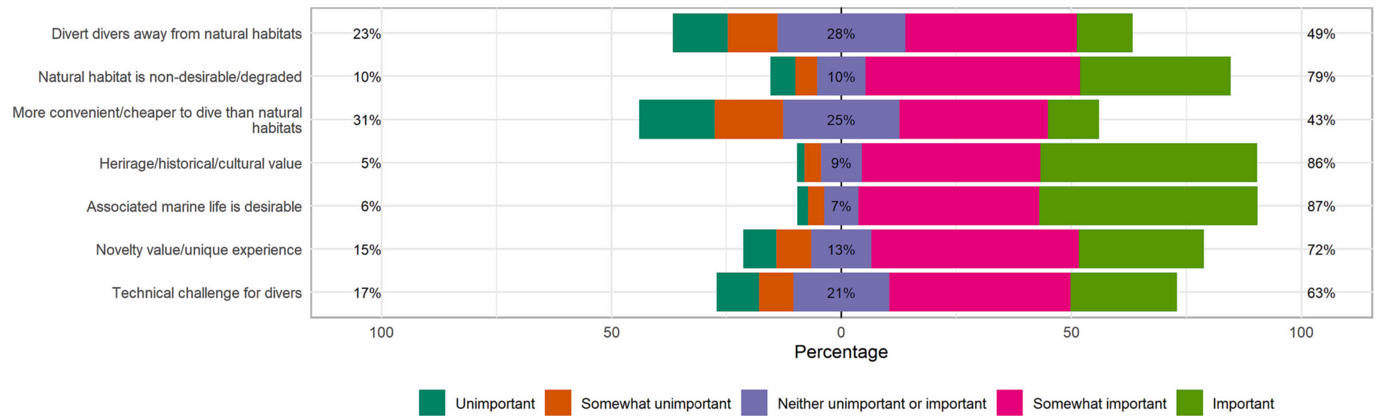

Fig. 5. Perceived importance of artificial habitats as dive sites for different uses.

more likely than those who prefer natural habitats to think artificial habitats are important when they have novelty value or provide a unique experience ($H(2) = 12.473$, $p = 0.002$).

3.4. Alternate roles for artificial habitat dive sites

To investigate perceptions around alternate uses for artificial habitats, respondents were asked if the artificial reefs in Fig. 6 could serve a purpose other than as a dive site, and if so, which purpose. For sites a and f, the most commonly perceived use of the sites other than as a dive site was for fish aggregation (site a: 42 %, site f: 49 %); these sites also had the highest number of respondents (23 % for both sites) who felt the purpose of the site was only as a dive site. Site b, the sunken ship, was perceived by 51 % of respondents to serve the purpose of fish aggregation and 51 % the preservation of historical or cultural heritage. Site c, the tyres, was the site most thought to serve the purpose of waste disposal (63 % of respondents) whilst site e was the site respondents felt most likely to serve the purpose of marine life restoration (69 %), followed closely by Site d (58 % of respondents). The second most perceived use of sites d and e was for fish aggregation (site d: 50 %, site e: 43 %).

When asked about their own personal experience diving on artificial habitats in a separate question, 30 % of participants had experienced a situation where they considered an artificial habitat or reef to be an example of ocean waste/rubbish/trash disposal. Out of the 186 respondent who elaborated via free text, 23.7 % ($n = 44$) mentioned encountering tyres/tires, 14.0 % ($n = 26$) mentioned diving on non-specific or general rubbish in the sea, and 14.0 % (n = 26) mentioned ships or barges perceived as rubbish or waste (Fig. 7). Interestingly, there were 21 (11.3 %) references to the associated marine biodiversity experiences diving amongst items the diver considered rubbish. Conversely, five (2.7 %) respondents declared that any man-made item

