

PAS 1401:2025

Nature-inclusive marine structures – Code of practice



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Foreword

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The provisions of this document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

The word “should” is used to express recommendations of this document. The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word “can” is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this document. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. “organization” rather than “organisation”).

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Introduction

Nature-inclusive design is an emerging discipline within eco-centric development, built on decades of ecological engineering research. By incorporating the needs of native marine species, these designs enhance biodiversity and promote resilient ecosystems around marine structures. This approach integrates ecology into construction, offering an improvement over traditional structures that lack such considerations. As human activity in marine environments inevitably alters natural habitats, nature-inclusive marine structures provide an opportunity to optimize these effects.

This PAS aims to make nature-inclusive design a standard practice globally by providing actionable recommendations and guidelines that integrate the needs of species and habitats into the construction process. It addresses not only the design but also how nature-inclusive principles can be systematically incorporated throughout the entire life cycle of marine structures.

As the planet faces simultaneous climate and biodiversity crises [1], with human activity significantly altering marine ecosystems, nature-inclusive design offers a practical solution to support biodiversity recovery. By fostering a symbiotic relationship between natural ecosystems and human infrastructure, these designs can also enhance ecosystem services, such as improved water quality and coastal defence.

However, nature-inclusive design cannot compromise the safety and efficacy of marine structures. This PAS provides recommendations to enable careful planning and optimization, integrating nature-inclusive principles throughout the life cycle of a structure – from planning and construction to monitoring and decommissioning.

Rather than replacing existing guidance on marine structures, this PAS complements it, ensuring that nature-inclusive design is systematically incorporated into all stages of construction. It offers a structured design procedure, not just a catalogue of potential measures, and addresses the inherent risks and impacts of marine structures without overstating their benefits. It is important to note that global policy around nature-inclusive design is in its infancy. This PAS does not aim to address policy gaps but rather provides technical clarity and guidance for nature-inclusive structures.

This PAS focuses on intentional designs from the outset and does not cover incidental positive effects that some structures might have on marine habitats. Its aim is to promote nature-inclusive design responsibly and avoid greenwashing or the justification of harmful projects under the guise of environmental benefit. While nature-inclusive structures are not a guarantee of a net positive effect on marine environments, they represent a significant improvement over traditional alternatives.

Users are encouraged to apply this PAS pragmatically, with the level of effort proportionate to the project's scale and environmental sensitivity. For smaller projects, a simpler approach might be appropriate, while larger projects might require more detailed analysis and monitoring. By balancing effort with impact, this PAS remains flexible and applicable to all marine construction projects.

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1 Scope

This PAS gives recommendations on the creation and management of nature-inclusive marine structures, ensuring sustainable, positive outcomes for nature and providing a structured, procedural approach to nature-inclusive design. It covers guidance relating to core philosophical principles of nature-inclusion, broad design considerations, planning, construction, augmentation with habitat-forming organisms, monitoring, communications and decommissioning.

This PAS is globally applicable to any structure or set of structures, that will be placed in any marine environment, during marine construction projects (hereafter referred to as “projects”). It includes both the above-water and underwater sections of structures, as well as all environments defined as marine (see 3.1.22). It is also applicable to the modification or enhancement of existing man-made structures already located in a marine environment. It is not limited to “add-on” units for habitat enhancement but covers the complete scope of structures destined for marine environments.

This PAS is intended for use by anyone procuring, using, designing, or developing marine structures, including:

- a) design and pre-construction professionals specifying nature-inclusive designs, selecting existing designs and developing new designs;
- b) developers and leaseholders procuring nature-inclusive structures or nature-inclusive design services;
- c) project managers and engineers integrating nature-inclusive designs or nature-inclusive structures into projects; and
- d) ecologists aiming to improve post-build biodiversity metrics of projects with nature-inclusive design.

This PAS is also of interest to marine licensing authorities and regulators responsible for the permitting of projects, aiming to verify eco-centric and sustainable development practices.

This PAS does not cover:

- 1) technical engineering criteria or tests, such as structural design, lifting methodologies or maintenance inspections;
- 2) quality control measures for the construction of structures;
- 3) deployment methods and logistics processes;

NOTE 1 Users are advised to follow existing specialist advice, industry standards, guidance notes and requisite legislation for these topics. For example, BS EN ISO 9001 provides guidance on the establishment of effective quality management systems.

