

Using drawings as a tool to monitor children's understanding of coral reef biodiversity

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ABSTRACT

Coral reefs are vital ecosystems that support biodiversity and human livelihoods, particularly in Pacific Island communities. While scientific and policy-based approaches to reef conservation are essential, engaging local populations (especially children) can enhance long-term environmental stewardship. Children's drawings can reveal their mental representations of the environment and their perceptions of ecosystem health. This study explores how children aged 9 to 16 in Bora Bora (South Pacific Ocean, French Polynesia) perceive coral reef biodiversity, human activities, and environmental threats through their drawings. A total of 23 groups of children participated, producing drawings of the lagoon environment. These were analyzed both quantitatively (e.g., taxa diversity, pollution items, human presence) and qualitatively (e.g., perceived environmental health). Results show that fish, corals, and algae were the most frequently depicted elements, and pollution (particularly waste) was commonly identified. The drawings also highlighted the activities children associate with the lagoon. Age-related differences may suggest developmental changes in ecological awareness, with older children producing more accurate depictions of marine life. Children's strong knowledge of the lagoon could reflect the numerous ecological education programs implemented on the island (e.g., the Marine Educational Area and Bora Biodiv project). These findings demonstrate that children's drawings could be valuable tools for assessing environmental perceptions and for designing targeted conservation education. This approach also contributes to establishing a long-term, community-based coral reef monitoring program in Bora Bora, incorporating the analysis of children's drawings every two years. This initiative aligns with the vision of UN Sustainable Development Goal 4 (SDG 4), which aims to empower children to "transform our world" toward sustainability by 2030.

1. Introduction

Coral reefs, often referred to as the "rainforests of the sea", play a crucial role in marine biodiversity and overall ocean health. Hosting more than 4000 species of fish, coral reefs support approximately 25% of the world's fish biodiversity and contribute around 10% of global fisheries (Spalding et al., 2001). However, coral reefs are increasingly

threatened by both natural and human-induced stressors, including hurricane damage, pesticide runoff, ocean acidification, and temperature-driven bleaching events (Hoegh-Guldberg et al., 2007; Hughes et al., 2017; Lecchini et al., 2020; Juncker et al., 2026). Despite these threats, coral reefs provide vital ecosystem services for human communities: they protect coastlines from erosion and generate food and income through fishing and tourism (Costanza et al., 2014;

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Hoegh-Guldberg et al., 2015; Wilkinson and Salvat, 2012). Their degradation could have severe economic and social consequences, particularly for Pacific Island nations whose economies heavily depend on reef-related resources (Almany et al., 2010; Bambridge, 2019; Gatouillat et al., 2024; Minier et al., 2023b). Various management strategies, including mitigation, protection, restoration, and adaptation, have been implemented to address climate change and local anthropogenic impacts (Comte and Pendleton, 2018; Krimou et al., 2024). However, while science-based policies are essential, it is often local communities who lead conservation efforts (Almany et al., 2010; Dunlap et al., 2021). This is especially true in the Pacific Islands, where community-based management is common, and resource access is governed by cultural norms, local history, and political structures (Bambridge, 2019; Lecchini et al., 2021). In these small island settings, public engagement and local involvement are not only more feasible but also critical for long-term conservation success.

Among the many communication tools available to reef management programs (e.g., TV, radio, print media, conferences, and social media), art stands out as a powerful means of raising awareness about environmental issues. Art can illustrate the threats facing coral reefs, such as climate change, pollution, and overfishing, in emotionally compelling and accessible ways (Curtis, 2011; Flowers et al., 2015). It fosters emotional connection and can make complex ecosystems like coral reefs more relatable and understandable across generations, from children to grandparents (Marks et al., 2017; Roosen et al., 2018). Art is also a valuable educational tool. It uniquely connects children's minds with their hands, hearts, and natural surroundings (Bartram, 2005). Encouraging children to express their environmental understanding through drawings can provide insights for researchers (Carrière et al., 2017; Chabanet et al., 2018; Fache et al., 2022). Education in childhood is key to ensuring sustainable, long-term conservation efforts (Fernández Tarrío et al., 2010). Children often have their own knowledge systems and cultural expressions, collectively referred to as “children's culture”, which are distinct from those of adults (Corsaro, 2012; Rennie and Jarvis, 1995). Thus, their drawings can reveal aspects of the environment that are frequently overlooked by adults, offering valuable insights for research (i.e., unique point of view). Therefore, the challenge for the researchers becomes gaining access to children's perceptions of their environment.

Children's drawings about their perceptions of the environment offer several advantages (Carrière et al., 2017; Fache et al., 2022; Özsoy and Ahi, 2014; Profice, 2018; Profice et al., 2015; Snaddon et al., 2008). Drawing enables children to express their perceptions and emotions about their surroundings in ways that may be difficult to articulate verbally (i.e., creative expression). Drawings can also illustrate how children interact with their environment, or how they observe others, such as their parents, engaging with it (i.e., understanding interactions). Involving children in environmental drawing activities can increase their awareness of ecological issues and encourage them to reflect on the importance of protecting their natural surroundings, especially in Pacific Islands, where coral reef conservation is crucial to the local economy and well-being of many communities (i.e., awareness-raising and education). To sum up, drawings can serve two distinct purposes: (1) expressing emotions or autonomous perceptions, and (2) communicating environmental issues. In the first case, the goal is to elicit children's personal expressions about nature; in the second, it is to educate and raise awareness about environmental issues. The outcome in the first case is a unique, individual expression, whereas in the second, the drawing reflects issues that may have been explained in school. In both cases, drawings are a valuable and accessible communication tool, providing a starting point for discussions with children about environmental topics and helping them develop a deeper understanding of the issues at stake (Howlett and Turner, 2023; Morón-Monge et al., 2021; Moula et al., 2021).

The use of children's drawings to assess South Pacific coastal ecosystems is still in its infancy (e.g., Fache et al., 2022). We still lack a clear

understanding of how age influences drawings and how to direct children's attention toward the specific part of the ecosystem under investigation. In our study, we used children's drawings to assess their awareness of biodiversity, human activities, and both global and local stressors affecting coral reefs. Children often have a tendency to depict what they see, experience, or imagine through drawing (Stein et al., 2001)—a tendency that may be useful for researchers to use, especially in the South Pacific, where children commonly spend time in lagoons, playing with friends after school or fishing with their families on weekends (Sabine et al., 2021). Our research, conducted in Bora Bora (South Pacific), invited children aged 9 to 16 to draw their perceptions of marine biodiversity and human use of coral reefs. The drawings, obtained in 2024 from two primary schools and three levels of junior high school, help to improve the effectiveness of future conservation messaging. Furthermore, this study lays the groundwork for the first long-term coral reef monitoring program based on children's drawings. We hypothesized that both the quantitative representation of the lagoon (e.g., the number or size of items) and the qualitative assessment of the perceived health of the lagoon environment may vary across age classes.

2. Material & methods

2.1. Information concerning the study site

Bora Bora is a 38 km² tropical island in French Polynesia, located in the South Pacific Ocean, with a population of over 10,000 inhabitants (Garanger and Robineau, 1977). It is a volcanic island renowned as a major international tourist destination, particularly for its marine-focused luxury resorts. Its lagoon hosts numerous water-based activities, both for recreation and subsistence. Recreational activities are diverse and may be unrelated to marine fauna (e.g., jet skiing) or directly connected to it (e.g., shark and ray watching).