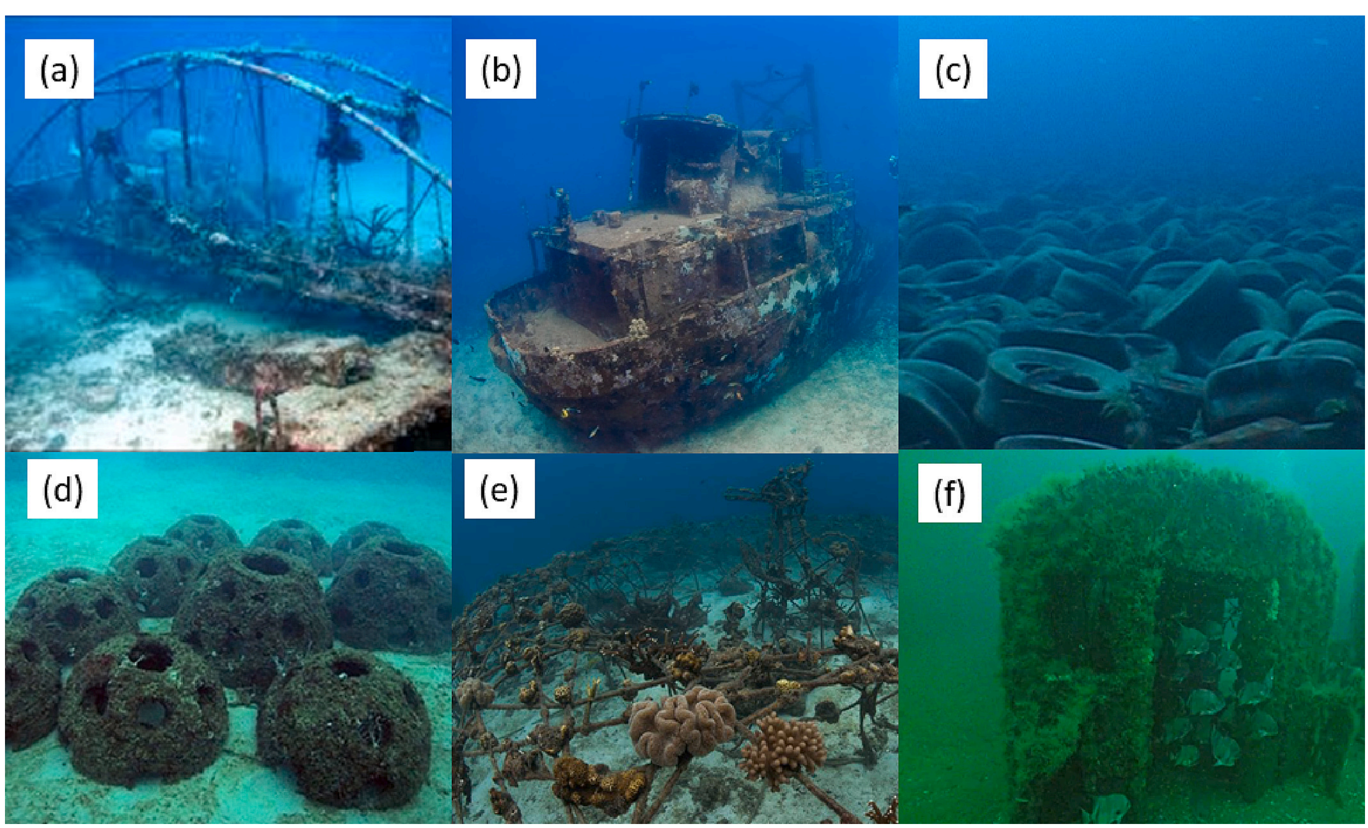

Fig. 6. Respondents were asked about their perceptions on which uses, other than as a dive site, these artificial reefs might fulfil.

in the sea is rubbish, though it was acknowledged that sometimes there can be co-benefits (such as hosting marine life).

To understand how natural habitat scarcity may impact willingness to pay to dive in natural habitats, participants were asked if they would be willing to pay more to dive on natural habitats, such as coral reefs, over artificial habitats if natural habitats become rarer. Sixty-eight percent of respondents asserted that they would be willing to pay more to dive on natural habitats than artificial if natural habitats become rarer, whilst 14 % responded that they would be unwilling to pay more. There was no statistically significant relationship between response to this question and diver habitat preference or if divers feel artificial habitats have a role in diverting divers from natural habitats.