- 4) recommendations for specific nature-inclusive design features to suit different locations;

NOTE 2 For design feature recommendations, users are advised to seek up to date guidance documents, especially those that synthesize ecological engineering theory and peer reviewed research, for example, Evans, 2021 [2]; Glarou et al., 2020 [3]; Lengkeek et al., 2017 [4].

- 5) specific guidance on the comprehensive assessment and mitigation of environmental impacts across a project;

NOTE 3 Environmental impacts and appropriate mitigation has to be assessed on a project-by-project basis.

- 6) guidance on whether the use of marine structures is appropriate to a given area or on the criteria for acceptance of a project during licensing processes; or
- 7) comprehensive guidance on the development and management of nature-based solutions.

NOTE 4 *Nature-inclusive design can be used as a tool within nature-based solutions, in which case users are advised to integrate nature-inclusive structures with wider good practice for the management of nature-based solutions, for example, Bridges et al., 2021 [5]; International Union for Conservation of Nature (IUCN), 2020 [6].*

NOTE 5 *It is important to provide clarity on the crossovers and distinctions between these concepts: nature-based solutions and nature-inclusive design. Both nature-based solutions and nature-inclusive design aim to enhance biodiversity or ecosystem services while addressing societal needs, with a strong emphasis on sustainability and the integration of natural processes. Nature-inclusive design can be seen as a specific approach or tool within the broader framework of nature-based solutions. However, there are notable differences: nature-based solutions (see 3.1.29) have a broader scope, addressing a wide range of societal challenges through ecosystem-based approaches, often at larger scales such as landscapes or regions. In contrast, nature-inclusive design (see 3.1.30) is more focused on the built environment and infrastructure, dealing with the integration of natural elements within man-made structures. Additionally, nature-inclusive design is typically implemented at a more granular level, such as individual buildings or construction areas, whereas nature-based solutions can span larger geographical areas and encompass more diverse applications.*

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions, or limits the application, of this document¹⁾. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 14040, *Environmental management – Life cycle assessment – Principles and framework*

BS EN ISO 14044, *Environmental management – Life cycle assessment – Requirements and guidelines*

BSI Flex 350, *Alternative binder systems for lower carbon concrete – Code of Practice*

¹⁾ Documents that are referred to solely in an informative manner are listed in the Bibliography.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purpose of this PAS, the following terms and definitions apply.

3.1.1 adaptive management

process of iteratively planning, implementing and modifying strategies for managing resources in the face of uncertainty and change

NOTE Adaptive management involves adjusting approaches in response to observations of their effects and changes in the system brought on by resulting feedback effects and other variables.

[SOURCE: BS EN ISO 14090:2019, 3.3]

3.1.2 biodiversity metrics

quantification of biodiversity and quality of ecosystems by assessing factors such as habitat type, species diversity, and abundance

NOTE This encompasses statutory measures, like habitat units in the UK's Biodiversity Net Gain (BNG) metric, as well as scientific metrics, like species richness (see Annex A for more examples).

3.1.3 biodiversity net gain (BNG)

specific, quantifiable outcome of project activities that deliver demonstrable benefits for biodiversity compared to the baseline situation

[SOURCE: BS 8683:2021, 3.1.6, modified – notes removed]

3.1.4 biogenic

produced by living organisms

3.1.5 biotope

combination of an abiotic habitat and its associated community of species

NOTE 1 Biotope is used here in the marine context.

NOTE 2 This term is used to describe spatially discrete ecological units in marine and aquatic systems.

3.1.6 biomass

total mass of organisms in a given area or volume

3.1.7 competent person

person who can demonstrate they have acquired through training, qualifications or experience, or a combination of these, the knowledge and skills enabling that person to perform a specified task

[SOURCE: BS 8683:2021, 3.1.7]

3.1.8 ecological engineering

design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both

NOTE An expanded definition of this can be found in Mitsch, W.J., 2012 [7].

3.1.9 ecosystem

biological community of interacting organisms and their physical environment

3.1.10 ecosystem service

benefits people obtain from ecosystems

NOTE Classifications for different types of ecosystem services have evolved since popularization of the term in the 2005 Millenium Ecosystem Assessment [9], users are advised to seek up to date guidance on the classification of ecosystem services from sources such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

[SOURCE: Millenium Ecosystem Assessment, 2005 [8] and IPBES²⁾]

3.1.11 endobenthos

organisms that live within the substrates of aquatic environments, such as the sediments of oceans, rivers, lakes, and seas

NOTE 1 This group encompasses a variety of life forms, including animals, microorganisms, and other organisms that burrow into or reside within the sediment, rather than on its surface.

