SWST – International Society of Wood Science and Technology

How young visitors perceive mangrove ecosystem services: Technology use, environmental concern, and satisfaction in Indonesian ecotourism

BIOPRODUCTS BUSINESS

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Abstract: Understanding how ecotourism visitors perceive ecological environments is consequential for destination management and conservation planning, yet the perceptual dimensions through which visitors engage with mangrove ecosystems remain empirically uncharted. This study addresses that gap using data from young Indonesian visitors at two managed mangrove ecotourism sites in Bali and Kepri (Batam and Bintan). Exploratory factor analysis identified three perceptual dimensions: ecosystem condition, ecological learning, and ecological engagement. Partial least squares structural equation modeling (PLS-SEM) testing showed that smart technology use was most strongly associated with cognitive dimensions—ecological learning and ecosystem condition—while environmental concern showed its strongest association with ecological engagement. Ecological learning was the strongest predictor of visitor satisfaction, followed by ecological engagement and ecosystem condition. The structural model fit is acceptable though imperfect, and the dimensions are exploratory constructs requiring confirmatory validation before generalization. The results suggest that investment in interpretation infrastructure—particularly digital tools designed to deepen ecological comprehension—offers the most direct returns in visitor satisfaction at comparable ecotourism sites.

Keywords: mangrove ecotourism; visitor perceptions; ecological learning; smart technology; environmental concern; visitor satisfaction.

1. Introduction

Mangrove ecotourism has grown considerably as a form of nature-based tourism in coastal regions across Southeast Asia, with Indonesia—home to the world's largest mangrove coverage—at the forefront of developing these ecosystems as structured visitor destinations (Arifanti et al. 2022; Blanton et al. 2024). Visitors to mangrove sites are not passive observers; they walk boardwalks, engage with biodiversity, participate in conservation activities, and encounter ecological interpretation programs that make ecosystem services tangible (Kurniawati et al. 2022; Romanazzi et al. 2023). This direct, on-site engagement makes mangrove ecotourism a particularly instructive context in which to examine how visitors perceive the ecological environments they visit, and what shapes those perceptions.

Three gaps in the existing literature motivate this study. First, a lack of empirical studies identifying and validating the specific perceptual dimensions through which visitors to mangrove ecotourism sites interpret their ecological experiences. Prior research on ecosystem services has focused predominantly on ecological measurement and economic valuation; but how individual visitors perceive these services at the experiential level, namely what they notice,

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BioProducts Business 11(5), 2026, pp. 69–82. ISSN 2378-1394
https://doi.org/10.22382/bpb-2026-005

what they learn, and what they feel, has yet to be systematically modelled or measured in a mangrove context (Romanazzi et al. 2023; Xiao et al. 2025). Second, while the tourism experience literature has examined general dimensions of nature-based experience quality (Spalding et al. 2023; Sahabuddin et al. 2024), it has not identified dimensions that are empirically distinguishable in mangrove settings, nor whether they predict satisfaction differentially. Third, smart technology and environmental concern are frequently cited as relevant to visitor behavior in ecological settings (Shen et al. 2020; Pham and Khanh 2021), but their differential effects across distinct perceptual dimensions of the ecosystem experience, rather than on a single aggregated construct, remain underexplored.

Addressing these gaps requires an approach that combines scale development with structural modelling. This study first conducted focus group discussions to generate measurement items grounded in visitors' own descriptions of their mangrove experiences, then employed exploratory factor analysis (EFA) to identify the underlying perceptual dimensions, and finally applied partial least squares structural equation modeling (PLS-SEM) to test how smart technology and environmental concern influence those dimensions and how the dimensions influence visitor satisfaction. The study was conducted at two sites in Indonesia—Bali and Kepri (Batam and Bintan)—where mangrove ecotourism is well established and ecologically diverse.

Two research objectives guide the inquiry: to identify the empirical dimensions through which young visitors perceive mangrove ecosystem services, and to examine how smart technology and environmental concern are differentially associated with those dimensions and with visitor satisfaction.

2. Literature review and hypotheses development

2.1 Ecosystem experience as a visitor-level construct

A fundamental distinction runs through this study: ecosystem services are an environmental concept, while ecosystem experience is a visitor-level perceptual construct. Ecosystem services, the provisioning, regulating, and cultural benefits that natural systems deliver to human well-being (Costanza et al. 1998; Chan et al. 2012), describe what ecosystems do. Ecosystem experience, as used here, refers to what visitors perceive and feel when they interact with ecosystems on-site. The two are related but not identical: a mangrove forest provides coastal protection and carbon sequestration regardless of whether any visitor is present, but whether visitors perceive the ecological quality of the site, learn from its interpretive programs, or feel emotionally connected to the environment depends on the visitor's own attention, values, and motivation. Visitor perceptions are not direct readouts of ecological conditions; they are mediated by what visitors notice, how they interpret information, and what emotional responses they bring to the encounter. Experience economy theory (Pine and Gilmore 1998) holds that meaningful experiences emerge when individuals actively engage with distinctive environmental stimuli, and cultural ecosystem services in Chan et al.'s (2012) taxonomy encompass precisely the educational, aesthetic, and psychological benefits that arise from this engagement.

