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COLOUR IN UNDERWATER PHOTOGRAPHY: TECHNICAL CHALLENGES, VISUAL AESTHETICS AND MARINE CONSERVATION PERSPECTIVE

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ABSTRACT

Colour is central to underwater photography, yet improvements in visual appeal do not necessarily establish colour accuracy or reliable ecological interpretation. This paper examines the optical challenges affecting underwater colour, its aesthetic role in photographic storytelling, and its implications for marine conservation. A qualitative narrative review combines literature-based discussion with illustrative visual interpretation, organised around optical image formation, photographic meaning and ocean literacy. The synthesis identifies three connected issues: absorption and scattering constrain colour reproduction; lighting and digital enhancement influence subject visibility and visual meaning; and conservation applications require transparent processing and appropriate reference information. Artificial intelligence offers additional enhancement capabilities, but perceptual improvement alone cannot validate ecological accuracy. The paper proposes a conceptual connection between image formation, visual interpretation and conservation use, while distinguishing interpretive propositions from measured audience responses. Practical implications include retaining original image files, documenting editing decisions and using standardised acquisition procedures when photographs support ecological monitoring. The contribution is an interdisciplinary account of colour as both an aesthetic resource and an evidential responsibility in underwater photography.

Keywords: Underwater Photography, Colour Fidelity, Visual Communication, Marine Conservation, Image Enhancement

INTRODUCTION

Underwater photography brings together artistic practice, technical image production and marine observation. Its uses range from photographic storytelling to ecological documentation, yet these purposes place different demands on colour. An image may be visually compelling while providing an uncertain record of the photographed subject. The distinction between restoration and enhancement is therefore important: restoration seeks to compensate for image degradation, whereas enhancement may prioritise perceived quality or a particular computational task (Li et al., 2020).

The research problem concerns the relationship between attractive colour reproduction and dependable environmental representation. Selective attenuation and scattering change recorded colour, while lighting and processing introduce further variation. Li and Cavallaro (2022) show that commonly used no-reference quality measures do not satisfactorily rank enhanced underwater images. Consequently, an improved image-quality score or a more colourful appearance should not automatically be interpreted as evidence of accurate colour.

This distinction has particular significance for conservation. Colour can support assessments of coral condition when observations follow a validated reference procedure, as demonstrated by Siebeck et al. (2006). However, uncontrolled changes in illumination, white balance and saturation may complicate comparisons. A photograph intended to draw attention to reef biodiversity and one intended to document bleaching therefore require different evidential safeguards.

Technical reviews examine image-formation models, enhancement algorithms and evaluation methods (Li et al., 2020; Cong et al., 2024). Ocean-literacy scholarship considers communication, emotional connection and trust within broader relationships between people and the ocean (McKinley et al., 2023). The gap addressed here lies at the intersection of these perspectives: how photographic colour decisions relate to both visual interpretation and conservation use. This is an integrative conceptual problem, rather than a claim that technical enhancement or ocean communication has not previously been studied.

For creative-industry practice, this problem matters because photographers, editors and educators select and process images for different audiences. The same reef image may appear in a tourism advertisement, an educational resource or a monitoring record. Its intended use should guide decisions about colour treatment, contextual information and disclosure. The following discussion connects these practical decisions with the technical and interpretive literature.

METHODOLOGY

This paper adopts a qualitative narrative-review approach to secondary literature and illustrative visual interpretation. It develops a conceptual discussion rather than reporting a new imaging experiment, ecological survey or audience study. Technical publications, photographic scholarship and conservation literature provide complementary perspectives; the figures illustrate the discussion and are not treated as an independently sampled research dataset.

The literature discussed includes recent underwater-imaging research and earlier foundational work on photographic interpretation and coral-colour monitoring. These foundational sources are retained because their conceptual or methodological relevance extends beyond the recent-publication window. The review is not presented as a systematic review or as an exhaustive assessment of all available studies.

The synthesis is organised into three analytical domains: optical and technical constraints on colour reproduction; aesthetic interpretation and photographic authenticity; and conservation communication and ecological documentation. Within each domain, the discussion distinguishes the findings reported by cited studies from the interpretive implications developed in this paper. It then examines tensions across domains, particularly where increased visual appeal may conflict with evidential consistency.