The island is surrounded by coral reefs covering approximately 70 km². Marine biodiversity in the area is well documented, notably through the long-term *Reef Check* monitoring program (Lecchini et al., 2021), and the Bora Biodiv project, which is a collaboration between researchers, *Polynésienne des Eaux*, the association *Vai Ma Noa Bora Bora*, and the Bora Bora town council to describe and monitor the lagoon's biodiversity in a sustainable way. In addition, the island hosts extensive research in biodiversity and bioacoustics (Krimou et al., 2023; Lecchini et al., 2026; Minier et al., 2023a, 2023c; Raick, 2026; Raick et al., 2023, 2024, Raick et al., 2026), which is reflected in several educational chapters (Bonfanti, 2024; Métian et al., 2024; Poupin, 2024; Raick, 2024a, 2024b; Salvat, 2024; Thiry et al., 2024). The island is also home to a Marine Educational Area (MEA), which consists of a portion of the lagoon monitored by children with the support of their teachers and researchers. This is further supported by conferences, exhibitions, and in-class interventions carried out by researchers from local research centers and universities.

The island hosts three primary schools (children aged 6–10 years) and one junior high school (children aged 11–18 years). All schools on the islands were included in this study. Since the first year of junior high school, children start to learn about coral reef biology, ecology, and conservation as part of the official French Polynesian education program. To assess children's understanding and perceptions of coral reefs at different developmental stages, we invited them to express their vision through drawings as children's drawings are a recognized tool for evaluating cognitive, emotional, and social development, particularly in relation to their environment. In this study, we analyzed how children's representations of coral reefs evolved between the ages of 9 and 16.

2.2. Experimental design

Between September and December 2024, children from two primary schools (ages 9–10) and from three grade levels in the only junior high school on the island participated in the study: two classes of 11–12-year-

olds, two classes of 13–14-year-olds, and two classes of 15–16-year-olds. We did not group children by age, but by class level (every other class), and translated the French education system class names into more internationally accessible terms by providing the corresponding age ranges. Prior to the sessions, CRILOBE researchers (S.K. & M.F.) met with school principals and teachers to obtain the necessary permissions. During each session, the researchers entered the classrooms without prior notice to the children. The purpose of the visit was explained within 5 min. Each class was then divided into three relatively balanced groups of boys and girls. At this stage, it is important to acknowledge the potential bias in how the groups were organized (for example, having children with similar hobbies within the same group) as well as differences in the degree of collaboration, with some groups working more collectively than others.

A total of 23 children groups participated in the study: 5 groups for the 9–10 age group, and 6 groups each for the 11–12, 13–14, and 15–16 age groups. Each group received an A3-sized sheet (297 × 420 mm) featuring an outline drawing of Bora Bora Island and its lagoon (Fig. 1), along with colored pencils. The children were given 30 min to illustrate how they currently perceive the lagoon, including local marine biodiversity, human uses, reef health, and potential pollution sources. It is

important to recognize that language use and comprehension vary between children aged 9 and 16, and that they may interpret the instructions differently. To avoid external influence, children were not allowed to use books, smartphones, or images. Researchers and teachers did not intervene during the drawing process, but children were encouraged to discuss their ideas within their groups. After the drawing period, researchers reviewed the illustrations with the children and, when necessary, asked for clarification on elements that were unclear. This draw and explain technique is a method used to understand children's ideas and how concepts are structured (McWhirter et al., 2000). The 23 drawings were then photocopied and independently analyzed by three researchers.

2.3. Analysis of drawings

Children's drawings were analyzed using both quantitative and qualitative methods. This method was not shared with the children. For the quantitative analysis, three distinct types of assessments were conducted. The first involved counting natural items represented in the drawings. This included recording (1) the number of different taxa, as well as the number of (2) teleost fish, (3) rays, (4) sharks, (5) turtles, (6)

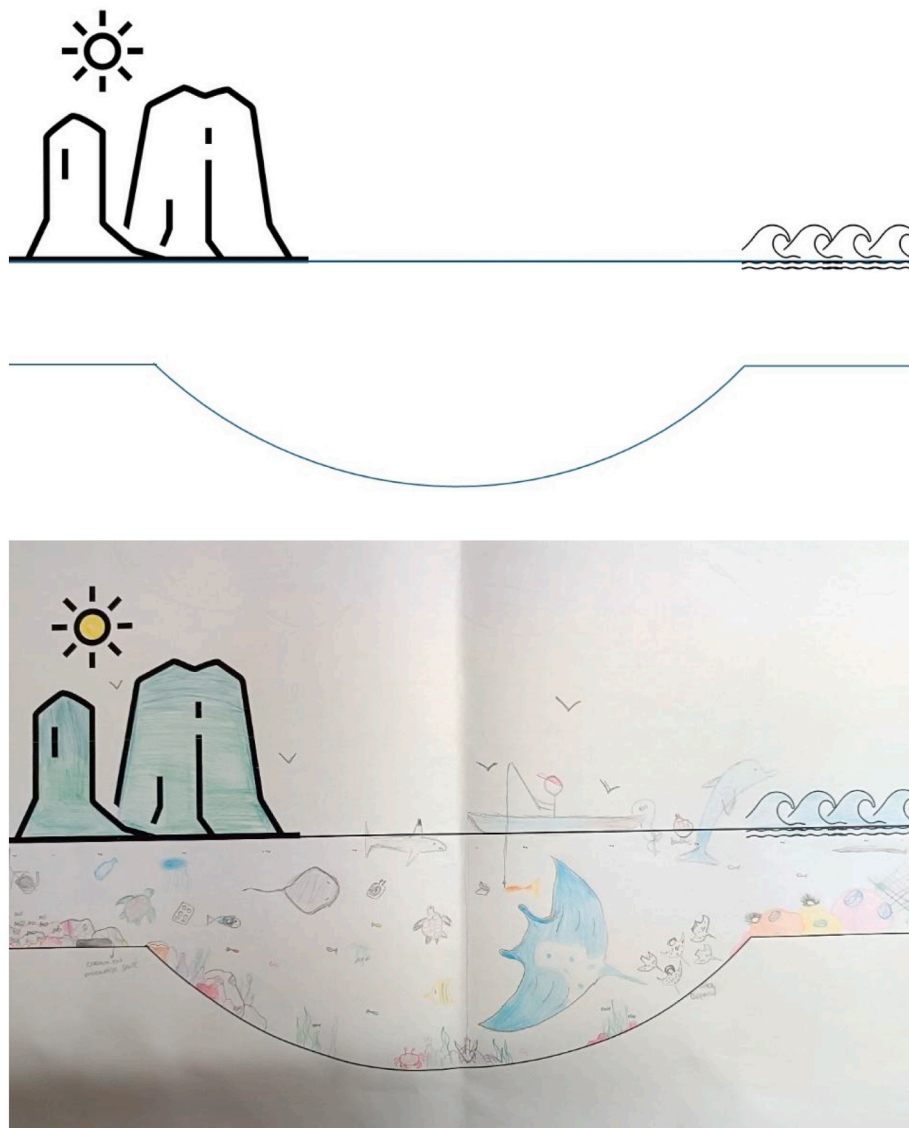


Fig. 1. Blank initial template showing the island and lagoon of Bora Bora provided to all participants (top) and example of a drawing by children aged 15–16 years (bottom). Children were asked to represent marine biodiversity, human activities, and environmental conditions within the predefined layout.

giant clams, (7) corals, (8) algae, (9) sea urchins, (10) octopuses, (11) crabs, and (12) sea stars. The total number of natural items was calculated as (13) the sum of these eleven categories. Birds and terrestrial animals were excluded from the analysis because we chose to focus exclusively on aquatic animals found in the lagoon. The size of marine organisms (teleost fish, rays, sharks, giant clams, and turtles) was also measured.

