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Water-based tourism dynamics: spatial and temporal characterization in three coral reefs from Bahía Culebra, North Pacific of Costa Rica

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ABSTRACT

Introduction: Coral reefs are essential ecosystems for tourism-based economies worldwide, offering ecological, social and economic benefits. However, increasing on-water activities represent a risk to reef health. In Culebra Bay, there is limited understanding of how on-water tourism interacts with the coral reefs of the area.

Objective: To characterize the spatial and temporal distribution of on-water tourism interactions around coral reefs sites in Culebra Bay.

Methods: Direct observations were conducted twice a month from April 2021 to April 2022, at three coastal coral reefs to document the number of interactions and users, the types of activities and watercraft involved, and the duration of each interaction. A Kruskal-Wallis test was applied to evaluate differences across sites, and the U Mann-Withney test for compare tourist seasons (peak and off-season). Additionally, a Correspondence Analysis (CA) was used to explore the relationship between activities and sites.

Results: We recorded 2,437 interactions involving 6 728 users, and identified ten tourism-related activities. The spatial distribution of tourism interactions was heterogeneous among sites, with the highest volume of interactions, activities, and users concentrated at Jícaro reef. The activities involving watercraft-based activities were dominant, representing 93% of all interactions. Also, the recorded activities were different by site: Blanca reef was mainly linked to non-motorized tours, while Virador reef was primarily used for transit. We found no statistical differences in the volume of users, the temporal distribution of interactions and its duration between seasons.

Conclusion: Aquatic tourism in Bahía Culebra was concentrated at Jícaro reef and dominated by motorized activities. This pattern may pose potential environmental risks for reef resilience.

Key words: coral reefs; tourism; marine-based activities; coastal management.

RESUMEN

Dinámica del turismo acuático: caracterización espacial y temporal en tres arrecifes de coral de Bahía Culebra, Pacífico Norte de Costa Rica

Introducción: Los arrecifes de coral son ecosistemas esenciales para las economías basadas en el turismo en todo el mundo, ya que ofrecen beneficios ecológicos, sociales y económicos. Sin embargo, el aumento de las

actividades realizadas sobre el agua representa un riesgo para la salud de los arrecifes. En Bahía Culebra existe un conocimiento limitado sobre cómo el turismo acuático interactúa con los arrecifes de coral del área.
Objetivo: Caracterizar la distribución espacial y temporal de las interacciones turísticas realizadas sobre el agua en los arrecifes de coral de Bahía Culebra.
Métodos: Se realizaron observaciones directas dos veces al mes entre abril de 2021 y abril de 2022 en tres arrecifes costeros para documentar el número de interacciones y usuarios, el tipo de actividad y de embarcaciones involucradas, y duración de las interacciones. Para evaluar las diferencias entre sitios se empleó la prueba de Kruskal-Wallis, mientras que la prueba U de Mann-Whitney se utilizó para comparar las temporadas turísticas (pico y fuera de pico). Además, se realizó un análisis de correspondencia (CA) para examinar las asociaciones entre las actividades y los sitios arrecifales.
Resultados: Se registraron 2 437 interacciones que involucraron a 6 728 usuarios, y se identificaron 10 actividades directamente relacionadas con el turismo. La dinámica espacial del turismo fue heterogénea entre sitios, con el mayor volumen de interacciones, actividades y usuarios concentrado en el arrecife Jícaro. Las actividades que involucraron embarcaciones fueron dominantes, representando el 93 % de todas las interacciones. Asimismo, las actividades variaron según el sitio: el arrecife Blanca se asoció principalmente con tours no motorizados, mientras que el arrecife Virador se utilizó principalmente para tránsito. No se encontraron diferencias estadísticas en la dinámica turística entre temporadas.
Conclusión: El turismo acuático en Bahía Culebra se concentra en el arrecife Jícaro y está dominado por actividades motorizadas. Este patrón podría representar riesgos ambientales potenciales.

Palabras clave: arrecifes de coral; turismo; actividades marinas; gestión costera.

INTRODUCTION

Coral reefs are the most diverse marine ecosystems in the world (Gaston, 2013), where important biological processes and complex ecological relationships occur (Karlson, 1999). For such attributes, these ecosystems are able to provide local communities with a variety of ecosystem services, such as food provision, coastal protection, recreational opportunities, and, in many coastal zones, economic opportunities through the use of reefs as a tourism resource (Pabel & Prideaux, 2018). It is estimated that the tourism industry on a global scale contributes approximately 10% to gross domestic product (GDP) and generates direct and indirect employment (World Tourism Organization [UNWTO], 2017). Coral reef tourism alone generates an estimated USD 35.8 billion annually worldwide (Spalding et al., 2017).

However, all that glitters is not gold. Coral reefs are currently facing profound transformations caused by the tourism industry and its associated coastal development (Dong, 2025). While tourism may sustain the economy of several coastal areas, it also brings significant challenges to vulnerable ecosystems such as coral reefs (Chakraborty, 2021; Wolf et al., 2019). Major significant concerns include environmental degradation and pollution, ecosystem destruction, and the loss of marine and coastal resources (Hall, 2001). Such effects may depend on tourism and coastal development depend on a country’s ecological conditions, local governance structures, and economic priorities.

Culebra Bay, located in the Gulf of Papagayo on the North Pacific coast of Costa Rica, is an area historically characterized by the development of the most extensive coral reefs (up to 2 km long) in that region of the country (Cortés, 1996-1997; Cortés & Jiménez, 2003), primarily dominated by the branching coral *Pocillopora* and the presence of abundant associated marine fauna (Cortés, 2012; Cortés & Jiménez, 2003). This area is influenced by the intensification of the Easterly trade winds between December and April, generating a seasonal upwelling phenomenon characterized by an increase in nutrients and a decrease in seawater temperature (Cortés, 1997). Due to these natural characteristics, its scenic beauty, and cultural richness, the Gulf of Papagayo was deemed suitable in the 1970s for the creation of a mass tourist destination and to promote economic development in the area. It was not until 1991 that the large-scale tourism project "Polo Turístico Golfo de Papagayo" (PTGP) was implemented (Cordero-Ulate, 2010; Sánchez-Noguera, 2012), and since its implementation, the area has experienced unprecedented changes in the rapid development of hotel infrastructure, luxury residences, and an increase in the supply of recreational activities (Sánchez-Noguera, 2012).