Interpretation is bounded by the type of evidence available. Algorithmic performance claims are attributed to the relevant publications; the photographs do not establish comparative performance. The discussion of engagement identifies possible communicative functions rather than measured psychological or behavioural effects. No inter-coder agreement, participant validation or statistical testing is claimed.

Conceptual framework. The discussion links three complementary perspectives. Underwater image-formation research explains how the medium and imaging process affect recorded colour (Akkaynak & Treibitz, 2019). Barthes (1981) provides an interpretive perspective on photographic meaning, without supplying a predictive theory of colour emotion. Ocean literacy connects visual communication with knowledge, emotional connection and trust (McKinley et al., 2023). Together, these perspectives guide the analysis of how a colour image is produced, interpreted and used. This integration is a conceptual framework proposed for discussion, not an empirically validated causal model.

LITERATURE REVIEW AND CONCEPTUAL DISCUSSION

Optical Behaviour of Light Underwater

Underwater colour is shaped by the wavelength-dependent absorption and scattering of light as it travels through water. Image formation depends on illumination, water properties, subject reflectance and the distance between subject and camera. These processes cannot be explained simply by the greater density of water. Physically informed restoration models distinguish attenuation of the subject signal from backscatter contributed by the intervening water (Akkaynak & Treibitz, 2019).

Under many clear-water conditions, longer visible wavelengths are attenuated more rapidly than blue-green wavelengths. However, there is no universal depth at which a colour disappears: the observed result varies with water composition, optical path length, illumination and camera sensitivity. Depth-based colour diagrams should therefore be read as simplified illustrations rather than universal measurement rules (Li et al., 2020).

These constraints explain why ambient-light images can show a strong colour cast and reduced subject contrast. Turbidity and greater camera-to-subject distance may intensify degradation. The relationship is important for photographers because processing choices cannot be evaluated independently of acquisition conditions (Li et al., 2020).

For photographic practice, the implication is to consider subject distance, illumination and exposure together when planning colour reproduction (Edge, 2010).

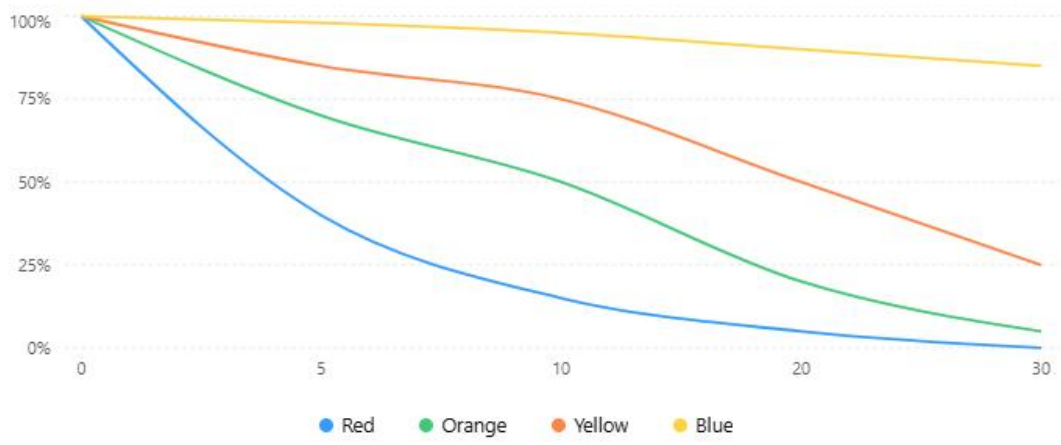


Figure 1. Illustration of wavelength-dependent colour attenuation underwater.

Figure 1 introduces the concept of differential attenuation. Any plotted depths or visibility values require a documented source and should not be interpreted as universal thresholds for underwater photography.

Scattering Effects and Water Visibility

Light scattering redirects illumination through interactions with water and suspended material. Forward scattering can reduce detail, while backscatter contributes veiling light to the image. Particles illuminated near the camera may appear as bright spots. These effects complicate the interpretation of apparent brightness and colour because recorded light does not originate solely from the subject (Li et al., 2020).