4. Discussion

Our results supported our hypotheses that the majority of divers would have a preference for natural over artificial reef dive sites, and that shipwrecks would be rated higher than other types of artificial reef. Despite our sample population being predominantly European, the general pattern for similar percentages of divers exhibiting a preference for natural reefs (60.1–72 %) was represented across all regions. The only region for which this was not the case was the Middle East (33.3 %), but given there were so few respondents represented from this region ($n = 6$), we do not interpret this to mean anything. Furthermore, despite our sample population having other education, experience, age and gender biases, these results are in agreement with previous studies which found a preference for natural over artificial sites (Kirkbride-Smith et al., 2013; Oh et al., 2008; Pitcher and Seaman Jr, 2000; Şensurat-Genç et al., 2022), and shipwrecks over other artificial reefs (Ditton et al., 2002; Leeworthy et al., 2006; Shani et al., 2012). Respondents demonstrated both greater use of (78 %) and overall preference for (62 %) natural dive sites over artificial reefs. The photo perception results revealed that the majority of divers chose natural sites (coral reef, kelp forest) as their first choice of dive site (70 %) and

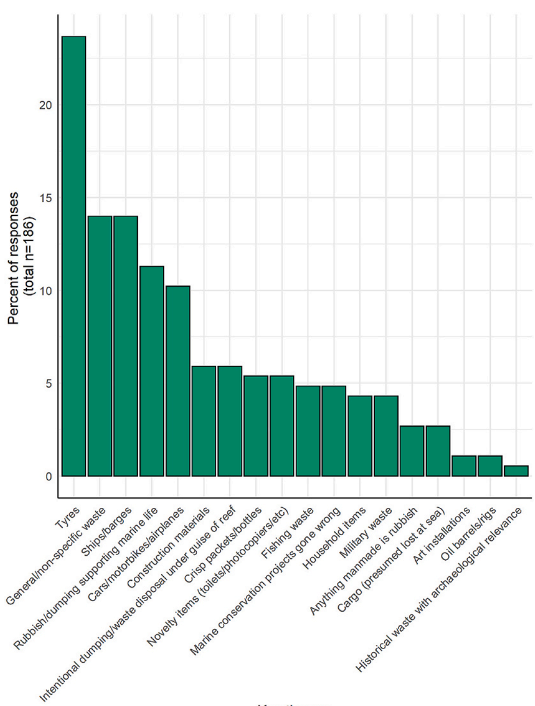

Fig. 7. Percentage of respondents ($n = 186$) mentioning key themes in response to the free text request for elaboration on the question 'Have you ever experienced a situation where an artificial habitat/reef could be considered an example of ocean waste/rubbish/trash disposal?'.

artificial reefs as their least favoured sites (also 70 %). Importantly, the indeterminate metal structure was by far the least attractive dive site with 60 % of divers selecting it as their least favoured and only 5 % selecting it as their 1st choice. Artificial reefs appear to be more attractive to both men and experienced divers compared to women and novice divers. In all instances, where divers exhibited a preference for natural sites, 'associated biodiversity/wildlife' and 'naturalness' dominated the selection criteria for this preference. For divers who prefer artificial reefs, the selection criteria were much more diverse, particularly for wrecks, with selection criteria spanning a general interest in wrecks, excitement/challenge, associated biodiversity, and historic interest. Whilst natural dive sites appeal to people predominantly for their inherent natural or biological characteristics, artificial reefs have the potential to offer a diverse range of dive opportunities and appeal to a diversity of divers to attract them away from and help to conserve natural dive sites.