Unfortunately, the synergy between natural and anthropogenic disturbances, at both global and local scales, including seasonal upwelling, intense El Niño events, Harmful Algal Blooms (HABs), eutrophication, and coastal development, has led to a decline in marine water quality, structural changes in the benthos community through the development of macroalgae such as the invasive alga *Caulerpa sertularioides*, and an increase in the population of the bioeroding sea urchin *Diadema mexicanum*. These factors have resulted in local coral bleaching and coral mortality (Alvarado et al., 2018; Fernández & Cortés, 2005; Jiménez, 2007; Morales-Ramírez et al., 2001).

Consequently, the average live coral cover decreased from 44% in some sites in the 1990s to 1-4% in 2011 (Alvarado et al., 2018; Sánchez-Noguera et al., 2018). Despite this, Culebra Bay remains one of Costa Rica's most important tourist destinations, even after the complete shutdown due to COVID-19 (Costa Rican Tourism Institute [ICT], 2023). Given the urgent need for sustainability in tourism activities and the conservation of marine resources, the first coral reef restoration project in the country's North Pacific was implemented in 2019 (Fabregat-Malé et al., 2024) through a public-private partnership. However, restoration processes demand an understanding of current tourist pressure, since the success of a restoration project depends not only on technical aspects, but also on the intensity of tourist use and good tourism practices.

While the effects of tourism development have been documented in various coral reefs around the world, and the ecological aspects of reefs in Culebra Bay have been extensively studied (Cortés, 2012), much of this research has focused primarily on the effects of coastal urbanization expansion, pollution, and waste management (Sánchez-Noguera et al., 2018). Meanwhile, the impact of aquatic tourism activities, including recreational diving, snorkeling, boating, etc., has been less studied locally. However, in other reefs worldwide, it has been determined that such activities can cause harmful disturbances to ecosystems, including direct damage from anchoring, sediment resuspension, changes in marine fauna behavior, and introduction of nutrients into the water. These disturbances may affect the health of coral reefs and consequently affect the human communities that depend on this resource for their livelihoods.

Unfortunately for Culebra Bay, which lacks any status of protection, the precise details of aquatic activities occurring there, number and types of watercraft and visitors, and how the intensity of water tourism varies between peak and off seasons are unknown. This gap of information limits the assessment of potential negative impacts of on-water tourism on the bay's reefs. Therefore, the research question of this study was: What are the spatial and temporal characteristics of on-water tourism on three coral reefs undergoing ecosystem restoration in the North Pacific of Costa Rica?

MATERIALS AND METHODS

Study area: This study was conducted in Bahía Culebra (10°36'54.38" N, 85°39'32.86" W), located in Northwestern Costa Rica, a semi-enclosed bay covering approximately 24 km^2, and reaching depths up to 42 m (Cortés, 2012). This bay is an important biodiversity hotspot and one of the major coastal tourist destinations in Costa Rica (Sánchez-Noguera, 2012). Its reefs are dominated by branching corals (*Pocillopora* spp.) and characterized by the presence of massive species such as *Pavona clavus* and *Porites lobata* (Jiménez, 2001; Sánchez-Noguera et al., 2018). The seasonal upwelling phenomenon occurs between December and

April, coinciding with the peak tourism season in the country (Alfaro et al., 2015).

The bay lies within the PTGP developing area; therefore it has promoted the establishment of hotel complexes and luxury residential infrastructure and a marina along its coastline (Sánchez-Noguera, 2012). Its reefs support a variety of marine-based recreational activities, including snorkeling, SCUBA diving, boating, wildlife watching, and sport fishing.

The three selected coral reefs (Fig. 1) are in front of different beaches inside the bay**.** Both Blanca and Virador reefs lie adjacent to a luxury hotel, however these two sites can be visited by the general public, as they are freely accessible by land. Jícaro reef is a relatively isolated site that can be only accessed by boat. During this study, the three sites were part of the coral reef restoration project.

Data collection: Direct observations were conducted twice per month from April 2021 to April 2022 on three coral reefs within the bay. Each visit consisted of at least 4 h of observation of the aquatic activities on the reef's surface area between 08:00 and 16:00. Observations were made using binoculars from fixed shore-based points. The coral reefs were delimited by buoys indicating the presence of underwater restoration structures, ensuring that counts were conducted within the desired area. Either the environmental conditions and distance did not limit visibility or affect the accuracy of observations as none of the sites were located more than 400 m away from the shoreline. In order to standardize the collecting data process, two previous visits were made to train aspects such as identification, classification of activities and watercraft types. Moreover, a single observer conducted all observations.

For each interaction observed, the following attributes were recorded: type of activity (tourism fishing, transport, patrolling, scientific), aquatic vehicle involved (e.g., catamaran, boat, panga, jet ski, kayak), number of users, time of interaction, and duration of the interaction. For this study, the duration of interaction was the total time spent by an interacting element (e.g. a swimmer, a diver, a vessel, etc.) inside of the delimited coral reef area, regardless

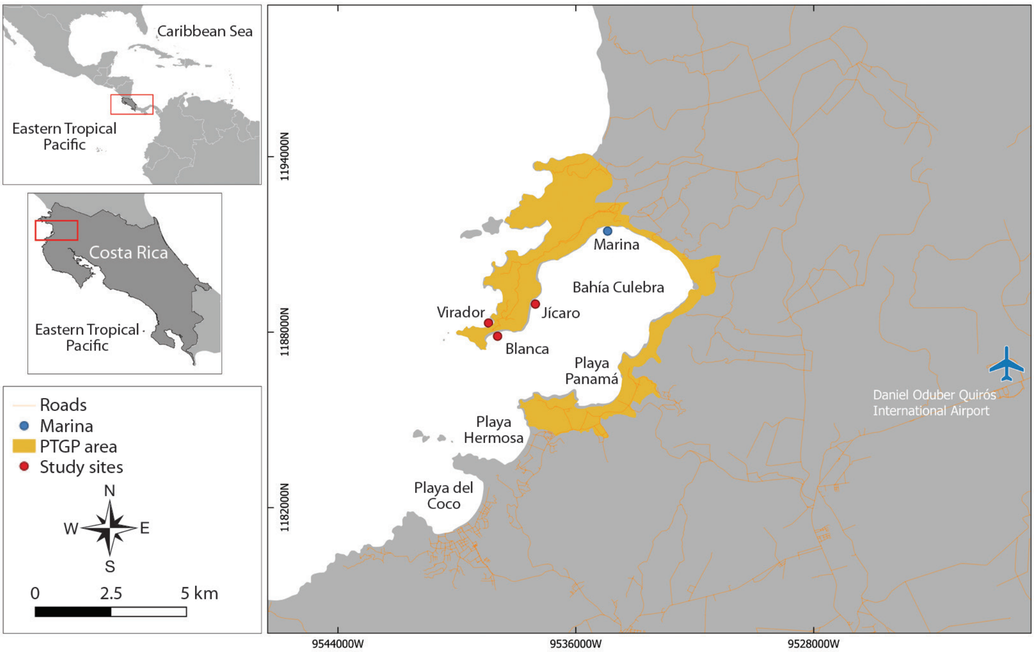

Fig. 1. Location of the study sites (red dots) in Bahía Culebra, northwestern Costa Rica.

the activity involved was simple transit or a longer use. For motorized vessels, the duration was recorded regardless of whether the engine was on or off.