Empirical research suggests that visitors to nature-based environments do not perceive ecological environments uniformly; they distinguish among qualitatively different aspects of the experience. Spalding et al. (2023) show that satisfaction in nature-dependent tourism is shaped separately by perceptions of ecological integrity, learning opportunities, and emotional engagement. Xiao et al. (2025) find that urban park visitors distinguish between environmental quality evaluations and broader experiential benefits when assessing ecosystem services. In mangrove-specific contexts, Marasinghe et al. (2021), Murniati et al. (2025), and Lu et al. (2025) all find evidence of multidimensionality in visitor responses—visitors differentiate the physical condition of the site from its educational offerings and from their emotional connection to the natural setting. Chang et al. (2024) further demonstrate, in a broader tourist wellbeing framework, that affiliation with nature encompasses distinct affective, cognitive, and normative responses, each of which is empirically separable. Taken together, this body of evidence supports the proposition that visitor perceptions of mangrove ecosystem services are structured into recognizable dimensions rather than constituting a single undifferentiated response.

On this basis, the present study conceptualizes ecosystem experience as a multidimensional visitor-level construct with three empirically derived dimensions (Section 4.2). The first, ecosystem condition, captures how visitors evaluate the mangrove site's physical and ecological quality—its cleanliness, vegetation health, water clarity, and perceived protection from disturbance. The second, ecological learning, reflects visitors' perceived acquisition of knowledge about mangrove ecosystems and conservation through guides, interpretive programs, and educational activities on-site. The third, ecological engagement, captures the affective and restorative dimension of the visit: the sense of stress reduction, emotional connection with the natural environment, and heightened environmental responsibility that the encounter produces. All three are perceptual constructs in that they reflect what visitors report experiencing, not what the ecosystem objectively delivers. The proposed model examines how smart technology and environmental concern are each separately associated with all three dimensions and how each dimension is in turn associated with visitor satisfaction. Figure 1 presents the full structural model with nine hypothesized paths.

2.2 Smart technology and perceived ecosystem experience

Smart technology in ecotourism encompasses digital tools—mobile applications, QR-linked interpretation panels, augmented reality guides, and interactive ecological maps—that mediate the relationship between visitors and ecological environments (Chon and Hao 2025; Shen et al. 2020). The Technology Acceptance Model (TAM; Davis 1989) provides a relevant theoretical lens: the degree to which a technology is perceived as useful and easy to use is associated with the depth of engagement it generates. In this study, perceived usefulness is treated not as a driver of technology adoption, but as an interpretive mechanism through which visitors make sense of ecological environments. In an ecological interpretation context, digital tools perceived as genuinely informative may be associated with richer visitor comprehension of what they are observing. Lee and Jan (2018) provide supporting evidence in an integrative ecotourism model, demonstrating that the perceived usefulness of ecological information technologies is positively associated with how actively visitors engage with ecological environments. The implied mechanism is interpretive: tools that make ecological complexity legible may facilitate a shift from passive observation to more active perceptual engagement. This suggests relatively stronger associations with cognitively oriented dimensions—ecosystem condition and ecological learning—where comprehension of observable features is central, and a comparatively weaker association with ecological engagement, where emotional connection with the natural environment may draw more on direct sensory experience than on screen-mediated information.

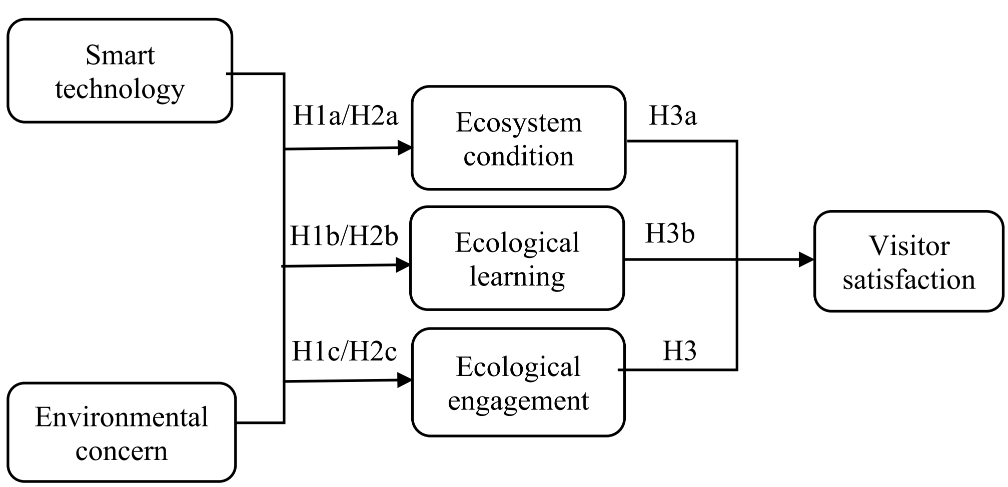

Figure 1. Ecosystem experience formation model.