The second quantitative category focused on negative items, including representations of (14) plastic pollution, (15) coral damage (e.g., anchor on coral), (16) terrigenous pollution, and (17) general trash. These four elements were summed to obtain (18) the total number of negative items in each drawing.

Third, human activities depicted in the drawings were recorded, including (19) gun fishing, (20) net fishing, (21) angling, (22) the presence of modern leisure boats, (23) traditional pirogue boats, and (24) freediving. These six activities were also summed up to provide (25) an overall count of human-related uses of the lagoon. Additionally, any representations of human presence were noted and categorized as (26) fisher people, (27) scientists, (28) other men, and (29) other women. Regarding the last two categories (men and women), we acknowledge that the external appearance such as clothes or hair length in a drawing does not reliably indicate the gender of the person depicted. Furthermore, we do not aim to make assumptions or statements about gender identity, our categorization is therefore a simplification, used solely for the purposes of analysis within the constraints of this study.

The qualitative analysis aimed to assess perceived environmental quality of the lagoon environment as represented in participants' drawings. Each drawing was independently evaluated by three researchers with expertise in ecology (D.L., S.K. & M.F.), who classified it as either "rather positive" (indicative of a healthy or intact ecosystem) or "rather negative" (indicative of environmental degradation). Classification was based on a shared evaluation framework considering visual indicators such as perceived pollution, presence of coral and algae, and extent of human activity. To ensure consistency in interpretation, evaluators used an agreed coding guideline developed prior to analysis. Each classification was converted into a binary score (−1 for "rather negative", +1 for "rather positive"). (30) A composite environmental quality index was then calculated for each drawing as the mean of the three independent ratings, resulting in a continuous score ranging from −1 (consistently perceived as degraded) to +1 (consistently perceived as healthy). This approach allows partial agreement between evaluators to be reflected in intermediate values, providing a more nuanced representation of perceived environmental quality.

2.4. Statistical analysis

To visualize and compare the data, violin plots were used to present both the quantitative counts and the qualitative environmental quality index. Comparisons were made across four age groups: 9–10, 11–12, 13–14, and 15–16 years old. Given the relatively small sample size for each group, this approach was favored over complex modeling. Statistical analyses began with graphical assessments of normality and Levene's tests for homogeneity of variances. Based on these results, one of three statistical methods was applied on each of the 30 previously described features: ANOVA when assumptions of normality and equal variances were met; Welch's ANOVA when variances were unequal; and Kruskal–Wallis tests for non-parametric data. Where appropriate, *post-hoc* comparisons were carried out using Games–Howell tests following Welch's ANOVA and Dunn's tests after Kruskal–Wallis tests. In these cases, *p*-values were adjusted using the Benjamini–Hochberg procedure to control for false discovery rates. None of the ANOVAs yielded significant differences, and as such, no *post-hoc* tests were conducted for those comparisons. The alpha level was set at 0.05. Values in the general observations section are presented as mean ± standard deviation (minimum – maximum). All statistical analyses were performed using R version 4.3.0.

3. Results

3.1. General observation of a typical drawing

The lagoon of Bora Bora, as depicted in children's drawings, featured an average of 9.07 ± 2.26 (range: 5–13) different taxa. The most abundant taxa included fish (13.09 ± 9.85 , range: 1–41), corals (7.88 ± 5.68 , range: 2–24), and algae (4.90 ± 4.76 , range: 0–17). Larger animals commonly illustrated included sharks (52.39 ± 14.88 mm, range: 31–78.67), rays (48.61 ± 17.66 mm, range: 23–80), and turtles (29.30 ± 10.96 mm, range: 12–50). The taxa most frequently illustrated and the relative sizes of animals represented are consistent with their presence in the real environment. Pollution appeared in many, though not all, of the drawings, with an average of 6.38 ± 6.30 items (range: 0–26). This is expected, as the instructions specifically asked about potential sources of pollution. This included approximately 4.00 ± 3.78 (range: 0–14.67) pieces of trash and 2.16 ± 2.46 (range: 0–9.67) plastic pollutants. Other forms of pollution were less commonly represented. Lastly, Humans were also depicted in the drawings. Fisher people were more frequently represented (1.07 ± 0.94 , range: 0–3) than individuals in other human categories (0.10 ± 0.42 , range: 0–2). Considering the limitations outlined in the Methods section on external appearance of men and women, more men than women were depicted (0.75 ± 1.64 , range: 0–6 vs. 0.12 ± 0.31 , range: 0–1). Leisure boards were far more frequently illustrated than traditional boats (0.84 ± 0.97 , range: 0–4.67 vs. 0.029 ± 0.14 , range: 0–0.67), which aligns with the current reality in Bora Bora. Fishing activities were illustrated in the following order of frequency: angling (0.81 ± 0.70 , range: 0–3), net fishing (0.36 ± 0.52 , range: 0–1.67), and spearfishing (0.26 ± 0.41 , range: 0–1).

3.2. Combining drawings

The previous section illustrated the overall depiction of the Bora Bora lagoon by children, based on the average values from all drawings. In addition to counting the number of items (e.g., rays) in a drawing, another valuable metric is the number of drawings in which each item appears (regardless of quantity), which is partially reflected in the standard deviation reported earlier. Only corals and fish were represented in all drawings. Turtles appeared in 87% of the drawings, followed by rays and algae (83%), and then sharks, giant clams, and sea urchins (74%). Trash was present in most drawings (83%), followed by plastic items (65%). Fisher people were represented in most drawings (65%), whereas other male figures appeared in 30% and female figures in only 13% of the drawings. As observed previously, angling was more common than net fishing and spearfishing, with respective frequencies of 70%, 39%, and 35%. Modern leisure boats were depicted in 74% of the drawings, whereas the traditional pirogue appeared in only one drawing (4%).

3.3. Comparison across age groups

The first notable result concerns the variation in the number of specific item categories depicted across age groups. Indeed, as children grew older, certain elements became more or less frequently represented. For instance, the number of sea urchins drawn increased with age, whereas octopuses and sea stars appeared less frequently in older children's drawings. Humpback whales were depicted twice by children aged 9–10, once by children aged 11–12 and 13–14, and were completely absent in the drawings of the 15–16 age group. This trend may reflect a developmental increase in ecological realism, where older children demonstrate greater understanding of the typical composition of the lagoon environment. For example, some species (such as octopuses) are cryptic and therefore harder to observe, while others (like whales) are not generally present within the lagoon itself, but rather in offshore waters or bays. However, alternative hypotheses can be considered, for example, sea urchins may have been more represented

because they are eaten by local populations. Additionally, sound waves were visible in one drawing, indicating that non-visible elements can be depicted, thereby challenging the previous hypothesis regarding the absence of cryptic animals. No variation in the size of marine organisms (teleost fish, rays, sharks, giant clams, and turtles) was found across age groups (Anovas; fish: $F = 1.81$, $p = 0.18$; sharks: $F = 2.44$, $p = 0.096$; giant clams: $F = 2.61$, $p = 0.14$; turtles: $F = 2.00$, $p = 0.15$).