Our results partially supported our hypothesis that the majority of people would not be aware of the importance of artificial reefs in diverting pressure away from natural sites. Whilst 84 % of survey participants responded with 'yes' when asked directly as part of a separate survey question "Do you think artificial habitats can be used to divert divers from natural habitats in order to preserve/protect natural habitats?", the Likert scale responses revealed that only 49 % of respondents perceived artificial reefs as being important or somewhat important in diverting divers away from natural habitats. This means that 51 % of respondents perceived artificial habitats to either be unimportant or neither unimportant nor important for diverting divers from natural habitats. Our results also revealed that more experienced divers and those who prefer natural reefs were less likely to perceive artificial reefs as important for diverting pressure from natural sites. Interestingly, of the 54 people who ranked the photo of the coral reef as their least favoured dive site, the top reason for this choice was 'declining/vulnerable habitat'. Whilst this could be because these divers have only dived in places where coral reefs are highly degraded, there is evidence that some people are not only aware of artificial reefs for diverting pressure from natural dive sites, but they appear to exhibit a preference to avoid coral reefs in order to protect them. Given that the vast majority of our respondents were both very experienced divers, plus highly educated, these results highlight the fact that there needs to be more done to educate divers about the potential importance of artificial habitats for diverting divers from natural reefs.

This study extends our knowledge of how diving can be made more sustainable in a world where ecotourism is increasing and natural reefs are experiencing ever more anthropogenic and environmental pressures. However, as with all self-selected surveys, it is not without its limitations. Whilst we had a very good response rate (679 respondents) to our survey, our respondents were predominantly European (73 %), highly educated, young (under 30) and experienced divers, which has implications for the inferences obtained in this study. The gender balance of divers surveyed here was also significantly different with more men (56 %) than women (43 %) represented. This differs to the global balance of newly PADI-certified divers which in 2018 comprised 38 % of female divers and 62 % male divers (PADI records sex rather than gender; PADI, 2020). Consequently, men may have been slightly underrepresented in our study, which may also influence the results.

4.1. *With great knowledge comes great responsibility*

Many artificial reefs may provide opportunities for conservation despite having been created for different purposes such as fishing or tourism. Through incorporating positive messaging, better education, and a wider range of opportunities for offsetting the environmental impacts of dive tourism, many divers are more likely to select sites that have less of an impact on the environment (Castelló y Tickell et al., 2019). Even the most experienced divers, who have minimal direct impact on dive sites and their inhabitants have myriad indirect impacts