The following hypotheses are proposed:

H1a: Smart technology positively influences perceived ecosystem condition.

H1b: Smart technology positively influences perceived ecological learning.

H1c: Smart technology positively influences perceived ecological engagement.

2.3 Environmental concern and perceived ecosystem experience

Here, environmental concern is defined as an individual's awareness of ecological problems and their disposition to respond through attentive and protective behaviors (Hackett 1993). Value-belief-norm (VBN) theory offers a plausible account of how this disposition may translate into differential visitor experience (Stern 2000; Stern et al. 1999). The theory proposes a value-to-norm sequence: biospheric values are associated with beliefs about the consequences of environmental degradation, which in turn are linked to personal norms toward protective or engaged behavior. In an ecotourism context, this sequence may be associated with heightened attentiveness to ecological cues, active engagement with conservation content, and a stronger felt connection with the natural environment. Lee et al. (2025) provide supporting evidence in a natural heritage destination setting, demonstrating that VBN-activated environmental awareness is positively associated with responsible and engaged visitor behaviors.

Applying this framework to the three dimensions yields differentiated predictions. Perceived ecosystem condition—evaluated primarily through visible physical cues such as water clarity, vegetation density, and site cleanliness—is relatively independent of visitor values; a clean, well-maintained site will be perceived as such by both concerned and unconcerned visitors. The effect of environmental concern is therefore predicted to be modest for this dimension. Ecological learning and ecological engagement, by contrast, require both motivationally oriented attention, which is receptiveness to conservation content, and a willingness to engage with ecological meaning. VBN-activated personal norms are expected to be associated with this orientation, with the strongest predicted association for ecological engagement, where value-driven environmental concern may accompany a more personally meaningful encounter with the natural environment.

The following hypotheses are proposed:

H2a: Environmental concern positively influences perceived ecosystem condition.

H2b: Environmental concern positively influences perceived ecological learning.

H2c: Environmental concern positively influences perceived ecological engagement.

2.4 Perceived ecosystem experience and visitor satisfaction

Visitor satisfaction in ecotourism is shaped differently from satisfaction in conventional tourism, where facility quality and service performance are primary drivers. In nature-dependent settings, the ecological environment itself is the primary experience asset, and satisfaction depends on the quality of the visitor's encounter with it (Spalding et al. 2023; Sahabuddin et al. 2024). Mangrove ecotourism is particularly demanding in this respect: the ecosystem is fragile, ecologically complex, and often unfamiliar to visitors. The three experience dimensions capture a gradient of engagement depth, from surface perception of physical quality through cognitive enrichment to emotional connection.

Each dimension is expected to contribute to satisfaction through a distinct pathway. Ecosystem condition functions as a quality signal. It may signal that the destination is well managed and ecologically healthy—a necessary but not sufficient condition for satisfaction. Ecological learning contributes through cognitive enrichment. The transformation of a recreational outing into a meaningful educational encounter is a process particularly consequential for young, educated visitors who seek purposeful travel experiences (Murniati et al. 2025). This learning–satisfaction link is supported by Liu et al. (2024), who find that ecological experiential learning in marine protected areas predicts satisfaction through both cognitive and affective pathways. Ecological engagement contributes through affective restoration: attention restoration theory (Kaplan 1995) suggests that soft-fascination stimuli of mangrove environments—tidal movement, root systems, birdlife—may be associated with recovery from directed attention fatigue and a sense of refreshment visitors evaluate positively.

The following hypotheses are proposed:

H3a: Perceived ecosystem condition positively influences visitor satisfaction.

H3b: Perceived ecological learning positively influences visitor satisfaction.

H3c: Perceived ecological engagement positively influences visitor satisfaction.

3. Research methods

3.1 Scale development

Because no validated instrument existed for measuring visitor perceptions of ecosystem services in mangrove ecotourism, the ecosystem experience scale was developed for this project. Two focus group discussions (FGDs) were conducted with individuals who had previously visited at least one mangrove ecotourism site in Indonesia within the prior 12 months. Participants were recruited purposively through visitor networks and social media groups associated with nature-based tourism in coastal Indonesia. The first FGD comprised eight participants and the second seven, all within the 18–35 age range. Sessions were audio-recorded and transcribed verbatim.

Scale development followed a thematic content analysis procedure (Braun and Clarke 2006). Two researchers independently coded the transcripts, generating 47 initial codes across both sessions. Codes were compared, disagreements resolved through discussion, and semantically overlapping codes merged into thematic clusters. This process yielded 20 candidate indicators capturing the range of participants' experiential descriptions. Content validity was established through review by two academics with expertise in ecotourism and tourism experience measurement, who assessed item clarity, unambiguity, and representativeness of each thematic cluster. Five items were revised based on their feedback, and a pilot test with 20 young mangrove visitors produced two further minor wording adjustments. All 20 items were retained.

Scales for the remaining constructs were adapted from established studies. Environmental concern was measured with five items reflecting ecological awareness and affective responses to environmental degradation (Gonzalez-Rodriguez and Tussyadiah 2022). Smart technology was assessed with five items capturing perceptions of digital interpretation tool usefulness during the visit (Jeong and Shin 2020; Shen et al. 2020). Visitor satisfaction was measured with three items evaluating overall visit quality (Astor et al. 2024; Quynh et al. 2021). All items were rated on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree).