Although the accuracy of animal representation was not specifically assessed through our methodology, notable differences in fidelity were observed across age groups. While some children used symbolic or generic representations of marine life (e.g., simple, schematic fish shapes, Fig. 2D), others drew animals in sufficient detail to allow species-level identification. Examples include accurate depictions of *Coryphaena hippurus* (Fig. 2E) and *Carcharhinus melanopterus*. A particularly detailed example is the drawing of *Naso unicornis* (family Acanthuridae) by a 15–16-year-old child (Fig. 2F), featuring its distinctive horn (absent in *Naso lituratus*) and extended tips on the upper and lower parts of the caudal fin (not present in *Naso brevirostris*).

A second important result involves a pattern of high item counts among 9–10-year-old children, followed by a noticeable decline at ages 11–12 (coinciding with the transition from primary to secondary school in the French educational system) and a steady increase again through

ages 13–14 and 15–16. This pattern seems to be observed across several features, including total human activities, modern leisure boats, total negative items, plastic pollution, trash, total natural items, fish, rays, and corals (Figs. 3–7). Statistically, children aged 11–12 depicted significantly fewer modern leisure boats compared to all other age groups (Kruskal–Wallis test, $\chi^2 = 7.5$, $p = 0.013$; Dunn's post hoc test, $Z = -2.45$, -2.89 , -2.58 ; adjusted $p = 0.029$, 0.023 , and 0.0299 ; Tables 1 and 2). They also drew fewer trash-related items than children in the 9–10 and 15–16 groups (Kruskal–Wallis test, $\chi^2 = 9.94$, $p = 0.019$; Dunn's test, $Z = -2.88$ and -2.43 , $p = 0.024$ and 0.045 , respectively) and fewer plastic pollution items compared to the 15–16 group (Welch's ANOVA, $F = 4.25$, $p = 0.038$; Games–Howell post hoc test, $T = 3.35$, $p = 0.03$) (see Table 3).

Interestingly, the qualitative environmental quality index showed an opposite pattern. It peaked at age 11–12 (indicating higher perceived environmental quality), followed by decreasing values across the 9–10, 13–14, and 15–16 age groups. The differences were statistically significant between the 11–12 group and both the 13–14 and 15–16 groups (Kruskal–Wallis test, $\chi^2 = 10.15$, $p = 0.017$; Dunn's test, $Z = 2.65$ and 2.69 , adjusted $p = 0.024$ and 0.042 , respectively; Tables 1 and 2). This result aligns with the patterns observed in total negative items, plastic pollution, trash, and number of leisure boats. In addition to the negative categories explicitly assessed in our methodology, some drawings illustrated other forms of human impact not included in the quantified variables. These included activities such as illegal turtle hunting (Fig. 2A) and turtles entangled in fishing nets (Fig. 2B). Although these depictions suggest potential anthropogenic threats to marine life, it is not possible to determine whether the children intended to portray these as deliberate or accidental events based solely on the drawings.

4. Discussion

Drawing-based evaluation methods could serve as an excellent tool for gauging environmental literacy and perception of the knowledge of biodiversity (Gunstone and White, 2000; Howlett and Turner, 2023). Despite the growing importance of biodiversity conservation efforts in education (U.N., 2015) there is still limited empirical research on children's views about coral reef health (Fache et al., 2022). Our study, conducted with children from Bora Bora aged 9 to 16, highlighted the value of assessing children's drawings to obtain perception of lagoon's biodiversity and uses in Bora Bora. In addition to assess children perception, it could be used to assess their learning about conservation (bottom/up versus top/down learning). It emerges as a potential complementary tool to traditional research methods, offering valuable insights that could help policymakers and educators refine environmental and educational programs related to coral reefs. The drawing data showed that the children of Bora Bora seem to have a deep understanding of their environment, the various biodiversity factors present in a coral reef (e.g., corals, fish, benthic invertebrate, algae), and human uses of the lagoon, both positive and negative. This is not surprising given the strong biodiversity awareness embedded in the environment of children in Bora Bora (e.g., Marine Educational Area, Reef Check monitoring, Bora Biodiv, and local policies). These programs are aimed to explain the children's understanding of the lagoon and how this could be reflected in the evolution of their drawings. For example, the Bora Biodiv program has been in place since 2019, meaning that children who are now 16 years old were around 11 when the program began. A solid knowledge of coral reef biodiversity by children is crucial because human-induced environmental degradation threatens all life systems worldwide, including the lives of young children, and disrupts their development, with long-lasting consequences (IPCC, 2021). It is, therefore, essential to understand their perceptions of the health status of coral reefs.

Analyzing drawings from 209 Brazilian children, it was found that most children chose not to include humans in their forest landscapes (Profice et al., 2015). In the Bora Bora data, the assessment was

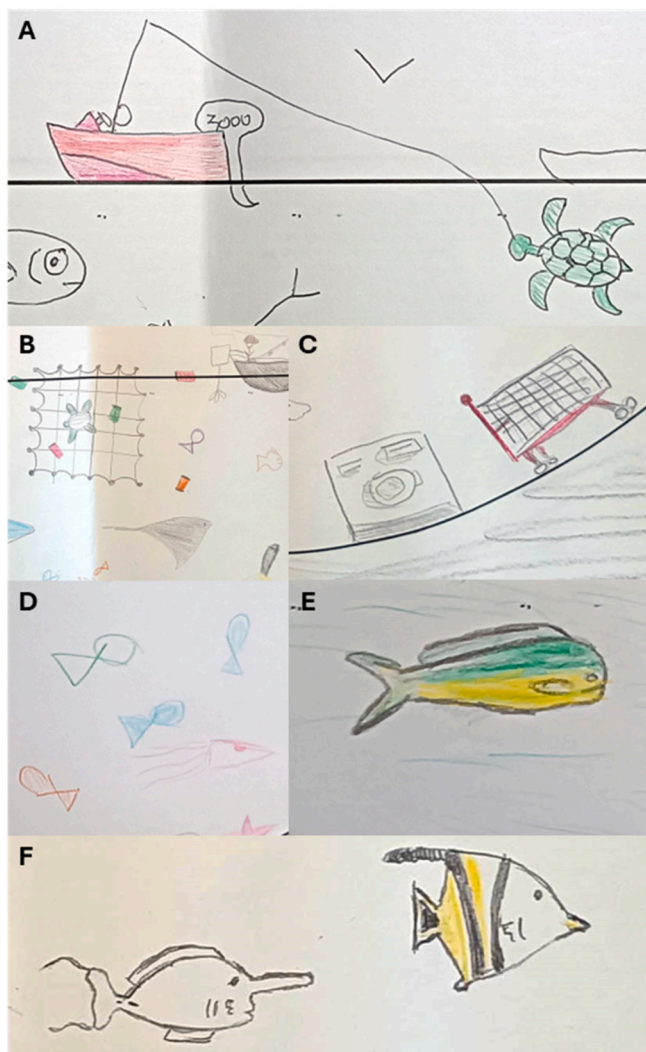


Fig. 2. Illustrations highlighting the relationship between certain human activities and pollution-related items (A–C), as well as variations in the schematic versus realistic representation of fish (D–F). Children age groups are as follows: A, 13–14 years; B and C, 15–16 years; D, 13–14 years; E and F, 15–16 years.