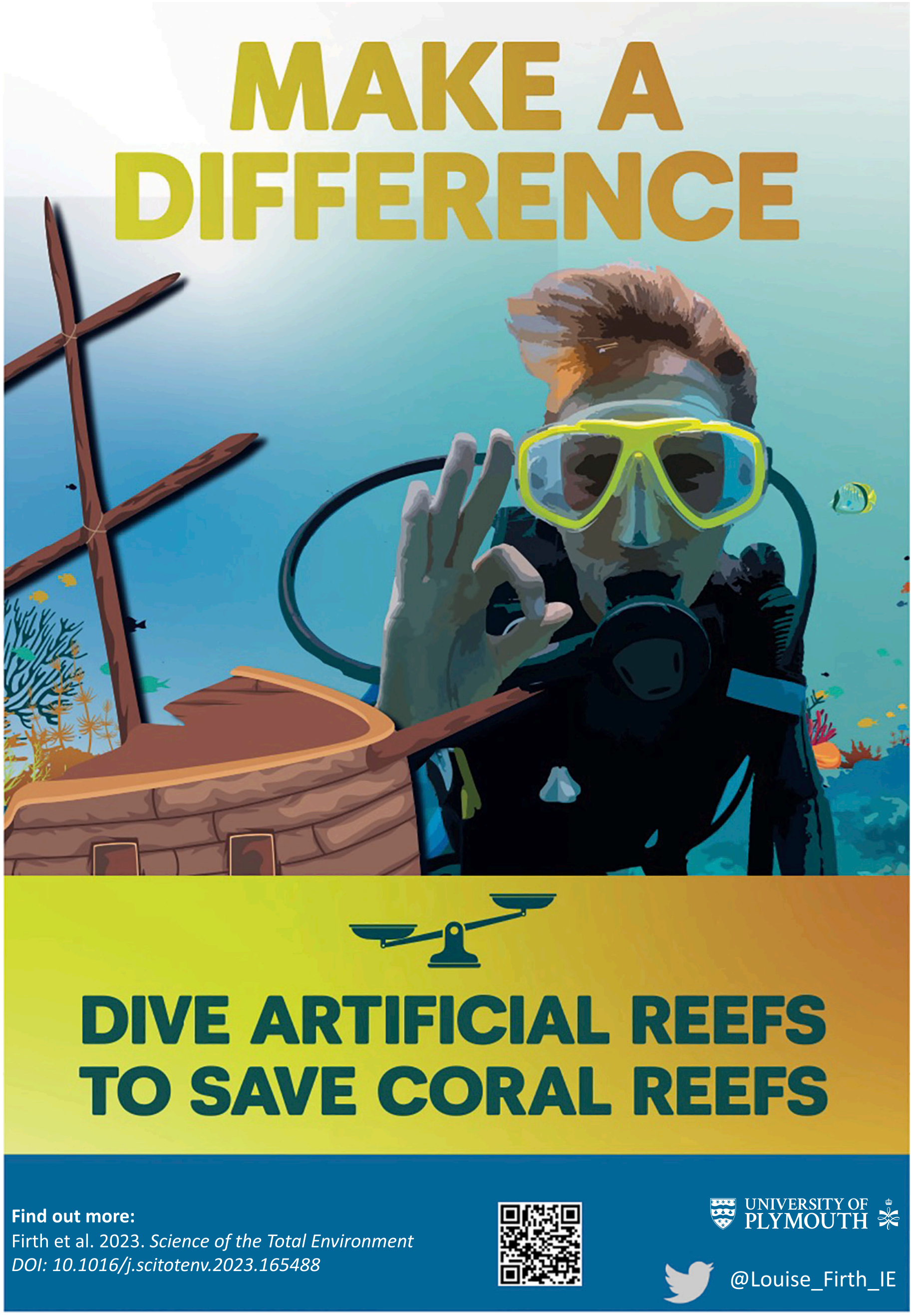

Fig. 8. Example of poster to put up in dive shop or resort to encourage divers to switch out a dive on a natural reef for an artificial reef.

on the local environment through noise and chemical pollution via boat transfers and dive boat anchoring (Ferrier-Pagès et al., 2021; Fine et al., 2019; Gil et al., 2015; McCloskey et al., 2023), coastal development, light and plastic pollution associated with dive resorts (Fine et al., 2019; Lamb et al., 2018) and possible overextraction of local fisheries (Fine et al., 2019). Indeed, dive tourism is responsible for the development and habitat alteration of many formerly 'pristine' coastal environments (Emang et al., 2016; Fabricius, 2005; Fine et al., 2019; Gil et al., 2015), and even the most environmentally aware divers will travel long distances by airplane to reach dive sites; all of these factors have wider reaching negative environmental impacts. Whilst some diving locations have protective measures in place such as Marine Protected Areas and restricted visitor numbers (e.g. Emang et al., 2016; Green and Donnelly, 2003; Peters and Hawkins, 2009), many locations are at serious risk of harm due to dive tourism (Hasler and Ott, 2008; Krieger and Chadwick, 2013; Worachananant et al., 2008). Based on this study, the authors suggest encouraging behavioural change through encouraging divers, where feasible, to switch out a proportion of their dives in vulnerable natural dive sites for dives on artificial reefs. If artificial reefs are not available in a particular location, divers could also be encouraged to opt for diving in locations less vulnerable to diving damage, or undertaking other environmental offsetting activities such as planting mangroves, coral restoration, litter picking or community engagement (sensu "voluntourism", Fletcher, 2019).

The target points for communicating such positive messaging should be dive training agencies, dive operators, dive clubs, magazines and locations where divers can acquire breathing gases and charter boats (Edney and Spennemann, 2014). The production of video messaging and poster production are two such options (Fig. 8 as an example of the kind of poster that could be displayed in dive shops or resorts). Through showing pre-dive videos to encourage responsible diving, studies have found that both snorkellers (Webler and Jakubowski, 2016) and divers (Giglio et al., 2017) had significantly less contact with coral reefs and cause less damage than if they did not watch the video. Global initiatives like the UNEP Green Fins Programme could be established or broadened to encompass the production of such media that could be widely distributed.