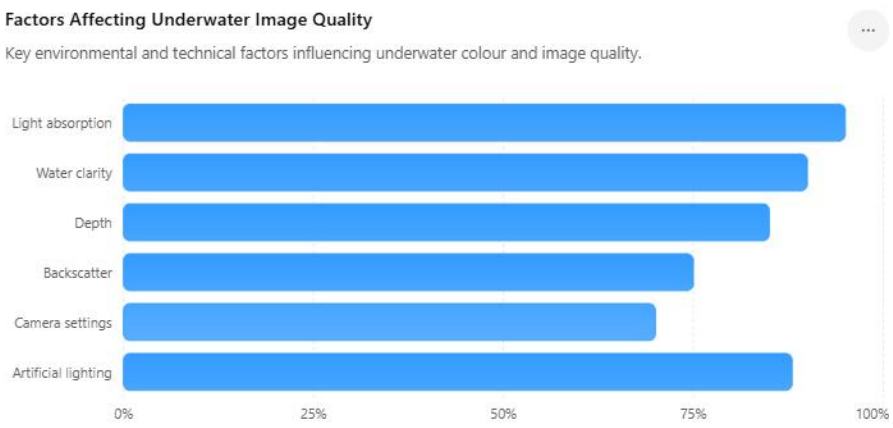


Figure 2. Environmental and technical factors relevant to underwater image quality.

Figure 2 brings together factors discussed in underwater-imaging practice. Its graphical ranking should not be interpreted as an empirical comparison without supporting data. Water conditions, subject distance and illumination interact, so their relative importance depends on the photographic situation.

Colour Cast and Capture Conditions

The blue or green appearance of an underwater image reflects selective spectral attenuation and scattering; it is not adequately described as a simple change in correlated colour temperature. White-balance adjustments can compensate for a colour cast when useful channel information remains, but cannot reliably recreate information that was not recorded (Li et al., 2020).

RAW capture gives photographers greater flexibility in white-balance and tonal adjustment than an already processed image. Nevertheless, exposure, subject distance and lighting remain important at capture. Artificial illumination can supply wavelengths that are weak in the ambient light reaching the subject, although the light still travels through water before reaching the camera (Edge, 2010).

Aesthetic and Emotional Functions of Colour

Colour as Visual Storytelling

Colour contributes to how a photograph directs attention and establishes visual atmosphere. A warm-coloured subject against blue water, for example, can create visible separation between subject and background. This is a compositional interpretation rather than evidence that a specific colour produces the same emotional response in every viewer (Edge, 2010).

In this paper, Barthes's (1981) discussion of photographic meaning supports attention to the relationship between what is depicted and how an image is experienced. Applied to underwater photography, it encourages interpretation of colour alongside subject matter and context. It does not establish a universal equation between blue and calmness, or between red and excitement.



Figure 3. Underwater photograph illustrating colour relationships and subject separation.

Colour Composition and Visual Hierarchy

Colour contrast can help establish a focal point, while differences in brightness and background tone contribute to spatial organisation. Complementary colour relationships are among the compositional resources available to underwater photographers (Edge, 2010). Figure 3 is used to discuss these visible relationships, not to demonstrate a measured increase in viewer engagement.

The conceptual framework distinguishes the optical production of colour from its interpretation. Subject separation may be discussed through the arrangement of colour and contrast, but claims about emotional effect require audience evidence. This distinction allows visual analysis to remain useful without presenting interpretation as a psychological measurement.

Artistic Interpretation and Authenticity

Digital colour correction and artistic colour grading serve different purposes. Correction attempts to compensate for recording conditions, while grading may deliberately establish a particular visual atmosphere. Both involve decisions about how the environment is represented, especially when photographs move between artistic, educational and documentary settings.

For documentary and conservation use, processing should preserve relevant environmental evidence and be disclosed where it affects interpretation. A pleasing result is not sufficient validation: Li and Cavallaro (2022) identify limitations in commonly used quality measures. In this paper, authenticity therefore refers to an accountable relationship between the recorded scene, the processing applied and the claim made with the image.

Technological Development in Underwater Colour Restoration

Artificial Lighting Technologies

Strobes and continuous lights provide local illumination that can reveal subject colours poorly represented under ambient conditions. Their effectiveness depends on working distance, beam coverage and placement. Practical photographic guidance emphasises managing the relationship between the light, the subject and the camera to control backscatter and exposure (Edge, 2010).