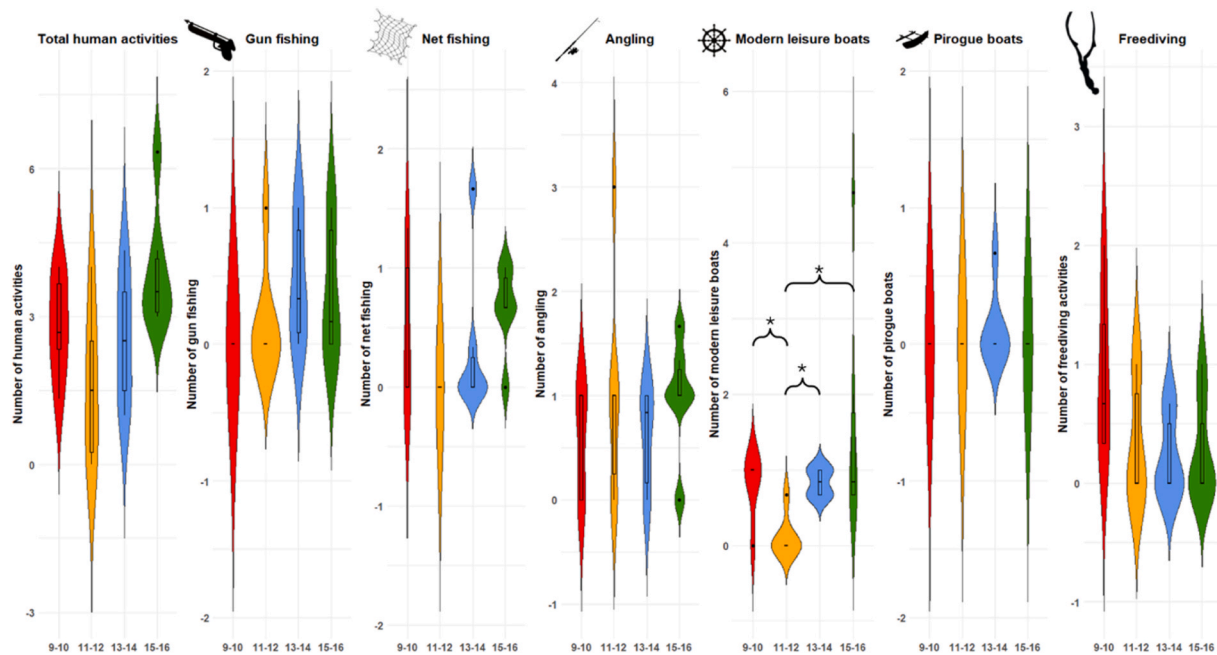


Fig. 3. Violin plots depicting human activity features across age groups: 9–10, 11–12, 13–14, and 15–16 years. Statistical significance is indicated by an asterisk (*). Boxplots represent the actual observed values and should be used for interpretation, whereas violin plots are shown only as a visual guide to the distribution. Given the small sample size, the violin plots should be interpreted with caution, as they may overemphasize distributional features.

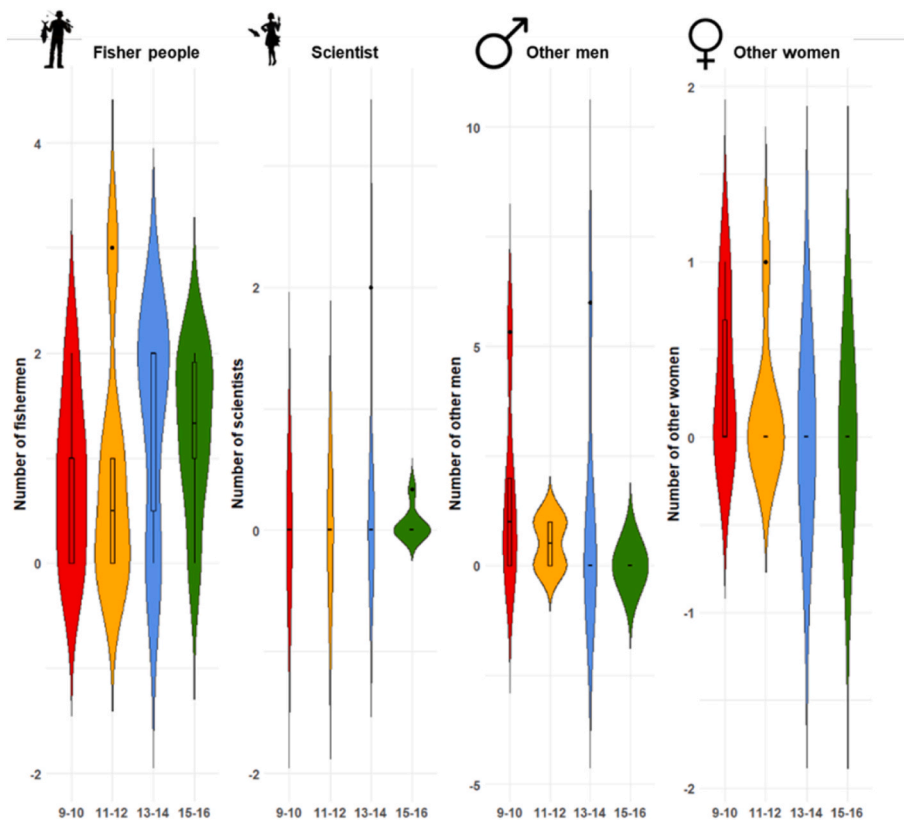


Fig. 4. Violin plots depicting humans across age groups: 9–10, 11–12, 13–14, and 15–16 years. Statistical significance is indicated by an asterisk (*). Boxplots represent the actual observed values and should be used for interpretation, whereas violin plots are shown only as a visual guide to the distribution. Given the small sample size, the violin plots should be interpreted with caution, as they may overemphasize distributional features.

conducted on a relatively small number of children (23 groups), which limits the generalizability of this exploratory study. We decided to work with groups because this approach may facilitate the participation of

more reserved children, allowing them to express themselves more comfortably within a shared project. However, the grouping procedure may have introduced bias because children were allowed to work