Data analysis: Comparative analyses were conducted on the following attributes: number of interactions, types of activities, number of users, watercraft, and interaction duration. Data normality was tested using the Shapiro-Wilk test. As the data did not meet normality assumptions, comparisons among sites and among months were performed using the Kruskal–Wallis test. When comparing the attributes by tourism seasons, Mann-Whitney U tests were applied. When statistically significant differences were found, Dunn's post hoc test with Bonferroni correction was applied to identify pairwise differences while controlling for Type I error.

In order to evaluate whether the frequency distribution of activity and watercraft types differed among sites, chi-square tests (χ^2) were performed. Additionally, Correspondence Analysis (CA) was conducted to visualize the relationship between activities and types of watercraft observed at each site.

Scheirer–Ray–Hare test was used to assess differences in interaction frequency due to activity type and season for each reef separately.

To ensure representativeness, activities recorded only once were excluded from interaction-duration analyses. All statistical analyses were performed in R (R Core Team, 2024).

RESULTS

Activity patterns: A total of 2 437 interactions were recorded distributed across twelve on-water activities in the study area. Two of which were not directly related to tourism or recreation: artisanal fishing and scientific diving. Regarding the volume of interactions, significant differences were detected among sites ($H = 26.48$, $p < 0.05$), with Virador reef showing significantly fewer interactions per day, while Jícaro and Blanca reefs presented similar values (Table 1, Fig. 2A).

Table 1

Tourism attributes of three coastal coral reefs at Bahía Culebra. * Only recorded once.

	Jícaro	Blanca	Virador
Mean interactions-day^{-1}	52.68 ± 17.40	36.18 ± 17.95	21.91 ± 11.39
Mean users-day^{-1}	184.13 ± 76.91	70.68 ± 31.98	51.00 ± 24.22
Mean watercraft interactions-day^{-1}	46.77 ± 16.01	35.32 ± 17.58	21.68 ± 11.39
Mean interaction duration (min)	20.86 ± 34.88	3.12 ± 20.62	4.08 ± 25.38
Tourism use On-reef activities	Snorkeling Motorized tours Non-motorized tours Free diving* Recreational diving* Surface supplied air diving*	Motorized tour Non-motorized tour Snorkeling	Motorized tour Snorkeling
Reef- adjacent activities	Leisure boating Transit Boat cleaning* Private patrolling	Leisure boating Transit	Leisure boating Transit Private patrolling*
Non tourism use	Artisanal fishing* Scientific diving	Scientific diving	Fishing Scientific diving
Watercrafts	Jet ski, Boat, Paddleboard, Kayak Catamaran, Panga boat Banana boat, Towable tube boat	Jet ski, Boat, Paddleboard Kayak, Panga boat Banana boat	Jet ski, Boat Panga boat, Catamaran

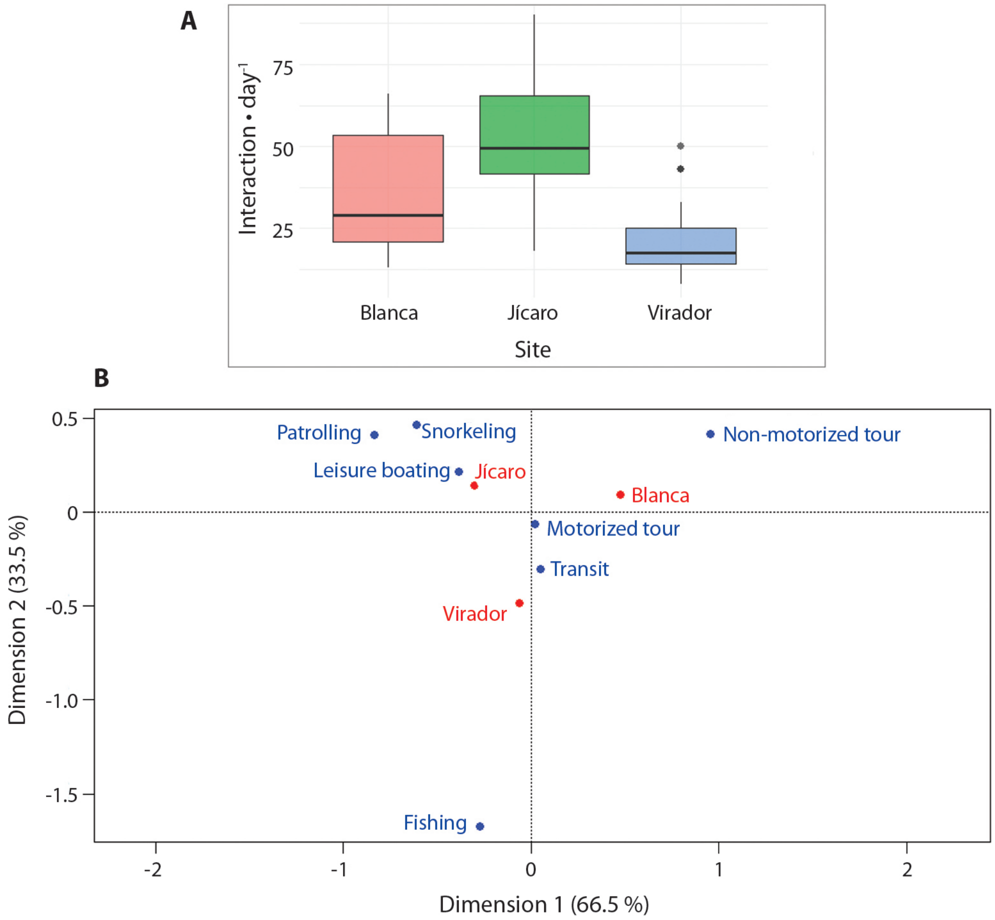

Fig. 2. A. Boxplot of daily interaction rates (interactions·day^{-1}) across study sites. The x-axis indicates the study sites, and the y-axis represents the number of interactions per day. Central horizontal lines within the boxes represent the median. Black points represent outliers. **B.** Correspondence Analysis (CA) between on-water activities and the sites. Blue points represent activities. Red items correspond to sites.