It is quite clear from this study that some materials such as tyres are likely to be considered by the majority of divers as dumped waste, rather than a stimulating marine habitat. In a conservation context, human activities have historically been considered undesirable; however, some have proposed an alternate framing of a two-way, multilayered, and dynamic relationship between people and nature (Mace, 2014). Results from our survey found that the combination of humans and nature (i.e., a social-ecological system) at artificial sites appealed to divers. As a consequence of shifting baseline syndrome (Pauly, 1995), younger divers are likely to have grown up in a more impacted world and thus have a lowered expectation of the natural environment. Consequently, they are more likely to be accepting of artificial reefs as dive sites than people who grew up prior to the impacts of mass dive tourism. Edney and Spennemann (2014) refer to the latter as 'future migrants' (akin to digital migrants) who have grown up in a time prior to the culture of continual change but who understand the need to and are capable of adapting to new circumstances. Whilst some people will just dive when and where they like with no care about the impacts or the future, it is the future migrants that are the prime 'market' for direct and indirect continued education programmes (Edney and Spennemann, 2014).

Protection of reefs in the future must come from a range of mechanisms, not least of which is meaningful change within the diving community itself. In this study, only 49 % of respondents indicated they felt artificial dive sites were important for diverting pressure from natural reefs. Similarly, only a small minority explicitly identified a preference for artificial reefs precisely for this reason. Cleary, there is a need for greater awareness about the potential role of artificial reefs in diverting pressure from natural habitats. This suggests a route through which divers' beliefs and attitudes could be further explored to increase artificial reef use and mitigate harm to natural sites. Campaigns must consider the audience they are intended to influence and understand the core normative opinions (i.e., beliefs commonly held by a community) on which actions are based. A diver's interest in diving artificial reefs, in particular shipwrecks, is likely to be heavily affected by the historical background of the vessel and the quality of the diving experience. For example, making high quality historical information available about a shipwreck and diagrams of the layout, suggested tours, as well as safe access to interior parts of the vessel, may increase the likelihood of the diver selecting the artificial reef site.

Using methods such as the Theory of Planned Behaviour via videos (see Webler and Jakubowski, 2016; Giglio et al., 2017), posters and articles (online and in magazines) may provide an avenue to improving communication with divers and prospective divers. The Theory of Planned Behaviour (Ajzen, 1991) predicts an individual's intention to engage in a specific behaviour, which depends on both the target's motivation and ability to undertake said behaviour (Ajzen, 2020). Firstly, the behaviour must be defined, for example: diving (action) a specific artificial reef (target) in the next year or beyond (timeframe). The stronger the intention and understanding (e.g., awareness of environmental threats, reduced environmental impact by diving the artificial reef), the more likely it is that the individual will undertake that action. If this is combined with positive social norms and perceptions which support the action, it is also more likely to occur. This means relaying to divers' ideas and actions already held within the community, rather than implementing an 'outsider' opinion and campaign. Understanding the dynamic system by which divers make decisions will enable encouragement of positive change and provision of targeted information relevant to the underlying motivations. Often knowledge alone is not sufficient to drive change, because other factors influence actions such as behavioural norms or valence of attitudes (positive or negative) (Nolan et al., 2008). Behavioural Prioritization could be used in tandem with Theory of Planned Behaviour. Behavioural Prioritization is intended to identify the behaviours which should be advocated to the target audience. This requires consultation with that group before (e.g. via a pre-dive video or poster), rather than after, a campaign is developed, to resolve conflicts between the information provider (e.g. dive operator) and the recipient (the diver) (Schultz, 2011). In an age when most divers have smart phones, QR codes and links to videos and information produced according to these considerations can be easily accessed from a range of different digital and physical media. Realistically, however, the behaviour of opting for an artificial reef dive over a natural reef dive may not be palatable to some divers. Our study represents a valuable first step, by characterising opinions of divers, including those attitudes associated with the use of artificial reefs, and providing avenues through which more in-depth discussions could take place. Ultimately, we hope that this study will provide a platform for discussion to inspire a diver-led campaign to increased uptake of artificial reef use, resulting in reduced impacts on natural reefs.