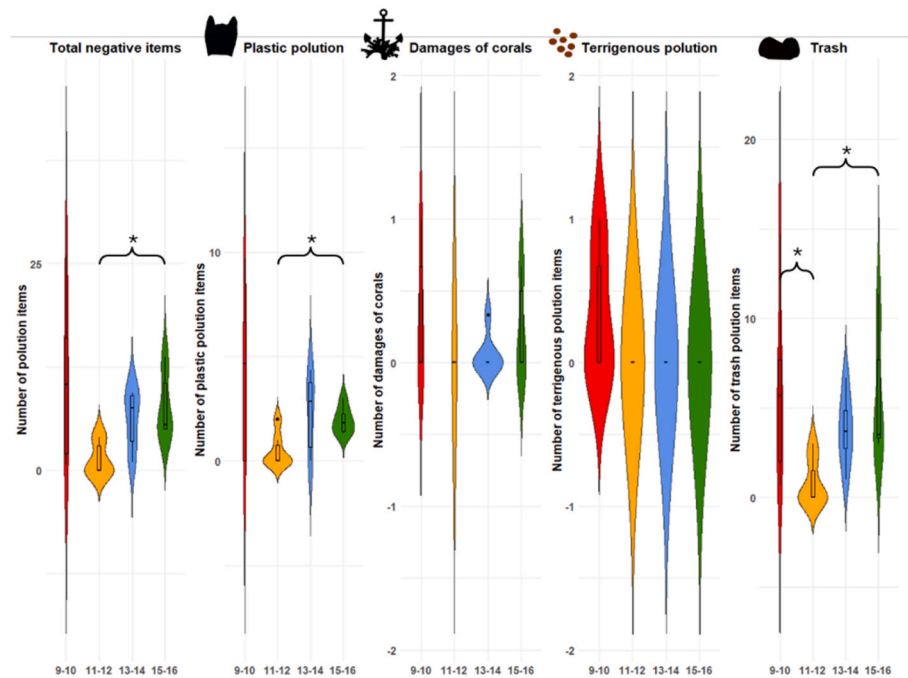


Fig. 5. Violin plots depicting negative features across age groups: 9–10, 11–12, 13–14, and 15–16 years. Statistical significance is indicated by an asterisk (*). Boxplots represent the actual observed values and should be used for interpretation, whereas violin plots are shown only as a visual guide to the distribution. Given the small sample size, the violin plots should be interpreted with caution, as they may overemphasize distributional features.

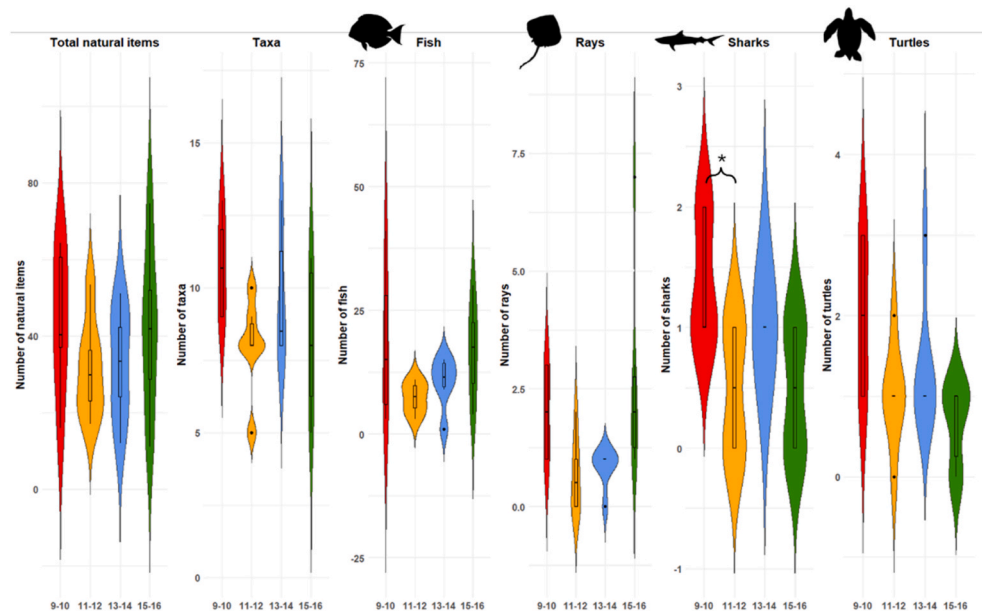


Fig. 6. Violin plots depicting natural items (part I) across age groups: 9–10, 11–12, 13–14, and 15–16 years. Statistical significance is indicated by an asterisk (*). Boxplots represent the actual observed values and should be used for interpretation, whereas violin plots are shown only as a visual guide to the distribution. Given the small sample size, the violin plots should be interpreted with caution, as they may overemphasize distributional features.

collaboratively. Some groups may have been dominated by one or two children, whereas others may have worked more collectively. Nonetheless, we observed that 83% of the drawings included humans. Miller et al. (2018) examined American children's gender stereotypes associating science with humans over five decades of “Draw-A-Scientist” studies. Children's drawings of scientists depicted female scientists more often in recent decades, but less often among older children (Miller et al., 2018). Children's portrayal of scientists has diversified over time, but they continue to associate science with men as they grow older.

In Bora Bora drawings, children may still associate more men than women with activities linked to the sea (quantified excluding fisher people and scientists for whom sex was not assessed): 30% of the drawings appear to depict men and 13% represented women. However, this result is highly speculative, as it depends on the sex assessment made by the researchers, which was not straightforward. Additionally, figures that appear male could simply be generic pictographic representations, with no specific gender assigned. Therefore, we advise exercising extreme caution with such assessments in future studies.

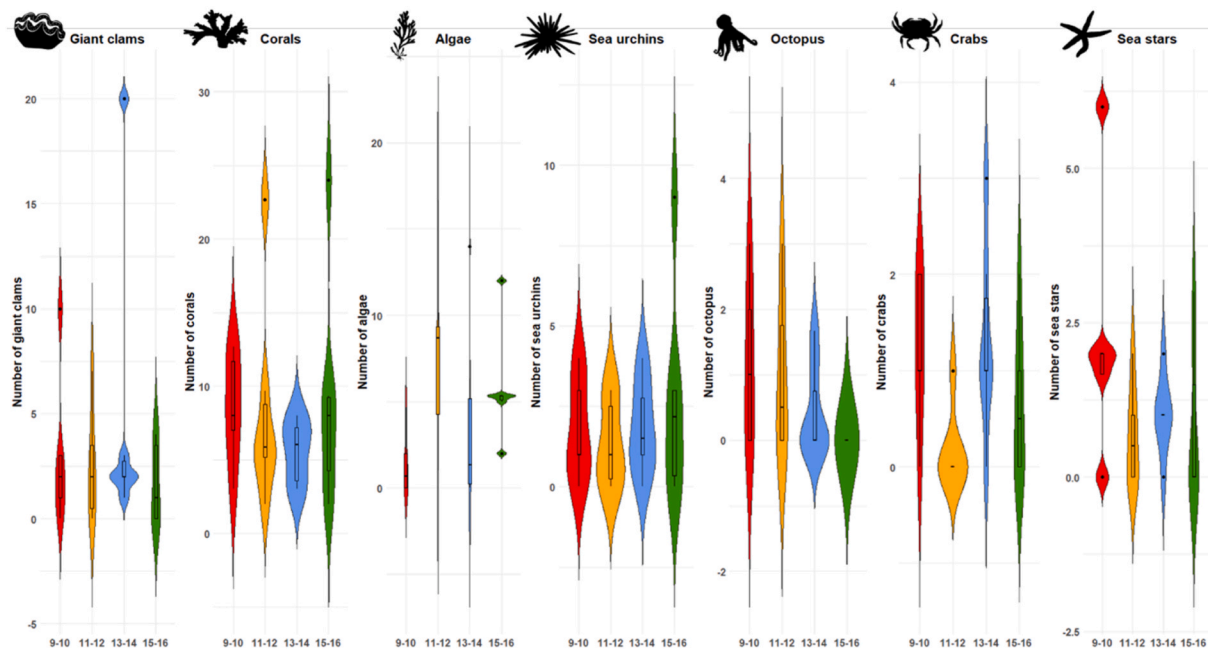


Fig. 7. Violin plots depicting natural items (part II) across age groups: 9–10, 11–12, 13–14, and 15–16 years. Statistical significance is indicated by an asterisk (*). Boxplots represent the actual observed values and should be used for interpretation, whereas violin plots are shown only as a visual guide to the distribution. Given the small sample size, the violin plots should be interpreted with caution, as they may overemphasize distributional features.