All tourism-related activities were observed at Jícaro reef, however, five of them were recorded only once during the monitoring period (Table 1). At Blanca and Virador reefs, only five tourism-related activities were recorded. The activities that occurred on all reefs were motorized tours, leisure boating, transit and snorkeling. Of which, the motorized tours exhibited the highest value of interactions-day-^{1} (Table 2), while snorkeling interactions showed the lowest value of interactions-day-^{1}. The rest of activities differentially occurred on the studied reefs.

The Scheirer–Ray–Hare test (SRH test) revealed significant differences in the relative frequency of activities at the Jícaro (H = 9.899, p = 0.042) and Virador (H = 35.379, p < 0.001) reefs, but not at Blanca (H = 7.325, p = 0.120). This indicates that activities at Blanca exhibited more homogeneous frequencies. Post hoc Dunn tests showed that at Jícaro, motorized and non-motorized tours had significantly different frequencies (p = 0.048). At Virador reef, the motorized tours exhibited significantly higher interaction values compared with leisure boating (p = 0.045) and transit (p < 0.001)

Table 2

Mean (+ SD) of daily tourism indicators by activity at three coastal coral reefs in 2021-2022 in Bahía Culebra, North Pacific of Costa Rica. * groups-day^{-1}.

Activity	Jícaro			Blanca			Virador		
	Mean interactions-day^{-1}	Mean users-day^{-1}	Mean time of interaction (min)	Mean interactions-day^{-1}	Mean users-day^{-1}	Mean time of interaction (min)	Mean interactions-day^{-1}	Mean users-day^{-1}	Mean time of interaction (min)
Snorkeling *	5.09 ± 1.98*	34.71 ± 19.04	36.81 ± 24.81	0.63 ± 0.84*	3.40 ± 2.99	10.29 ± 7.56	0.23 ± 0.00*	1.80 ± 1.30	14.60 ± 14.25
Motorized tours	24.07 ± 11.57	44.95 ± 15.41	6.71 ± 19.45	19.86 ± 12.29	30.52 ± 16.40	0.56 ± 3.68	13.50 ± 6.30	20.19 ± 11.05	0.42 ± 1.48
Non-motorized tours	1.63 ± 3.81	5.00 ± 3.74	8.17 ± 12.89	6.95 ± 6.13	9.90 ± 9.13	4.08 ± 19.59			
Leisure boating	10.72 ± 4.27	75.50 ± 36.62	52.88 ± 46.70	2.77 ± 2.51	23.00 ±16.52	11.54 ± 50.50	2.00 ± 3.49	17.21 ± 12.93	28.63 ± 75.73
Transit	6.73 ± 9.44	31.59 ± 40.12	9.77 ± 23.29	5.72 ± 5.08	17.11 ± 12.02	3.07 ± 24.39	5.82 ± 6.14	19.04 ± 10.81	0.44 ± 1.63
Private patrolling	0.63 ± 1.01	3.71 ± 1.70	51.28 ± 46.90						
Fishing							0.31 ± 0.46	3.86 ± 0.89	64.29 ± 22.89
Scientific diving	0.59 ± 0.74	5.88 ± 3.36	56.46 ± 39.99	0.22 ± 0.57	7.66 ± 2.81	75.80 ± 53.02			

(Table 2). Which indicates that interaction volume varied according to activity type.

Additionally, the distribution of activities at the three reefs was not random and showed a significant association between activities and sites ($\chi^2 = 426.34$, $p < 0.05$). The Correspondence Analysis (Fig. 2B) revealed that the widespread activities such as motorized tours and transit were not specifically related to any of the reefs, as they occurred across all sites, reflecting their common practice in the inner area of the bay. The rest of activities were differentially associated to each site (Fig. 2B).

Concerning temporal aspects, despite higher mean daily interactions per day were recorded in the high season, no significant differences were found between tourism seasons ($U = 614$, $p = 0.23$) across all sites. Neither at each site (Blanca: $U = 78$, $p = 0.25$; Jícaro: $U = 70$, $p = 0.99$; Virador: $U = 79$, $p = 0.25$) (Table 3). The RSH test also revealed that no significant differences were found in the daily number of interactions by activity type between high and low season at Jícaro ($H = 2.274$, $p = 0.132$), Blanca ($H = 0.046$, $p = 0.830$), or Virador ($H = 0.058$, $p = 0.809$), despite mean daily interaction rates were higher during the high season (Table 4). In addition, the distribution of activities by season was homogeneous across all three reefs (Jícaro: $H = 0.809$, $p = 0.937$; Blanca: $H = 4.541$, $p = 0.338$; Virador: $H = 0.535$, $p = 0.970$). Which means differences in interaction frequency were more strongly related to the type of activity than to the season.

On the other hand, significant monthly variations were detected in the number of interactions between Jícaro and Virador reefs ($p = 0.0002$), where Virador reef exhibited lower daily interaction rates (Fig. 3). The highest number of interactions was recorded at Jícaro reef in March 2022 (79.0 ± 15.6 interactions-day^{-1}), while both Virador and Blanca reefs showed peaks in July 2021 (46.5 ± 4.9 and 61.0 ± 7.1 interactions-day^{-1}, respectively).

User patterns: A total of 6 728 users were registered across the three monitored sites. Significant differences were detected in

Table 3

Mean (± SD) of daily tourism indicators at coastal reefs during high and low seasons in Bahía Culebra, North Pacific of Costa Rica.

Site	Mean interactions-day^{-1} (nhigh = 10) (nlow= 12)	Mean users-day^{-1} (nhigh = 10) (nlow= 12)	Mean aquatic vehicles interactions-day^{-1} (nhigh = 10) (nlow= 12)	Mean interaction duration (min)
Jícaro	$\overline{X}_{high}$ = 52.6 ± 19.7 $\overline{X}_{low}$ =52.8 ± 16.1	$\overline{X}_{high}$ = 178.1 ± 67.2 $\overline{X}_{low}$ = 189.2 ±86.8	$\overline{X}_{high}$ = 48.1 ± 18.6 $\overline{X}_{low}$ = 46.7 ± 14.8	$\overline{X}_{high}$ = 21.9 ± 35.8 (n = 526) $\overline{X}_{low}$ = 20.0 ± 34.1 (n = 633)
Blanca	$\overline{X}_{high}$ = 40.3 ± 16.0 $\overline{X}_{low}$ = 32.8 ± 19.5	$\overline{X}_{high}$ = 85.8 ± 34.2 $\overline{X}_{low}$ = 58.1 ± 24.7	$\overline{X}_{high}$ = 38.6 ± 15.9 $\overline{X}_{low}$ = 36.7 ± 19.5	$\overline{X}_{high}$ = 4.8 ± 28.2 (n = 403) $\overline{X}_{low}$ = 1.4 ± 6.4 (n = 393)
Virador	$\overline{X}_{high}$ = 23.8 ± 9.6 $\overline{X}_{low}$ = 20.3 ± 12.9	$\overline{X}_{high}$ = 59.2 ± 27.2 $\overline{X}_{low}$ = 44.5 ± 20.0	$\overline{X}_{high}$ = 23.5 ± 9.4 $\overline{X}_{low}$ = 20.2 ± 13.0	$\overline{X}_{high}$ = 4.3 ± 32.4 (n = 238) $\overline{X}_{low}$ = 3.9 ± 15.9 (n = 244)

Table 4

Seasonal mean (± SD) of interactions-day^{-1} of shared activities in three reefs from Bahía Culebra, Costa Rica.