3.2 Sample and data collection

The study targeted young Indonesian visitors (aged 18–35) at two mangrove ecotourism sites in Indonesia: the Bali site (Tahura Ngurah Rai) and the Kepri site (Batam and Bintan). The Bali site is a government-managed conservation area of 1,373 ha with a 1.9 km boardwalk. The Kepri site (Batam and Bintan) spans two islands with contrasting management models: the Batam component is community-managed, while the Bintan component is operated as a resort-based ecotourism destination by a major private tourism company. Both sites share a similar digital interpretation profile: on-site interpretation panels are present throughout, with QR codes and augmented reality features available at selected points rather than uniformly deployed. A mobile application is accessible at each site, though uptake varies by visitor. The Bintan component of the Kepri site additionally features a locally developed species identification application. This pattern of partial, incremental digital deployment is characteristic of Indonesian ecotourism sites across the management spectrum—from community-managed boardwalks to resort-based commercial operations—where full-scale smart technology integration remains the exception rather than the norm (Chon and Hao 2025). The smart technology items in this study captured visitor perceptions of digital interpretation tools encountered during the visit and were appropriate for this infrastructure context, with the acknowledgment that individual exposure to specific tools varied across respondents. Data were collected from 147 respondents at the Bali site and 192 at the Kepri site, reflecting relative visitor volumes during the collection period. Ten trained research assistants approached visitors at exit points immediately following their site exploration and invited them to complete a self-administered questionnaire. Invitations to participate were offered to those who had completed their visit and had interacted directly with the mangrove environment. Two formats were used: printed forms distributed on-site and an equivalent online version accessed via QR code. Of 375 individuals approached, 339 completed the questionnaire, yielding a response rate of approximately 90.4%. The high rate reflects the on-site timing, assistant-supported administration, and brief instrument duration of approximately 8 minutes. Social desirability pressure from the presence of an assistant represents a potential bias risk that cannot be fully excluded.

The sampling strategy was purposive sampling: respondents were selected based on their presence at the sites during the data collection period, not through a probabilistic mechanism. Although the sample size exceeded minimum PLS-SEM requirements (Hair et al. 2022), those requirements address estimation stability—not representativeness. The sample skewed toward college-educated young adults, reflecting the actual visitor profile at managed urban-adjacent mangrove sites in Indonesia, and environmental concern scores likely sit toward the higher end of what an unselected population would yield. Site was not included as a formal control variable; the two subsamples differ in size and in management context, meaning site-level variation cannot be ruled out as a partial confound—a limitation addressed in Section 7. The mixed questionnaire modes introduce potential mode effects that cannot be disentangled analytically. These constraints are discussed fully in Section 7.

Institutional review board approval was obtained before data collection. All participants provided informed consent, and survey respondents received a study information sheet covering purpose, voluntary participation, and anonymity. No identifying information was collected.

3.3 Analytical procedure

The analysis comprised two stages. The first used exploratory factor analysis (EFA) in SPSS—principal axis factoring with oblique rotation—to identify the latent structure of the 20 ecosystem experience items. Factors were retained using three convergent criteria: eigenvalues exceeding 1.0, a clear scree plot elbow, and theoretical interpretability. EFA identified empirical groupings within this sample; it did not confirm stable, generalizable constructs. The three dimensions are therefore exploratory, and sample-specific factor solutions were carried forward because their structure was sufficiently clear to justify structural testing.

The second stage used PLS-SEM in SmartPLS to test the proposed relationships among smart technology, environmental concern, the three experience dimensions, and visitor satisfaction. PLS-SEM was selected for its suitability for exploratory constructs and EFA-derived scales, its tolerance of non-normal distributions confirmed by preliminary skewness and kurtosis inspection, and its appropriateness for models with few indicators per construct (Hair et al. 2022). The measurement model was assessed for reliability employing Cronbach's Alpha and Composite Reliability (CR), convergent validity (AVE), and discriminant validity (HTMT). The structural model was evaluated for path coefficients, bootstrapped significance, explained variance, model fit (SRMR, NFI), and evidence of problematic multicollinearity (VIF). The absence of confirmatory validation in this two-stage approach is acknowledged in Section 7. Common method bias was assessed using Harman's single-factor test (Podsakoff et al. 2003). An unrotated principal component analysis of all 33 items yielded a first factor accounting for 28.7% of total variance, well below the 50% threshold conventionally associated with dominant common method variance. This result offers preliminary reassurance, though Harman's test is a necessary rather than sufficient check and does not rule out more diffuse method inflation.

4. Data analysis

4.1 Respondent characteristics

Table 1 summarizes the demographic profile of the 339 respondents. The sample is gender-balanced and skews young, with the majority aged 18–24 and holding college or university qualifications. Most visited with friends or family. This profile—young, educated, socially motivated—is consistent with the actual visitor base at managed urban-adjacent mangrove sites in Indonesia and shapes the interpretive frame for the findings: these are visitors with the educational background and social context to engage meaningfully with ecological interpretation, which bears directly on the satisfaction patterns observed.