Table 1

Summary of Levene's tests for assessing homoscedasticity of variance, along with the statistical tests performed (ANOVA, Welch's ANOVA, or Kruskal–Wallis) to test for differences among age groups, and their corresponding test statistics and P-values.

Feature	Levene F	Levene p	Test	Statistic	Test p
Total Human	0.53	0.67	Anova	3.08	0.052
Gun	1.71	0.20	KW	5.71	0.13
Net	0.97	0.43	KW	6.91	0.075
Angling	0.42	0.74	KW	2.58	0.46
Boat	1.47	0.26	KW	10.83	0.013
Pirogue	0.94	0.44	KW	2.83	0.42
Freediving	0.47	0.71	KW	5.40	0.14
Fisher people	0.12	0.95	KW	1.96	0.58
Scientist	0.83	0.49	KW	1.92	0.59
Other men	1.03	0.40	KW	5.36	0.15
Other women	1.52	0.24	KW	4.67	0.20
Total negative	3.39	0.039	Welch	5.66	0.018
Plastic pollution	5.61	0.0063	Welch	4.25	0.038
Damage on coral	1.56	0.23	KW	3.54	0.32
Terrigenous	3.10	0.051	KW	7.53	0.057
Trash	1.54	0.24	KW	9.94	0.019
Total natural	0.83	0.49	Anova	0.67	0.58
Taxa	0.83	0.49	KW	5.12	0.16
Fish	3.14	0.049	Welch	2.31	0.14
Rays	1.32	0.30	KW	9.45	0.024
Shark	5.37	0.0076	KW	9.14	0.028
Turtle	0.79	0.51	KW	7.17	0.067
Clams	0.20	0.90	Anova	0.59	0.63
Corals	0.59	0.63	Anova	0.43	0.73
Algae	0.76	0.53	Anova	2.11	0.13
Sea urchins	0.94	0.44	Anova	0.44	0.73
Octopus	3.18	0.048	KW	5.25	0.15
Crabs	1.06	0.39	KW	6.83	0.077
Sea stars	0.67	0.58	KW	3.47	0.32
Qualitative index	2.76	0.071	KW	10.15	0.017

Among the most frequently displayed human activities, angling was the most common. Profice (2018) asked children aged 6–14 from Tupinamba ($n = 91$), an indigenous village in Brazil, and New York ($n = 54$) to draw images of nature. Compared to the New York children, the Tupinamba children's drawings were more diverse, with many animal

and plant elements, and included more human constructions such as roads and houses (Profice, 2018). Indigenous children thus integrated human and non-human elements into their drawings more often than city children. Drawings by children from Fiji and New Caledonia indicated that most perceived the sea as part of a land-sea continuum, depicting both human and non-human elements, as well as themes of exploitation and conservation of marine life (Fache et al., 2022). Asking UK children to draw a rainforest, it was found that children had a detailed view of rainforest environments that encompassed a diverse range of habitats and animal species, though vertebrate taxa, especially mammals, birds, and reptiles, which were overrepresented (Snaddon et al., 2008). In our study, many different taxa were found in the drawings (average of 9 taxa) with also a huge representation of vertebrate taxa. The presence of cartilaginous fish, although they are neither commonly eaten on the island nor among the most abundant species, could be explained by their strong impact on children's imagination or by their visibility during observation activities and unauthorized feeding practices on the island.

Profice et al. (2015) showed that Brazilian children living in the Atlantic Forest drew an average of 11.79 natural elements for those under 9 years of age, and 14.21 elements for those over 9 years of age. In our study, regardless of the children's age, fish were present in all the drawings and in the greatest quantity. In addition to being highly visible in the lagoon, this is likely linked to the importance of fish as a food source for the inhabitants of Bora Bora. Polynesian activities on lagoon before European contact are closer to what we would call leisure or « sport » today (Oliver, 1975). Since European contact, activities on lagoon were transformed in two directions: more fishing and still leisure activities (Bambridge, 2016).

Minimal values for the number of fish were observed in the 11–12-year-old group. A similar increase was seen in the number of modern leisure boats from the 11–12 to the 13–14 and 15–16 age groups (statistically significant). Caution should be exercised in interpreting these results, as the number of model leisure boats was higher in drawings from children aged 9–10 than in those from children aged 11–12. Thus, our study seems to indicate that children have a strong understanding of the coral reefs where they live, the creatures inhabiting those reefs, and local environmental issues. In addition to the biodiversity awareness

Table 2

Summary of Dunn's post hoc tests conducted for non-parametric features where the Kruskal–Wallis test indicated significant differences. Adjusted P-values are reported using the Benjamini–Hochberg procedure.

		Z	p-value	Adjusted p-value
Number of leisure modern boats				
11-12	13-14	−2.45	0.014	0.029
11-12	15-16	−2.89	0.0038	0.023
13-14	15-16	−0.44	0.66	0.98
11-12	9-10	−2.58	0.01	0.0299
13-14	9-10	−0.24	0.81	0.97
15-16	9-10	0.18	0.86	0.86
Number of trash items				
11-12	13-14	−2.11	0.034	0.069
11-12	15-16	−2.88	0.0039	0.024
13-14	15-16	−0.77	0.44	0.66
11-12	9-10	−2.43	0.015	0.045
13-14	9-10	−0.42	0.68	0.81
15-16	9-10	0.32	0.75	0.75
Number of rays				
11-12	13-14	−0.34	0.73	0.88
11-12	15-16	−2.45	0.014	0.086
13-14	15-16	−2.11	0.035	0.070
11-12	9-10	−2.18	0.029	0.088
13-14	9-10	−1.86	0.063	0.095
15-16	9-10	0.16	0.88	0.88
Number of sharks				
11-12	13-14	−1.60	0.11	0.17
11-12	15-16	0	1	1
13-14	15-16	1.60	0.11	0.22
11-12	9-10	−2.51	0.012	0.036
13-14	9-10	−0.99	0.32	0.39
15-16	9-10	−2.51	0.012	0.073
Qualitative environmental quality index				
11-12	13-14	2.65	0.0081	0.024
11-12	15-16	2.69	0.0070	0.042
13-14	15-16	0.045	0.96	0.96
11-12	9-10	1.04	0.30	0.36
13-14	9-10	−1.49	0.14	0.20
15-16	9-10	−1.53	0.13	0.25

initiatives previously mentioned (e.g., the Marine Educational Area and the Bora Biodiv project, see previous paragraphs), several anthropological studies confirm this result: children from indigenous or island societies regard nature as more alive compared with those from Western societies (Crain, 2014; Diamond, 2013; Profice, 2018). As noted earlier, a shift in understanding coincides with the transition from primary to secondary school in the French educational system. An in-depth examination of this period, in connection with what is taught to children and their visits to the lagoon (for example, within the framework of the Bora Bora Marine Educational Area), constitutes another area of research to better understand this result. Alternate explanations may include factors such as differences in teacher expectations, stress related to the transition from junior to high school, increased distraction, etc.