Activity	Jícaro	Blanca	Virador
Leisure boating	$\overline{X}_{high}$ = 12.0 ± 4.9 $\overline{X}_{low}$ = 9.7 ± 3.5	$\overline{X}_{high}$ = 5.8 ± 1.8 $\overline{X}_{low}$ = 1.9 ± 1.4	$\overline{X}_{high}$ = 4.6 ± 2.6 $\overline{X}_{low}$ = 1.7 ± 0.5
Motorized tour	$\overline{X}_{high}$ = 32.7 ± 12.8 $\overline{X}_{low}$ = 22.3 ± 8.3	$\overline{X}_{high}$ = 23.7 ± 12.3 $\overline{X}_{low}$ = 18.2 ± 12.3	$\overline{X}_{high}$ = 16.1 ± 6.3 $\overline{X}_{low}$ = 7.6 ± 7.6
Non-motorized tour	$\overline{X}_{high}$ = 2.5 ± 1.0 $\overline{X}_{low}$ = 5.2 ± 4.9	$\overline{X}_{high}$ = 6.6 ± 3.9 $\overline{X}_{low}$ = 8.5 ± 7.6	
Transit	$\overline{X}_{high}$ = 2.3 ± 1.5 $\overline{X}_{low}$ = 12.2 ± 10.2	$\overline{X}_{high}$ = 6.3 ± 4.3 $\overline{X}_{low}$ = 8.2 ± 5.7	$\overline{X}_{high}$ = 4.1 ± 3.3 $\overline{X}_{low}$ = 6.2 ± 7.4
Snorkeling	$\overline{X}_{high}$ = 4.8 ± 1.5 $\overline{X}_{low}$ = 5.8 ± 2.3		

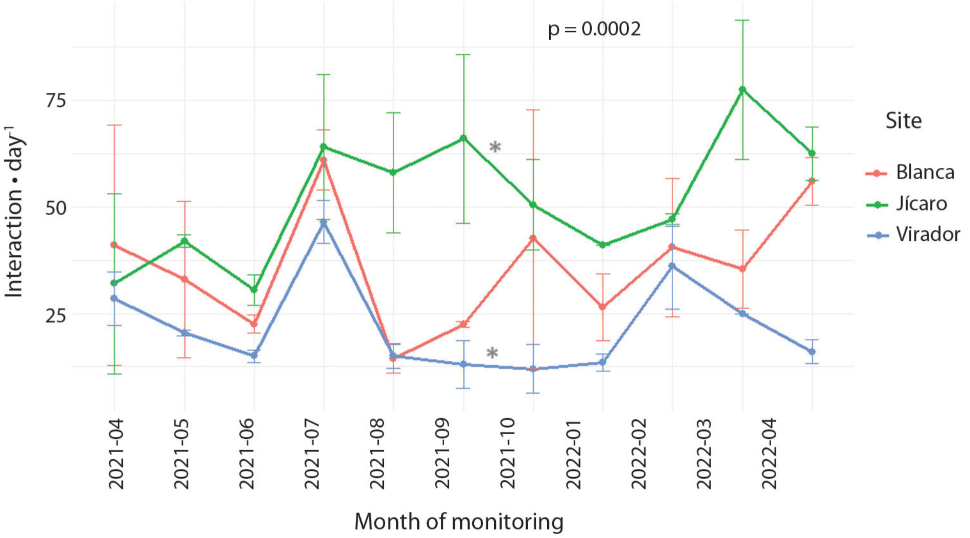

Fig. 3. Monthly variation of interactions during the monitoring period. Asterisks (*) indicate significant differences ($p < 0.05$), including the p-value from Dun's test. Error bars represent the standard deviation.

the number of users (H = 38.93, $p < 0.05$) among reefs (Fig. 4A). Jícaro reef exhibited significantly higher number of users, (a total of 4 055 users, representing 60.3 % of the total). Whereas Blanca and Virador reefs had a similar number of users ($p = 0.055$). See Table 1 for the daily average of users of each site.

Additionally, significant differences were detected in the number of users associated with each activity (H = 131.31, $p < 0.05$) across sites. Only transit exhibited similar values of users-day^{-1} across all sites (Table 2). At Jícaro reef, most of activities showed more associated users than at the other reefs, excepting for non-motorized tours had significantly more users at Blanca reef (H = 3.76, $p < 0.05$).

Regarding the temporal aspects of user patterns, the overall number of users did not differ significantly (U = 646.5, $p = 0.10$) between the high (111.0 ± 67.3 users-day^{-1}) and low seasons