4.2 Perceived ecosystem experience dimensions

Exploratory factor analysis of the 20 ecosystem experience indicators yielded a three-factor solution accounting for 66.9% of total variance. Sampling adequacy was confirmed by a Kaiser–Meyer–Olkin value of 0.940 and Bartlett's test of sphericity ($p < 0.01$). Cronbach's alpha values for all factors exceeded 0.80. Table 2 presents the factor loadings.

The three factors were interpreted as follows. Ecosystem condition reflects visitor perceptions of mangrove ecological quality—cleanliness, vegetation health, water quality, and site protection. The second, ecological learning, reflects perceived opportunities to acquire knowledge about mangrove ecosystems and conservation through educational activities, interpretive programs, and guides. The third, ecological engagement, reflects affective and restorative dimensions of the visit, including perceived stress reduction, sense of psychological restoration, feelings of environmental responsibility, and emotional connection with the natural environment.

Table 1. Respondent characteristics.

Variable	Description	Frequency	Percentage
Gender	Male	170	50.1
	Female	169	49.9
Age	18–24	196	57.8
	25–35	143	42.2
Education	Less than high school	2	0.6
	High school	118	34.8
	College Degree	166	49.0
	University Degree	53	15.6
Occupation	Students	76	22.4
	Private employee	112	33.0
	Government employee	37	10.9
	Professional	29	8.6
	Entrepreneur	39	11.5
	Other	46	13.6
Visit companion	Alone	31	9.1
	Friends/family	248	73.2
	Tour group	60	17.7

Table 2. Exploratory factor analysis results.

Indicator	Ecosystem condition	Ecological learning	Ecological engagement
Clean and well-maintained environment	0.826	0.221	0.128
Healthy mangrove ecosystem	0.698	0.316	0.126
Clear, unpolluted water	0.785	0.223	0.256
No visible litter or pollution	0.847	0.105	0.149
Area effectively protected from disturbance	0.757	0.240	0.220
Educational conservation activities	0.267	0.756	0.149
Learned about ecosystem threats	0.051	0.701	0.404
Increased knowledge of mangrove conservation	0.091	0.658	0.422
Accessible information about mangroves	0.452	0.586	0.135
Participated in conservation efforts	0.117	0.541	0.558
Knowledgeable guides	0.074	0.717	0.300
Clear safety measures	0.317	0.707	0.200
Insights into local culture and mangroves	0.413	0.733	0.123
Participation in conservation activities	0.522	0.569	0.235
Reduced stress	0.199	0.285	0.766
Peaceful atmosphere	0.367	0.203	0.706
Felt mentally refreshed	0.238	0.244	0.756
Photo-worthy spots	0.191	0.376	0.773
Increased sense of environmental responsibility	0.198	0.283	0.729
Felt connected to the mangrove ecosystem	0.491	0.008	0.557

The breadth of the ecological engagement construct—spanning restorative, aesthetic, and pro-environmental elements—warrants both theoretical comment and methodological caution. Theoretically, this breadth is consistent with Chang et al.'s (2024) conceptualization of tourist affiliation with nature as a unified wellbeing construct encompassing affective, restorative, and normative responses, and with Attention Restoration Theory's prediction that mangrove environments elicit an integrated cluster of restorative outcomes (Kaplan 1995). However, two indicators in Table 2 show cross-loadings that require explicit attention. "Participated in conservation efforts" loads 0.541 on Ecological Learning and 0.558 on Ecological Engagement—a difference of only 0.017, meaning it does not cleanly discriminate between the two factors. "Felt connected to the mangrove ecosystem" loads 0.557 on Ecological Engagement and 0.491 on Ecosystem Condition. Both indicators were retained on the basis of their primary loadings and acceptable reliability statistics, but they represent points of construct instability. Future scale development work should revise their wording to sharpen discriminant content or test whether they belong in a separate dimension.

4.3 Measurement model

Table 3 presents measurement model results. All reliability (α: 0.874–0.913; CR ≥0.90), convergent validity (AVE ≥0.50; all loadings ≥0.70), and discriminant validity (HTMT <0.90; Henseler et al. 2015) criteria are met. The measurement model provides an adequate basis for structural analysis.

However, statistical acceptability does not fully resolve the conceptual concerns surrounding ecological engagement. Its indicators span restorative experience (Kaplan 1995), aesthetic appreciation, affective bond with nature, and normative orientation. That these load onto a single factor is an empirical finding, not a theoretical given; in a different sample they may separate. The high AVE (0.706) establishes co-variation, not conceptual coherence. It bears stating explicitly: the measurement results reported here constitute exploratory structural evidence, not construct validation. The statistical criteria satisfied—reliability, AVE, HTMT—are necessary conditions for proceeding with structural analysis in an exploratory context; they do not confirm that the dimensions are stable or generalizable. Researchers using the ecological engagement construct in future studies should treat its boundaries as provisional and subject to refinement through confirmatory analysis.