Ozsoy and Ahi (2014) asked Turkish children of different ages to draw the pictures of the current state of the environment and how the environment fifty years from now would appear. 29% of the children depicted a clean future environment, 40% depicted a polluted future environment, and 31% portrayed a technological future environment (opposed to a “polluted environment” and “clean environment” in their study) (Özsoy and Ahi, 2014). A significant difference was found based on age. Younger children's drawings mainly included elements of nature such as trees, the sun, clouds, humans, birds, butterflies, mountains, seas, and rivers. Older children mainly drew environmental problems they observed in their immediate surroundings. A similar study with children aged 5 to 12 found that negative perceptions of the environment increased with the age of the children (Fleer, 2002). Our results

Table 3

Summary of Games–Howell tests following Welch's ANOVAs conducted when they indicated significant differences. Df = degree of freedom.

		Mean difference	Confidence interval	t-test statistic	Df	p-value
Number of negative items (pollution)						
11-12	9-10	−9.7	−28.45 to 9.1	2.03	4.3	0.31
13-14	9-10	−4.8	−23.25 to 13.6	0.98	4.8	0.76
15-16	9-10	−3.2	−21.56 to 15.1	0.65	5.0	0.91
13-14	11-12	4.8	−0.61 to 10.3	2.85	8.0	0.08
15-16	11-12	6.4	0.51 to 12.4	3.53	7.5	0.03
15-16	13-14	1.6	−5.10 to 8.3	0.74	9.9	0.88
Number of plastic pollution items						
11-12	9-10	−3.70	−11.29 to 3.9	1.93	4.3	0.34
13-14	9-10	−1.87	−9.22 to 5.5	0.91	5.4	0.80
15-16	9-10	−2.26	−9.88 to 5.4	1.18	4.2	0.67
13-14	11-12	1.83	−1.00 to 4.7	2.15	6.9	0.23
15-16	11-12	1.44	0.11 to 2.8	3.35	9.4	0.03
15-16	13-14	−0.39	−3.22 to 2.4	0.47	6.1	0.96

showed that the children in Bora Bora drew coral reefs as relatively healthy (qualitative index between −1 and 1, mean value: 0.33) but still with significant pollution items. Regarding the evolution of this trend with age, a similar observation to those noted earlier was made: a higher number of pollution items were found in the drawings of 9-10-year-olds, followed by a decrease in the 11-12-year-olds, and an increase again in the 13-14 and 15-16-year-olds. Further investigation is needed to determine whether the observed differences reflect a true effect of age or are explained by other factors.

Bogner and Wiseman (1997) reported that young people living in urban areas and suburbs have more positive opinions about the environment compared to their rural counterparts. However, when examining their behaviors toward the environment, it was found that their actual behaviors were more negative than those of their rural counterparts (Bogner and Wiseman, 1997). The children of Bora Bora live in a relatively healthy environment, close to nature, compared with those from Tahiti (the most densely populated island in French Polynesia) or major cities in France. However, these children may likely be quicker to notice changes in their environment; e.g., reduced size of fish caught, coral bleaching, plastic pollution (Gatouillat et al., 2024; Lecchini et al., 2020, 2021); than urban children.

Overall, assessments based on art or children's drawings, eco-art education (Inwood and Taylor, 2012), which encourage creativity and adapt to different modes of expression. It allows us to document children's perception of their lagoon environment. It can be a particularly useful complement to conventional tools (e.g., ecological monitoring based on visual or acoustic surveys), provided that the surveys are conducted with sufficient precision and that the evolution of children's drawings with age is well understood. However, their effectiveness and feasibility in various contexts have not been sufficiently studied (Fache et al., 2022; Flowers et al., 2015), and never in the context of coral reefs. The data show that the children seem to have a vision of their environment centered around ecosystem services, mainly fishing. Besides the differences related to a realistic vision of the lagoon that logically should increase with time, the drawings changed with the age of the children, particularly concerning the presence of boats and pollution

items. The difference in the drawings made by children at different ages may reflect their evolving relationship with the sea (children in Bora Bora tend to fish more frequently as they get older compared to when they are younger) and may be influenced by the school skills and abilities characteristic of their level of development (Farokhi and Hashemi, 2011). Another possible explanation is that younger children may tend to stay closer to the coast, where pollution could be more visible, while older children may go by boat to more remote parts of the lagoon, where pollution is often less apparent.

The children's drawings collected in Bora Bora in 2024 will serve as a reference point for establishing a long-term monitoring program based on these drawings (repeating the same study in the same classes every two years). This would allow analysis of the evolution and dynamics of children's environmental perceptions when conducted alongside monitoring of activities occurring on the island. This is crucial to distinguish between (1) students' mindsets and the potential success of education programs, and (2) new events such as recent massive bleaching or an increase in the number of jetskis in the lagoon. In order to do that, this monitoring will be associated with the Reef Check participatory monitoring program conducted annually by Bora Bora locals and scientists (Lecchini et al., 2021). Pellier et al. (2014) analyzed drawings made by children (ages 10–15) from 22 Indonesian villages in Borneo. They showed that children have negative expectations about their future environmental conditions, which has important political implications (Pellier et al., 2014). In addition to asking children about the current status of the lagoon, future research could explore their perceptions of its past and potential future. Our long-term monitoring program based on children's drawings aims to understand how children (who will be tomorrow's decision-makers and managers) perceive the biodiversity and human uses of the lagoon. Finally, to ensure the sustainability of this environmental education initiative on Bora Bora, funding from the Bora-Biodiv project (through 2031) will enable the study to be replicated every two years (2027, 2029, 2031). Furthermore, we plan to conduct the same study in 2027 on other Polynesian islands (e.g., Moorea, Tahiti, and several islands from the Marquesas and Tuamotu Archipelagos) to extend this knowledge to additional groups of children, who may have different relationships with the sea depending on their access to coral reefs for swimming or fishing. Thus, their personal development as humans who care about nature and will take care of it is just as important as developing optimal management and conservation policies for a tourist island like Bora Bora or other French Polynesia islands, which must constantly find the right balance between economic/touristic development and environmental preservation.

More broadly, understanding the lagoon's influence on children, as well as how children perceive anthropogenic impacts on the lagoon, is closely linked to the concept of Ocean Literacy. The UNESCO Ocean Literacy programme promotes an understanding of the ocean's influence on humanity and humanity's influence on the ocean. This objective aims to foster responsible ocean stewardship, which forms part of the broader Sustainable Development Goal 14 (Life Below Water). In addition to generating research findings, our study contributes to marine conservation through education, with the aim of empowering children to become actively engaged in building a sustainable lagoon.

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CRediT authorship contribution statement

David Lecchini: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Stéphanie Krimou:** Conceptualization, Investigation, Methodology. **Manon Fourriere:**

Conceptualization, Investigation, Methodology. **Camille Gache:** Resources. **Matthieu Juncker:** Resources. **Marine Coutelas:** Methodology. **Marie-Anne Germaine:** Resources. **Matthieu Ghilardi:** Resources. **Vincent Sturny:** Resources. **Milton Doom:** Resources. **Cécile Berthe:** Resources. **Tehani Maueau:** Resources. **Tamatoa Bambridge:** Resources. **Xavier Raick:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare no conflicts of interest.

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Data availability

All the drawings used in this study are available on-line (DOI: 10.5281/zenodo.15443123).

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