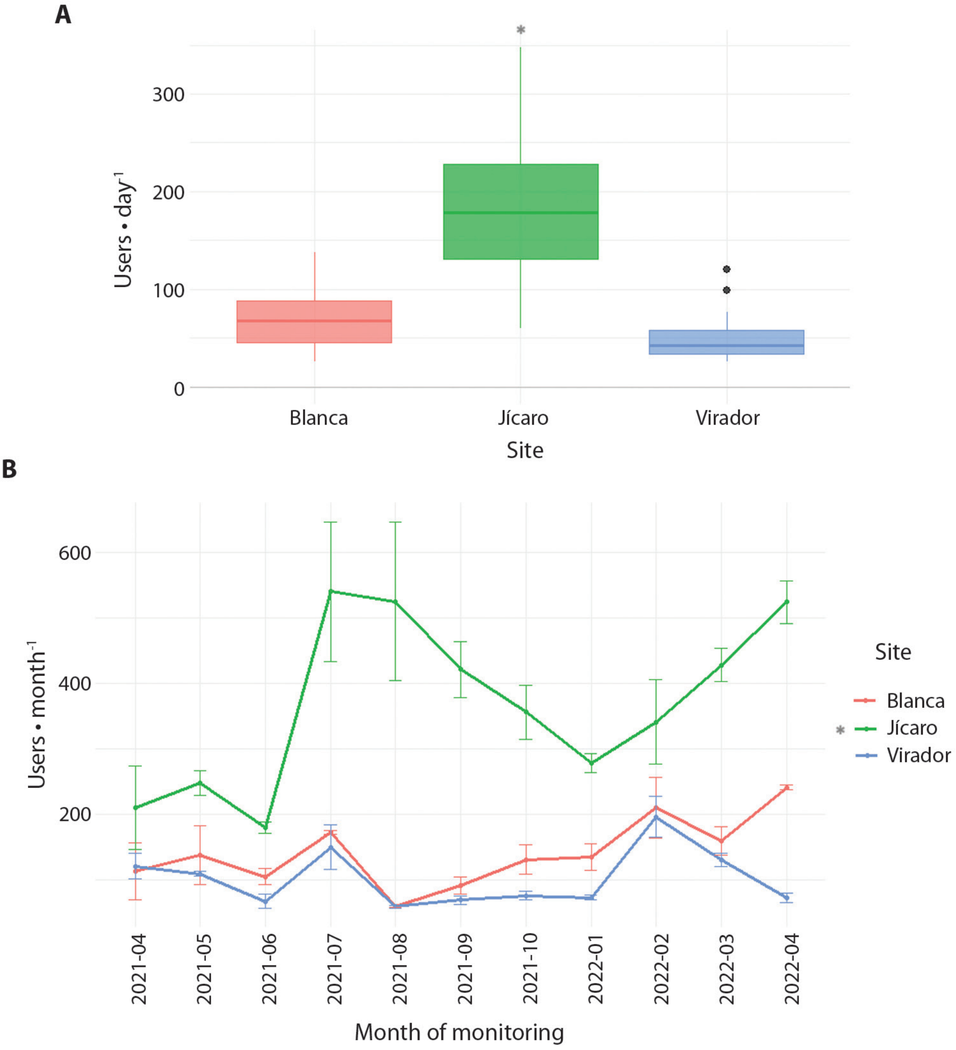

Fig. 4. A. Box plot of number of users-day^{-1} of each study site. The x-axis indicates the study sites, and the y-axis represents the number of users per day. Central horizontal lines within the boxes represent the median. Black points represent outliers. **B.**Monthly variation of interactions during the monitoring period. Asterisks (*) indicate significant differences ($p < 0.05$), including the p-value from Dun's test. Error bars represent the standard deviation.

(97.1 ± 84.1 users-day^{-1}). Similarly, when the analysis was conducted separately for each reef, no significant seasonal differences in the number of users·day^{-1} were detected at Blanca ($U = 88$, $p = 0.06$), Jícaro ($U = 60.5$, $p = 0.99$), or Virador ($U = 84.5$, $p = 0.11$) (Table 3).

Regarding monthly variation, significant differences in the number of monthly users were found among sites ($H = 21.5$, $p < 0.05$), with Jícaro reef showing the highest monthly mean users ($p = 0.004$) (Fig. 4B), whereas no significant differences were observed between Blanca and Virador reefs ($p = 0.56$). However, we did not find significant differences in the number of users among the monitored months (HBlanca = 12.83, HJícaro = 14.97, HVirador = 17.53, $p > 0.05$). Despite the absence of statistically significant monthly differences within sites, descriptive patterns indicated marked temporal fluctuations, with a decrease in user numbers across all sites in June 2021, followed by a sharp increase in July.

Watercrafts: We recorded a total of 2 284 interactions involving watercrafts, representing 93 % of all recorded interactions. Eight watercraft types were identified in the area (Table 1), of which jet skis (64.1%) and boats (23.4%) were the most abundant, followed by paddleboards (5.2%), kayaks (3.0%), catamarans (1.5%), panga, which is an artisanal short scale boat (1.5%), banana boats (1.4%), and towable tubes (< 1%). Mean interactions day^{-1} of jet skis and boats in each reef are shown in Table 5. When analyzing the number of watercraft interactions across sites, significant differences were detected ($H = 22.59$, $p < 0.05$). Jícaro and Blanca reefs showed similar values ($p = 0.07$) while Virador reef recorded significantly fewer watercraft interactions (Refer to Table 1 for mean watercraft interactions day^{-1} of each reef).

Table 5

Mean (± SD) interactions day^{-1}of jet skis and boats on three reefs from Culebra Bay.

	Jícaro	Blanca	Virador
Jet ski	28.31 ± 12.29	22.86 ± 12.79	12.07 ± 10.92
Boat	13.18 ± 5.28	5.90 ± 2.51	5.25 ± 3.32

A Correspondence Analysis (CA) revealed associations between specific watercrafts and the monitored sites ($\chi^2 = 312.37$, $p < 0.05$) (Fig. 5). Non-motorized watercraft such as paddleboards and kayaks were primarily

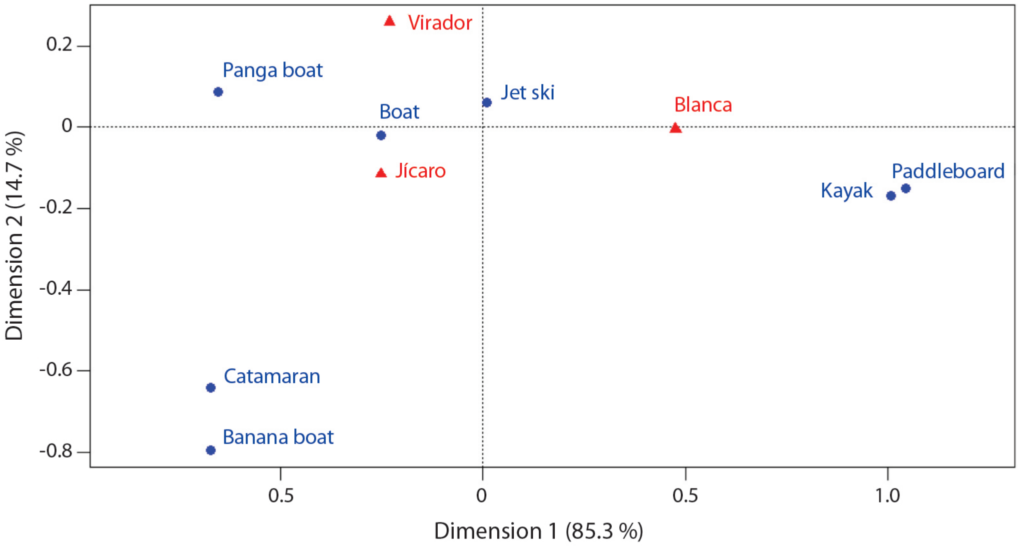

Fig. 5. Relationship between watercrafts and sites. Red points represent sites. Blue points represent watercrafts. The proximity between items indicates a stronger association between them.

associated with Blanca reef, whereas catamarans and banana boats were more frequent at Jícaro reef. Interactions involving pangas were mainly related with Virador reef. In contrast, jet skis and boats were the most frequent across all sites, showing no strong site-specific pattern.