4.4 Structural model

Before presenting the path results, two preliminary observations about model quality are warranted. First, the fit of the estimated model is acceptable but not strong. The SRMR of 0.091 exceeds the widely cited threshold of 0.08, and the NFI of 0.825 falls below the 0.90 level conventionally associated with good fit. The saturated model performs better (SRMR = 0.062), indicating that the structural constraints imposed by the estimated model account for some of the residual misfit. These values suggest the model captures the main patterns in the data but does not account for all covariation. It should therefore be interpreted as a useful approximation, not a well-confirmed structural description. Second, for the structural model relationships, all VIF scores fell below 3.0 (max = 2.193), making critical collinearity unlikely. Third, all nine direct hypotheses are statistically supported—noteworthy in a single-sample exploratory model where universal support may reflect common method variance or PLS-SEM path sensitivity rather than theoretical strength. Readers should interpret the supported hypotheses given these constraints.

With these qualifications in mind, the path coefficients in Table 4 reveal a pattern that is itself substantively informative. Statistical significance alone is not the appropriate criterion for evaluating substantive importance: effect sizes differ considerably, and those differences carry interpretive weight. For smart technology, effects on ecological learning ($\beta = 0.581$) and ecosystem condition ($\beta = 0.565$) are both large; the effect on ecological engagement ($\beta = 0.397$) is smaller, consistent with the expectation that affective connection is less susceptible to technological mediation. For environmental concern, the contrast is sharper: the path to ecosystem condition ($\beta = 0.093$, $p = 0.016$) is weak and statistically fragile, while paths to ecological learning ($\beta = 0.309$) and ecological engagement ($\beta = 0.414$) are substantially larger.

Among the three dimensions, ecological learning is by far the strongest predictor of visitor satisfaction ($\beta = 0.497$), with ecological engagement contributing

Table 3. Measurement model results.

Variable/Indicator	Loading	Cronbach α	CR	AVE
Ecosystem condition		0.900	0.925	0.712
Clean and well-maintained environment	0.863			
Healthy mangrove ecosystem	0.786			
Clear, unpolluted water	0.866			
No visible litter or pollution	0.864			
Area effectively protected from disturbance	0.838			
Ecological learning		0.915	0.928	0.591
Educational conservation activities	0.739			
Learned about ecosystem threats	0.759			
Increased knowledge of mangrove conservation	0.765			
Accessible information about mangroves	0.718			
Participated in conservation efforts	0.741			
Knowledgeable guides	0.782			
Clear safety measures	0.784			
Insights into local culture and mangroves	0.825			
Participation in conservation activities	0.800			
Ecological engagement		0.897	0.923	0.706
Reduced stress	0.877			
Peaceful atmosphere	0.822			
Felt mentally refreshed	0.834			
Photo-worthy spots	0.823			
Increased sense of environmental responsibility	0.843			
Felt connected to the mangrove ecosystem	0.825			
Smart technology		0.897	0.920	0.698
Used digital tools to access mangrove information	0.854			
Mobile app provided guidance during the visit	0.891			
Digital media helped explain mangrove ecosystems	0.857			
Navigation tools helped explore the mangrove area	0.751			
Digital information explained tides and water conditions	0.817			
Environmental concern		0.917	0.934	0.738
I feel concerned when ecosystems are damaged	0.788			
Protecting natural ecosystems is very important to me	0.859			
Ecotourism can support environmental conservation	0.891			
Visiting nature increases my environmental awareness	0.883			
Preserving mangrove ecosystems is important to me	0.870			
Visitor satisfaction		0.874	0.923	0.799
I am happy with my mangrove visit	0.895			
The experience met my expectations	0.882			
Overall, I am satisfied with this visit	0.904			

Note: All loadings significant at $p < 0.01$.

Table 4. Structural path results.

Relationship (Hypothesis)	β	t-value	p-value
Direct effects			
Smart technology → Ecosystem condition (H1a)	0.565	13.324	0.000
Smart technology → Ecological learning (H1b)	0.581	15.332	0.000
Smart technology → Ecological engagement (H1c)	0.397	8.148	0.000
Environmental concern → Ecosystem condition (H2a)	0.093	2.413	0.016
Environmental concern → Ecological learning (H2b)	0.309	6.473	0.000
Environmental concern → Ecological engagement (H2c)	0.414	8.170	0.000
Ecosystem condition → Satisfaction (H3a)	0.115	2.362	0.019
Ecological learning → Satisfaction (H3b)	0.497	9.912	0.000
Ecological engagement → Satisfaction (H3c)	0.275	5.025	0.000
Indirect effects			
Environmental concern → Satisfaction	0.278	6.417	0.000
Smart technology → Satisfaction	0.463	14.127	0.000

Note: SRMR (estimated model) = 0.091; SRMR (saturated model) = 0.062; NFI (estimated) = 0.825; R^2 Satisfaction = 0.631.

meaningfully (β = 0.275) and ecosystem condition making a comparatively modest contribution (β = 0.115). The R^2 for satisfaction is 0.631—substantial for a self-report perceptual model, though to be interpreted alongside the model fit concerns above. Indirect effects are also significant: smart technology (β = 0.463) and environmental concern (β = 0.278) both reach satisfaction through the three dimensions, consistent with the theoretical model. These effects are a function of the direct paths, however, and inherit their caveats.