4.2. Sustainable development of artificial reefs: avoid, minimize, restore, offset

The results of this research can be applied in the process of designing, manufacturing, deploying, and maintaining artificial reefs as part of sustainable dive tourism and ecosystem management. Despite the good intentions involved in diverting pressure away from vulnerable natural dive sites, effective planning and management are required to prevent potential negative impacts (Burt et al., 2021; Nelson, 1994; Shani et al., 2012; Wearing and Neil, 2009). We suggest a zoning strategy following the guiding principles of the Mitigation Hierarchy (Ekstrom et al., 2015) to achieve this. If a site has been identified as vulnerable to damage from dive tourism, the site should be protected, and all damaging activities ceased (step 1 – avoid). The remaining areas should be zoned to concentrate divers and boats into relatively small areas that are characterised by less vulnerable natural sites and modified areas. In less vulnerable natural sites, the numbers of boats, divers, and snorkellers should be restricted, and diver behaviour (both visitors and guides) monitored, policed and actioned upon (step 2 – minimize). For instance, the results from a study of diver impacts on coral reefs by Cerutti-Pereyra et al. (2022) led to the implementation of a warning and penalization system for tour guides and permit holders. Furthermore, fishing, and other extractive industries should also be prohibited and enforced in these areas. Otherwise, not only is there a risk to diver safety, but this obviously has a negative impact on marine life that divers are there to see. In modified and degraded sites efforts should be made to restore and rehabilitate natural reefs (step 3 – restore). Finally, in highly modified or degraded areas ONLY, consider sinking a shipwreck or constructing an artificial reef to provide valuable habitat for marine life but simultaneously functioning as a diver training site and to divert pressure away from natural sites (step 4 – offset).

In order to reduce diver impact on natural dive sites, artificial reefs need to be reframed as social–ecological systems, moving beyond comparisons with natural coral or rocky reefs to consider their roles as ecosystems in their own right (Castelló y Tickell et al., 2019). Additionally, before the installation of artificial reefs, serious consideration should be given to the design and the materials used, as this will greatly influence divers' perceptions of the value of the artificial reef. Our study has demonstrated that 25 % of divers stated their preferred dive site was a shipwreck. This would suggest that in regions without existing accessible shipwrecks creating artificial reefs from high quality, well prepared scuttled vessels may be a good option in reducing impacts on natural reefs. In the Red Sea for example, liveaboard dive boat itineraries in some areas include high numbers of wreck dives. Whilst perceptions of what is desirable may vary from location to location, the findings from this study and many others suggest that the associated biodiversity (particularly fish species, Milton, 1989; Stanley and Wilson, 1989) is of critical importance. Given that divers vary in terms of what they are attracted to, artificial reefs that attract a broad range of macro life as well as fishes, turtles and sharks are likely to satisfy the greatest number of divers. If artificial reefs or wrecks do support unique species that are hard to see elsewhere, this should be publicised to relieve pressure on natural reefs. Sunken naval ships of historic importance are particularly popular (Ditton et al., 2002; Kirkbride-Smith et al., 2013; Shani et al., 2012; Stolk et al., 2005), especially if they are penetrable (Edney, 2012). If artificial reefs are placed in sedimentary habitats that are not popular with divers, the introduction of novel hard substrata is likely to encourage the colonization of species assemblages that are likely to be popular with divers. It should be noted however, that the novel species assemblages may still differ from those on natural hard substrata (Burt et al., 2013; Hiscock et al., 2010; Firth et al., 2013). Even if a wreck is not particularly suitable for larger fish, holes could be created in the hull to attract them. Similarly, artificial reefs that are deployed as underwater museums or exhibits have strong potential to attract a wide range of divers to the site (Manglis et al., 2020; Picken, 2016). Belhassen et al. (2017) suggest that special attention should be given to a design that accommodates various diver activities, including touching bare areas, an engaging design and a thoughtful location, all of which can ensure exciting diving experiences at all levels, as well as sufficient light for photography. Furthermore, given the rise of photo-based social media (e.g., Leitão et al., 2022), features that are particularly photogenic, quirky, or interesting are likely to be popular with influencers and users alike.