Regarding the temporal attributes of watercrafts' occurring, no significant differences were found between high and low tourism seasons (38.0 ± 17.3 vs. 33.2 ± 19.0 interactions-day^{-1}; U = 612, p = 0.24), nor across individual months (H = 0.99, p = 0.61).

Interaction duration: In general, duration ranged from 0 to 480 min. Most interactions lasted less than one minute (65.6 %, n = 1 599), while 27.5 % (n = 670) lasted between 1 and 60 min. Longer interactions were less frequent: 5.7 % (n = 138) lasted between 61-120 min, and only 1.2 % (n = 30) exceeded 120 min. Significant differences were found among sites (H = 294.3, p < 0.005). As shown in Table 1, the mean interaction duration was similarly short at both Blanca and Virador reefs, with no significant difference between them (p = 0.71). In contrast, interactions at Jícaro reef were significantly longer. In addition, significant differences were detected in interaction duration among activities. Transit, motorized tours, leisure boating, and snorkeling lasted longer at Jícaro compared to Blanca and Virador (Table 2),while non-motorized tours and fishing showed similar durations in the sites where they occurred.

Concerning the interaction duration of watercrafts, significant differences were detected among sites (H = 689.4, p < 0.05). With the exception of paddleboards (p = 0.093) and panga boats (p = 0.263) which exhibited similar interaction duration across sites (Fig. 6). In contrast, jet skis (H = 75.1, p < 0.05), boats (H = 165, p < 0.05), and kayaks (H = 16.0, p < 0.05) showed significantly longer interaction times at Jícaro reef.

Concerning temporal aspects, interaction duration did not differ significantly between seasons at any of the reefs (Blanca: U = 83825, p = 0.49; Jícaro: U = 170960, p = 0.29; Virador: U = 29888, p = 0.41) (Table 3). In contrast, monthly differences in interaction duration

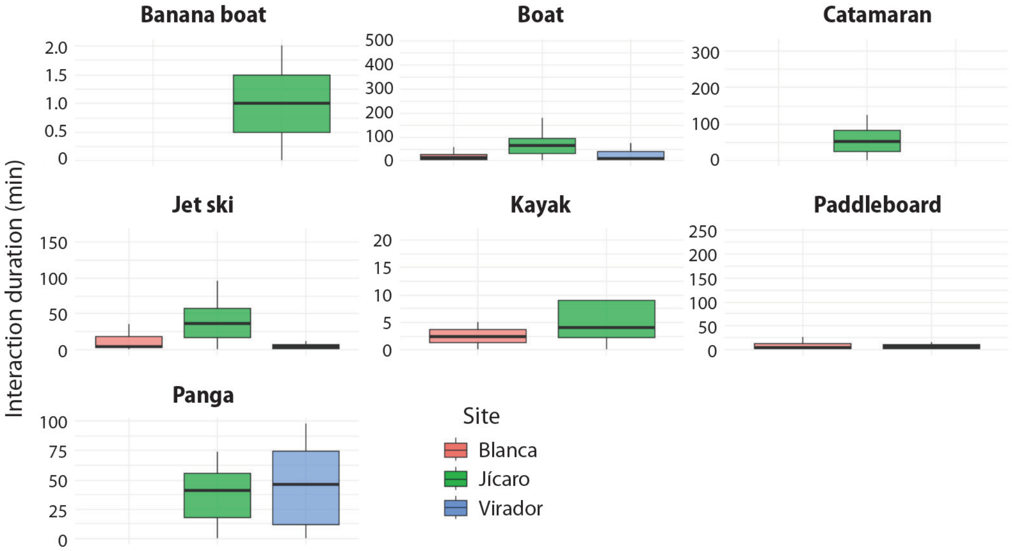

Fig. 6. Box plot representing the variability of interaction duration (min) across sites by the recorded watercrafts. The x-axis indicates the study sites, and the y-axis represents interaction duration (min). Central horizontal lines within the boxes represent the mean interaction duration. Black points represent outliers. Asterisks (*) indicate significant differences (p < 0.05).

were found across all sites ($H_{Blanca} = 26.94$; $H_{Jícaro} = 19.61$; $H_{Virador} = 26.69$; $p < 0.05$), with the longest mean durations occurring in April 2022 at Jícaro reef (32.39 ± 46.22 min), in February 2022 at Blanca reef (8.31 ± 33.27 min), and in January 2022 at Virador reef (19.59 ± 92.13 min).

DISCUSSION

Spatial characterization: The differences observed in the spatial distribution of tourism intensity among sites could be influenced by a combination of natural (Anfuso et al., 2017), social (Dolnicar et al., 2017; Giorgio et al., 2018), and economic factors (Spalding et al., 2017; Xiao et al., 2020). These include biodiversity richness, and ecosystem quality (McKenna et al., 2011), tourist preferences (Blanco-Pimentel et al., 2022), and the availability of tourism facilities and accessibility (Carey et al., 1997; Giorgio et al., 2018).

Jícaro reef received the highest proportion of tourism interactions (47% of the total), despite its lack direct infrastructure and restricted access by sea only. This phenomenon suggests that the site's pristine and exclusive environment may exert a stronger attraction than infrastructure-based convenience. Furthermore, Jícaro's natural characteristics, such as its limited exposure to waves, the shallow reef close to the shore, and its marine biodiversity, likely enhance its suitability for leisure boating and snorkeling (Wolf et al., 2019) compared to the other sites. This pattern is consistent with global tourism trends showing a growing tourist preference for pristine environments (Dolnicar, 2020; Dolnicar et al., 2017). Accordingly, Jícaro reef recorded the highest mean number of users significantly exceeding that of the other sites.