Figure 4 illustrates an artificially illuminated subject. It provides a practical example for discussing colour and detail, but it is not a controlled before-and-after comparison and does not quantify improvement.



Figure 4. Example of artificial illumination in underwater photography.

Digital Post-Processing Systems

Digital post-processing allows adjustment of white balance, tonal relationships and local contrast. These operations can improve legibility, but their acceptability depends on the image's purpose. For ecological comparison, consistent processing and retention of the original files are more defensible than independently optimising each image for visual impact.

Figure 5 illustrates an editing interface and processed imagery. The example should be accompanied by the software, relevant adjustments and source information before it is used to explain a particular workflow. It does not, by itself, establish that edited colours match a calibrated reference.

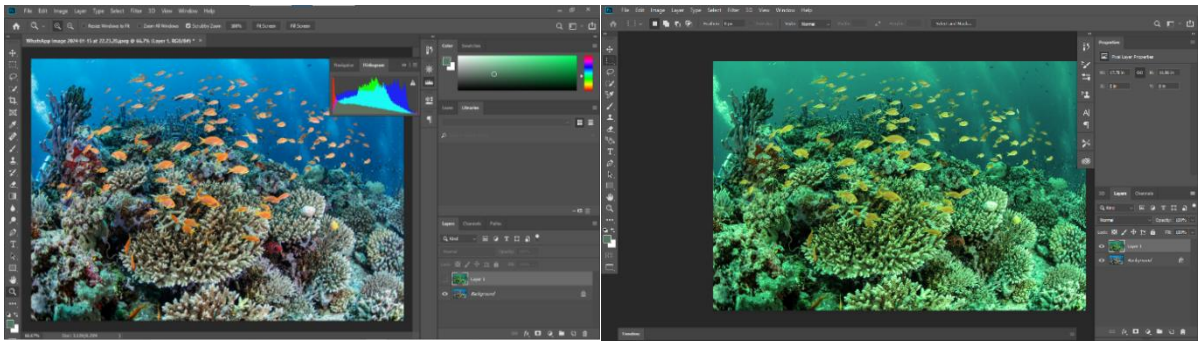


Figure 5. Illustration of digital post-processing of underwater imagery.

Artificial Intelligence and Computational Imaging

Learning-based methods offer alternatives to manual correction and physically parameterised restoration. WaterGAN uses synthetic underwater imagery within a learning pipeline for colour correction (Li et al., 2017). Wu et al. (2025) describe a transformer-based approach that separates dehazing and colour-restoration features before combining them. These studies demonstrate methodological developments within their evaluated settings; their reported performance should not be generalised automatically to every water type or photographic subject.

Cong et al. (2024) review deep-learning approaches alongside datasets and evaluation methods, showing why algorithm comparison requires attention to experimental conditions. For photographic practice, an enhancement model should therefore be considered in relation to its training data, evaluation evidence

and intended task. A visually natural output may still require independent validation before ecological measurements are extracted.

Within the proposed conceptual framework, computational enhancement modifies the image-production stage. It does not establish how viewers interpret the output or whether they change conservation behaviour. Those outcomes require separate evaluation.

Colour and Marine Conservation

Environmental Communication and Public Awareness

Underwater photographs can introduce audiences to environments that are otherwise difficult to observe directly. Within the ocean-literacy framework, their potential relevance includes communication, awareness and emotional connection, alongside trust and transparency (McKinley et al., 2023). This perspective supports discussion of photographic use in conservation, while leaving the magnitude and direction of audience effects open to empirical investigation.

Images of reefs, pollution or bleaching should be accompanied by information about place, time and ecological context. A photograph may make a condition visible, but its meaning depends on selection, captioning and comparison. Attractive imagery alone should not be treated as evidence of environmental health, and an isolated damaged site should not automatically represent an entire region.

Scientific Documentation and Ecological Monitoring

Colour has a more specific evidential role when observations follow a defined monitoring method. Siebeck et al. (2006) developed and evaluated a colour reference card for assessing coral bleaching. Their work demonstrates the importance of standardisation and observer uncertainty, rather than validating arbitrary colour values extracted from any photograph.