New artificial reefs should be designed to provide a stimulating environment for inexperienced divers under training (particularly initial certification), and for divers undertaking photography, particularly if the latter are also inexperienced divers, as both of these groups have been shown to damage corals to a disproportionate degree (Walters and Samways, 2001). Dive instructors usually control where inexperienced divers go. Local policies should explain why new divers are being taken to an artificial reef, as the divers are likely to be more accepting of this option, even if the diver wants to visit a natural site. Importantly, we suggest that all artificial reefs have some sort of educational component associated with them – particularly linked to environmental issues. This could be in the form of a dive trail with points of interest, with information (such as a video) given at the pre-dive briefing, or there could be interpretive boards underwater explaining the site's purpose. Any new artificial reefs should involve consultation with the local resident and visiting dive community. Dive operators should also offer ethical and sustainable local opportunities for customers to offset their environmental impacts (including carbon)(step 4 – offset).

Whilst some proponents suggest that artificial reefs are prudent recycling projects (Collins et al., 2001; Kong et al., 2022), many artificial reefs are merely disguised ocean dumping (Chou, 1997; Firth et al., 2020; Sherman and Spieler, 2006), either inadvertently if the reef fails to support much life, or through the deliberate disposal of waste material at sea under the guise of 'reef creation' (e.g., The Osborne (tyre) Reef, Florida). Scrap materials placed as artificial reefs may leach chemical pollutants (Gaylarde et al., 2021), or they may move during storms and impact natural habitats (Morley et al., 2008). Furthermore, artificial reefs attract both fish and fishers and can increase catch rates in the short term but contribute to regional overfishing in the long term (Watanuki and Gonzales, 2006; Simon et al., 2011). Artificial reefs can also support and facilitate the spread of invasive species (Adams et al., 2014; Airoldi et al., 2015; Gauff et al., 2023). Just like eco-engineering should not be used as a Trojan horse for facilitating harmful development (Firth et al., 2020), artificial reefs, should not be used as Trojan horses for ocean dumping.

5. Conclusions

Habitat alteration and biodiversity loss are increasing apace with the global human population. Dive tourism is one of the fastest-growing types of ecotourism (Doiron and Weissenberger, 2014; Gallagher and Hammerschlag, 2011; Giglio et al., 2020), with many people rushing to see vulnerable locations (e.g. the Great Barrier Reef) before they disappear – so called 'extinction tourism' (Fletcher, 2019). Whether people like it or not, artificial reefs are becoming more prevalent in the marine environment as part of sustainable development (Evans et al., 2021; O'Shaughnessy et al., 2020), fisheries enhancement and to divert pressure from dive tourism away from natural locations. Now is the time to change perceptions of artificial reefs and consider well designed structures as a critical part of sustainable tourism. Decision-makers should implement local policies which would require dive shops to use artificial reefs (where available) for divers with fewer than ten or twenty dives. We urge divers to switch out a proportion of their dives on natural reefs for artificial reefs, or to get involved in some local offsetting or conservation activity. Managers of artificial reefs can employ eco-engineering principles to design better structures to encourage better marine life and make them more attractive and interesting to divers. Dive operators can promote the use of local artificial reefs by educating visitors about their use in diverting pressure from natural reefs and their unique charms – be it historical interest, special residents, or best photo opportunities. Global initiatives such as UNEP Green Fins could develop high-quality visual messaging (e.g., videos, posters) that is standardized and appealing to divers, and easy to deliver by dive providers, magazines and websites. In the current era of the biodiversity crisis and the United Nations Decade of Action for Sustainable Development and Restoration, now is the time for divers to reconsider their behaviour and choices. Just like many people are opting to reduce their environmental impact by eating less animal protein and reducing their reliance on fossil fuels, members of the global diving community can play their part by reducing their impacts on fragile habitats.

CRediT authorship contribution statement

Louise B. Firth: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Mark Farnworth:** Writing – original draft, Writing – review & editing. **Keiron P.P. Fraser:** Writing – original draft, Writing – review & editing. **Abigail McQuatters-Gollop:** Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Following acceptance, data will be made available through Temperate Reef base - https://temperatereefbase.imas.utas.edu.au/static/landing.html.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2023.165488.

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