5. Discussion

This study identified perceptual dimensions of visitor ecological experience at mangrove ecotourism sites in Indonesia and examined their associations with smart technology, environmental concern, and visitor satisfaction. The findings are context-specific and exploratory and should not be generalized as explanations of how mangrove ecosystem services are interpreted elsewhere. The three dimensions are consistent with broader conceptualizations of visitor-nature interaction (Chan et al. 2012; Romanazzi et al. 2023) and with emerging cross-national evidence in mangrove ecotourism identifying differentiated visitor behavior pathways (Lu et al. 2025).

Smart technology showed its strongest associations with ecological learning and ecosystem condition, and a comparatively weaker association with ecological engagement. This pattern is consistent with the TAM-based interpretive argument (Lee and Jan 2018); digital tools perceived as genuinely informative co-occur with stronger reported perceptions of ecological knowledge acquisition and site quality. The pattern makes contextual sense: at both study sites, QR panels and mobile applications are deployed specifically at ecologically informative points along the boardwalks, directing visitor attention toward species characteristics, ecosystem functions, and conservation status. Visitors who engaged with these tools were simultaneously engaging with the environment in an interpreted, cognitively active mode—which may partly explain why technology use and ecological learning scores moved together in this sample. The result indicates an association, not a causal demonstration; ecologically curious visitors may have sought out digital tools and reported richer engagement independently of tool effects.

Environmental concern showed a different pattern, with its strongest associations on ecological learning and ecological engagement, and a near-threshold association with ecosystem condition. This is consistent with the VBN-based expectation that ecologically value-oriented visitors approach natural environments with heightened attentiveness and receptiveness (Stern 2000; Lee et al. 2025). At both study sites, where ecological quality is actively maintained and relatively visible, the physical environment likely registers as acceptable to most visitors regardless of their values—which may explain why environmental concern was only weakly associated with ecosystem condition perceptions in this sample. By contrast, ecological engagement and learning—which require motivated attention—appear to differentiate high- from low-concern visitors more meaningfully. These patterns remain associational, and the sample likely over-represents environmentally concerned visitors, so estimates may not generalize to less ecologically motivated populations.

Ecological learning was the strongest correlate of visitor satisfaction among the three dimensions, followed by ecological engagement, with ecosystem condition making a comparatively modest contribution, consistent with a hygiene factor interpretation. This pattern aligns with Liu et al. (2024), who found that ecological experiential learning in marine protected areas is associated with satisfaction through both cognitive and affective pathways. It is also consistent with the visitor profiles at both study sites: the majority were college-educated young adults visiting with friends or family—a group for whom a trip to a nationally recognized conservation park in Bali or a community-managed boardwalk in Kepri carries an implicit expectation of learning something meaningful, not merely of spending time outdoors. Visitors who reported higher ecological learning scores appear to have experienced the site in a way that matched or exceeded that expectation. Whether operators can reliably engineer these outcomes through interpretation improvements is a question this study raises but cannot answer from the current cross-sectional design. Two constraints apply to all findings: common method variance may have inflated the associations, and the three dimensions remain unvalidated in independent data.

6. Implications

6.1 Theoretical implications

Establishing new theory was not the purpose of this research; it applies existing frameworks to an underexplored context. Three bounded contributions can be defended. First, the study provides the first empirically structured account of visitor perceptions of ecosystem services in a mangrove ecotourism context, using scale development grounded in participant language. The three dimensions are sample-derived empirical groupings—a perceptual vocabulary for mangrove ecotourism that future confirmatory work can test, refine, or challenge. This is empirical mapping, not theory construction.

Second, the study extends TAM to the interpretive function of digital tools in ecological settings (Lee and Jan 2018). The finding that technology use is more strongly associated with cognitive experience dimensions than with affective engagement identifies a boundary condition worth investigating further: the affective dimensions of ecological experience appear to lie partly outside the reach of technological mediation. Third, the study operationalizes VBN in a visitor experience context (Lee et al. 2025): environmental concern shows its strongest association with ecological engagement and barely reaches significance for ecosystem condition—consistent with the expectation that value-activated orientations drive motivated engagement more than passive physical evaluation.

What this study does not contribute is a validated theoretical framework for understanding mangrove ecosystem experiences. The dimensions are exploratory, the model imperfect, and the sample narrow. Theoretical advancement will require confirmatory construct validation, multi-context replication, and longitudinal designs that trace on-site perceptions into longer-term conservation outcomes. The present study provides an empirically grounded starting point from which those confirmatory steps can proceed in a principled direction.