For photographic monitoring, the implication is to document acquisition and processing conditions, retain original files and use appropriate colour references where the protocol requires them. Comparisons across dates should account for changes in lighting and imaging conditions. Figure 6 illustrates a monitoring context; it does not supply an ecological dataset for this review.



Figure 6. Underwater photographic activity in a coral-reef monitoring context.

Sustainable Marine Tourism

Underwater imagery can also be used in marine-tourism communication. A conservation-oriented application would pair photographs with information about responsible diving, habitat protection and local conditions. This is a practical recommendation derived from the paper's emphasis on contextual interpretation and transparency, rather than a measured finding about tourism behaviour.

SYNTHESIS AND DISCUSSION

The literature-based synthesis identifies a distinction between colour visibility, colour fidelity and visual meaning. Visibility concerns whether a subject can be seen clearly; fidelity concerns the relationship between recorded colour and an appropriate reference; meaning concerns interpretation in a particular context. These dimensions can overlap, but improvement in one does not establish improvement in the others. This distinction provides the central contribution of the proposed conceptual framework.

At the image-production level, attenuation and backscatter explain why colour varies with acquisition conditions. Sea-thru provides an example of physically informed restoration, while WaterGAN and the approach of Wu et al. illustrate learning-based strategies (Akkaynak & Treibitz, 2019; Li et al., 2017; Wu et al., 2025). Their relevance here is the dependence of colour treatment on modelling and evaluation choices. This review does not reproduce their experiments or rank their methods.

At the interpretive level, photographic colour contributes to subject emphasis and atmosphere. The discussion draws on photographic practice and Barthes's interpretive perspective to consider meaning, rather than treating aesthetic features as direct measurements of emotion (Barthes, 1981; Edge, 2010). For example, making a reef subject more prominent may strengthen the image's visual organisation, but whether this increases concern or understanding remains an audience-research question.

At the conservation level, the distinction between communication and measurement is essential. A photograph used for ecological comparison needs a defined reference and consistent handling, whereas one used in public communication also requires contextual explanation. Coral-colour monitoring offers a concrete example of standardisation (Siebeck et al., 2006). Ocean literacy supplies a broader conceptual context for communication and trust, without implying that exposure to a photograph necessarily changes behaviour (McKinley et al., 2023).

Taken together, these perspectives suggest that processing decisions should be justified by intended use. Artistic work may permit expressive grading, provided it is not misrepresented as unaltered ecological evidence. Scientific documentation requires consistent procedures and validation appropriate to the variable measured. Conservation communication benefits from clear captions and disclosure of consequential edits. These are practice-oriented implications of the synthesis, not outcomes measured in a new field study.

The review is limited by its narrative scope and the absence of a systematic evidence-selection record in the reported analysis. It does not estimate the prevalence of particular findings, provide a pooled performance comparison or test audience responses. The conceptual framework should therefore be treated as a basis for further investigation. Its value lies in making the assumptions connecting colour production, interpretation and use explicit.

CONCLUSION

This narrative review connects underwater colour reproduction with photographic interpretation and conservation use. The technical discussion explains how absorption, scattering and acquisition conditions shape the recorded image. The aesthetic discussion treats colour as a compositional and interpretive

resource, while the conservation discussion distinguishes public communication from ecological measurement. Together, these perspectives show why visual appeal, colour fidelity and environmental evidential value require separate consideration.

For practice, photographers should determine the intended use before selecting a processing approach. Recommended steps include preserving original files, recording relevant acquisition conditions, documenting substantial colour changes and providing contextual captions. Where photographs support ecological monitoring, acquisition and processing should follow a suitable protocol with reference information and explicit treatment of uncertainty.

Future research should test the proposed framework using calibrated photographic comparisons and audience studies. Imaging studies could compare ambient lighting, artificial lighting, manual correction and AI enhancement across water conditions using an appropriate colour reference. Audience studies could examine whether different colour treatments affect understanding, perceived credibility and conservation intentions. These outcomes should be measured separately, rather than inferred from image attractiveness.

The contribution of this paper is conceptual rather than experimental. It offers a basis for connecting creative practice with the evidential responsibilities of conservation imagery, while recognising that the proposed relationships require further empirical validation.

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AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by all authors.

CONFLICT OF INTEREST

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

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study did not involve human participants or animals, and ethics approval was not required.

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