In contrast, the adjacent hotel infrastructure and better accessibility of Blanca and Virador reefs attract a different tourist segment (Dong, 2025), generating distinct patterns of site use (Mihai et al., 2023). At Jícaro reef, tourism intensity was characterized by group-based recreational activities, influenced by multiple external departure points to Jícaro reef (mainly Playa del Coco and Playa Hermosa), rather than by hotels within the immediate area (Cordero-Ulate, 2010; Sánchez-Noguera, 2012). Meanwhile, Blanca and Virador (Güiri-Güiri) reefs are more associated with logistical and operational uses linked to the nearby luxury hotel operations and services. This difference is reflected in the interaction duration: recreational activities at Jícaro reef lasted significantly longer than those at Blanca and Virador reefs, where interactions were shorter and primarily transit-related (Table 2). These findings suggest that Jícaro reef functions as a receiver of external tourism flows, contributing to its higher use intensity compared to the other two reefs.

Underwater activities were concentrated at Jícaro reef (Table 1), though their low frequency suggests they were isolated events. Other reefs in and near the bay (e.g., Monkey Head, Murciélago Island, Catalinas Islands) offer better conditions for diving, such a as greater visibility, depth and biodiversity (Giglio et al., 2015; Giorgio et al., 2018; Sánchez-Noguera, 2012). At Blanca reef, the prevalence of non-motorized tours likely reflects the availability of kayak and paddleboard rentals at the nearby hotel, rather than a genuine preference for these activities. This reinforces the idea that tourism infrastructure and natural reef features jointly shape activity distribution (Spalding et al., 2017). The case of Virador reef is interesting, as no direct reef-use touristic activities were identified there, but it was found that transit is the only tourism-related activity that occurs systematically there.

Fishing activity showed spatial shifts. While Jiménez (1997) and Jiménez (2001) reported 24 commercial dives off Playa Blanca (1995-1996), and none at Virador reef (Jiménez, 2001), our study found that fishing now occurs mainly at Virador reef, predominantly through snorkeling. We recorded 0.31 ± 0.46 interactions-day^{-1}, with an average interaction time of 65.60 ± 21.48 min. This shift may be related to recent improvements in ecosystem conditions following coral restoration efforts at Virador reef (Güiri-Güiri) (Fabregat-Malé et al., 2023).

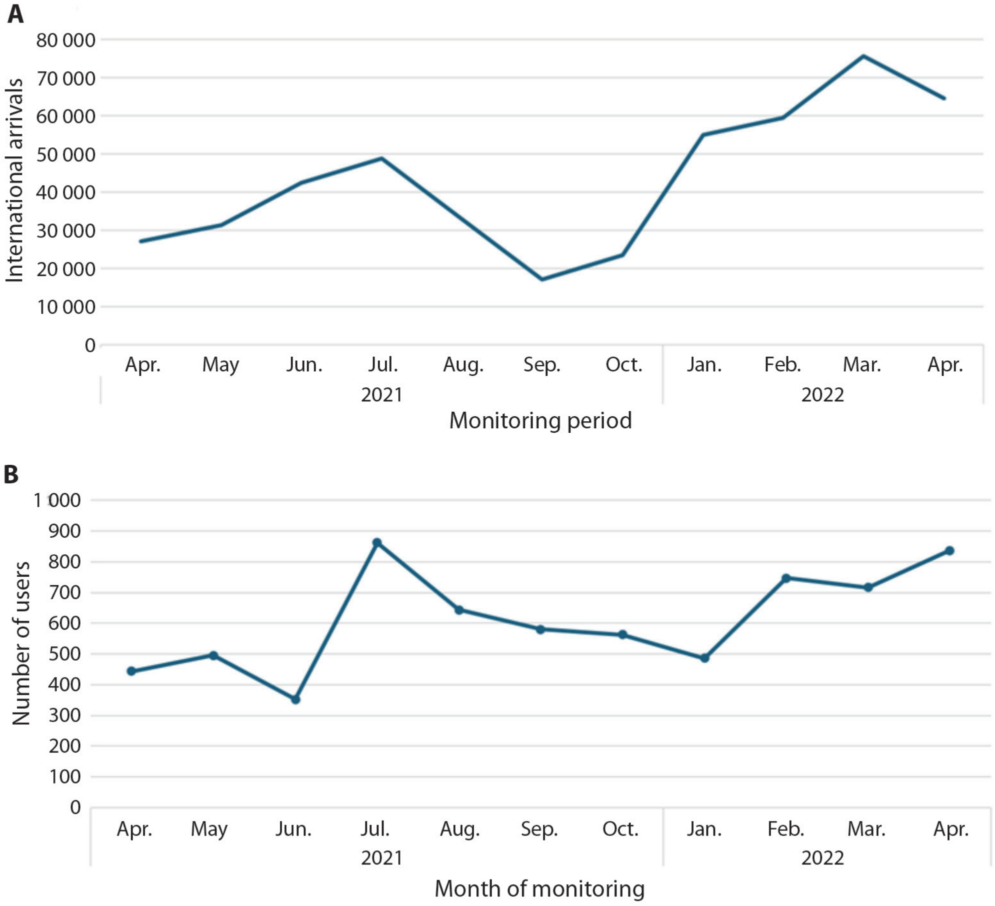

Fig. 7. A. International arrivals to International Airport Daniel Oduber Quirós, North Costa Rica, from national tourism authority (Instituto Costarricense de Turismo, ICT) data 2021-2022. **B.** Monthly variation of the number of users on the three sites.

Temporal characterization: During the monitoring period, Costa Rica was transitioning from COVID-19 restrictions toward gradual reopening of the tourism sector (Gómez-Meléndez, 2022; Instituto Costarricense de Turismo [ICT], 2023). In this context, we found that the mean ± SD number of interactions-day^{-1}, users-day^{-1}, interactions with aquatic vehicles-day^{-1}, and interaction time (min) were all higher during the high tourism season (December–April) compared with the low season (May–November). However, no statistically significant differences were detected between seasons or among individual sites. This absence of strong seasonality suggests a gradual recovery of coastal tourism one year after the “anthropause” (Rutz et al., 2020) caused by the COVID-19 shutdown.

To contextualize these dynamics, international tourist arrivals from the nearest airport were used as a proxy for regional tourism flow (Fig. 7). We observed a progressive increase in international arrivals between April 2021 and April 2022 (ICT, 2023), with marked peaks in July 2021 and March 2022. Although this pattern was not identical to the number of users in Bahía Culebra, similar peaks were evident in July 2021 and the first four months of 2022 (Fig. 7B). These temporal patterns may reflect local or national events, (e.g., national holidays, school breaks, spring break season), that temporally amplify visitor pressure. Comparable effects have been documented in other coral reef areas during special events (Widmer & Underwood, 2004), which often increase visitor numbers and alter behavior (e.g., alcohol consumption, lack of awareness of local regulations and the location of coral reefs and restoration sites). Such scenarios require adaptive management strategies to mitigate occasional surges in human impact and promote sustainable visitor behavior.

Ethical statement: The authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

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