6.2 Managerial implications

Investment priority 1: interpretation infrastructure as a budgetary commitment. Ecological learning was the strongest correlate of visitor satisfaction, and smart technology its strongest associated antecedent. The allocation logic differs by management type. At government-managed sites such as the Bali site, the case is for how conservation agencies justify digital interpretation spending within site budgets. At community-managed and privately operated sites such as those in Kepri, the case is for direct investment in interpretation infrastructure as a driver of visitor satisfaction. Across all three models, the pattern is consistent: where interpretation infrastructure is strong, visitor ecological learning—and satisfaction—follow. Practical tools include QR-linked species panels at ecologically significant boardwalk points, mobile audio guides narrated by local naturalists, and species identification applications accessible at site entry. Design quality matters: low uptake should prompt review, not additional promotion spending.

Investment priority 2: ecological quality as a non-negotiable baseline. Ecosystem condition showed the weakest association with satisfaction, consistent with a hygiene logic: visible deterioration would likely drive dissatisfaction sharply, but quality above a basic threshold yields diminishing returns. For government site managers, this translates into a defensible argument for maintenance appropriations: ecological upkeep is visitor retention, not discretionary enhancement. Visible indicators—clean pathways, unpolluted water, healthy vegetation—must reliably meet expectations. Conservation signage can convert maintenance effort into perceived commitment at marginal additional cost.

Investment priority 3: community engagement as both policy and practice. Ecological engagement was shaped more strongly by environmental concern than by smart technology, meaning its returns depend substantially on visitor profile. Sites like those at Bali and Kepri studied here, which draw environmentally motivated visitors, are well positioned for participatory programming: guided mangrove planting, biodiversity monitoring, and citizen science activities. Sites with more mixed profiles may need accessible entry points—short guided walks with ecological narratives—to build engagement first. The study sites illustrate two distinct but instructive models. At community-managed sites such as Batam, facilitation embeds local stewardship into operations and aligns livelihood incentives with ecological health—a model that bioproducts businesses can join by co-developing interpretation products with local facilitators. At professionally operated resort-based sites such as the Bintan component, the infrastructure and visitor profiles support more sophisticated ecological programming. Bioproducts businesses here can partner at a commercial scale, co-designing premium interpretation experiences that connect visitors directly to the ecosystem services underpinning the resort's appeal.

7. Limitations and future research

Several interconnected limitations define the appropriate scope of inference. The sampling design is purposive sampling confined to two sites, and the findings cannot be generalized beyond comparable managed urban-adjacent mangrove ecotourism sites in Indonesia. The two sites differ in management type, surrounding tourism economy, and digital infrastructure maturity; with subsamples of unequal size and no site variable in the structural model, site-level differences cannot be ruled out as a partial confounding of the observed paths. Future multi-site studies should include site as a grouping variable for multi-group analysis. A related limitation concerns the smart technology construct specifically: digital interpretation infrastructure at both sites was partially rather than uniformly deployed, meaning individual respondents varied in their actual exposure to QR panels, augmented reality features, and mobile applications during their visit. The smart technology scores therefore reflect perceptions of tools encountered rather than a standardized experience, and variation in exposure may have introduced measurement noise that cannot be disentangled from attitudinal variation in the current data. The respondent profile is narrow: college-educated visitors aged 18–35 are over-represented, and environmental concern scores likely sit toward the higher end of what an unselected sample would yield, which may attenuate estimated concern effects. The three experience dimensions are EFA-derived groupings from a single sample—they have not been subjected to confirmatory factor analysis, multi-group testing, or cross-sample validation. The ecological engagement construct in particular spans restorative, aesthetic, and normative elements that future confirmatory work may need to split or reconceptualize.

All constructs are measured through self-reported perceptions at a single time point, immediately post-visit. This design cannot establish associational direction and is subject to common method variance that may have inflated the path pattern. Social desirability pressure from assistant presence and mixed questionnaire modes represents further, unresolvable bias risks. The structural model fit is imperfect—SRMR exceeds the 0.08 threshold—indicating that the model provides a useful but incomplete account of the data.

These limitations point toward a specific future research agenda. The most critical next step is CFA in an independent sample to test whether the three-factor structure can be replicated and whether ecological engagement requires refinement. Multi-group analysis across site types (remote versus urban-adjacent; government-, community-, and privately managed) would establish boundary conditions. Longitudinal and experimental designs would trace how perceptions form, and whether technology interventions cause the associations observed here. Finally, broader demographic sampling would test whether VBN-based predictions generalize beyond self-selected ecotourism populations.

8. Conclusion

This study examined how young visitors to mangrove ecotourism sites in Indonesia perceive their ecological experiences and how those perceptions relate to visitor satisfaction. Three perceptual dimensions were identified through exploratory factor analysis—ecosystem condition, ecological learning, and ecological engagement—and PLS-SEM testing indicated that smart technology and environmental concern are differentially associated with these dimensions. Ecological learning was the strongest correlate of visitor satisfaction among the three. These patterns are consistent with the theoretical frameworks applied, but should be read as an exploratory, context-specific account rather than a confirmed causal model. If ecological learning consistently distinguishes satisfied from less satisfied mangrove ecotourists, then interpretation—not site marketing or infrastructure expansion—is where investment should concentrate. Making that outcome more reliably achievable is the work.

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