NOTE 2 Endobenthos is synonymous with "infauna".

3.1.12 environmental product declaration

claim which indicates the environmental aspects of a product or service, providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information

[SOURCE: BS EN ISO 14025:2010, 3.1, 3.2, modified – notes removed]

3.1.13 epibenthos

community of organisms that live on the surface of a substrate, especially in aquatic environments

NOTE 1 This term encompasses all organisms, including animals, plants, algae, bacteria, and fungi that live on the surface of substrates.

NOTE 2 Epibenthos is synonymous with "epifauna" and "epiflora".

3.1.14 greenwash

mislead (the public) or counter (public or media concerns) by falsely representing a person, company, product, etc., as being environmentally responsible

3.1.15 habitat

home or environment of an animal, plant, or other organism

3.1.16 habitat metric

quantification of physical structural aspects of a habitat created with nature-inclusive design

3.1.17 indicator species

organisms whose presence, absence, or abundance reflects a specific environmental condition or the health of an ecosystem, serving as a measure of the environmental conditions that are suitable for a wider group of species

²⁾ Available at: <https://www.ipbes.net/glossary/ecosystem-services>.

3.1.18 integrated greening of grey infrastructure

combination of green infrastructure with grey infrastructure, combined in a synergistic manner to improve the environmental effects of grey infrastructure engineering

NOTE 1 *In this PAS, the concept of integrated greening of grey infrastructure is considered as synonymous with the concept of nature-inclusive grey infrastructure, which has been designed to incorporate natural processes and features into built environments to enhance biodiversity, resilience, and ecological health.*

NOTE 2 *“Green” infrastructure refers to natural or living environments that act as infrastructure for human purposes such as flood defence, “grey” infrastructure refers to artificial, anthropogenic infrastructure.*

3.1.19 irreplaceable habitat

habitat that cannot be recreated within a specified time frame because it would be technically very difficult or impossible to recreate taking into account its age, uniqueness, species diversity, rarity and environmental or historical context

NOTE *In the context of planning in England irreplaceable habitat has a specific legal definition for more information see: <https://www.gov.uk/guidance/irreplaceable-habitats>.*

[SOURCE: BS 8683:2021, 3.1.8, modified – changed “their” to “its”, notes removed]

3.1.20 keystone species

species that has a disproportionately large impact on ecosystem function and diversity relative to its abundance, playing a critical role in maintaining the structure of an ecological community and influencing the types and numbers of other species in the habitat

3.1.21 life cycle assessment (LCA)

compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

[SOURCE: BS EN ISO 14044:2006+A2:2020, 3.2]

3.1.22 marine

all ocean and coastal waters, including intertidal zones and saltwater marshes, as well as adjacent coastal and riparian land areas, and extending, in the case of watercourses, up to the freshwater limit

[SOURCE: United Nations, 1992 [9]]

3.1.23 marine construction projects

planning, design, and execution of construction activities in marine (see 3.1.22) environments

NOTE *These projects typically involve the creation, maintenance, modification or decommissioning of structures and infrastructure to support various activities such as transportation, energy production, and coastal protection.*

3.1.24 marine structure

physical construction designed and placed in a marine environment for a specific purpose, as part of human development activities

NOTE 1 *This includes a wide range of built forms, from individual components to complex systems, intended for various uses such as coastal protection, habitat creation, resource exploitation, or recreational facilities. For example, both a single block intended for scour protection at an offshore wind farm and an entire scour protection berm made of multiple blocks are both considered here as “structures”.*

NOTE 2 *In this PAS, designed marine structures are referred to as marine structures.*

3.1.25 mature community

community that having undergone succession, is a stable and established ecosystem characterized by a complex structure, biodiversity, and interactions among organisms

3.1.26 microhabitat

small, specific area within a larger habitat that differs in environmental conditions from the surrounding area, offering unique living conditions for certain species

NOTE These variations can be due to factors such as moisture levels, light availability, sediment composition, temperature, or shelter, creating a specialized environment that supports a distinct community of organisms which might not thrive in the broader habitat.

3.1.27 mitigation hierarchy

hierarchical sequence of actions to anticipate and avoid impacts on biodiversity or ecosystem service; and, where avoidance is not possible, minimize; where impacts occur, restore; and finally where significant residual impacts remain offset

[SOURCE: BS 8683:2021, 3.1.9, modified – notes removed]

3.1.28 multi-criteria decision analysis (MCDA)

approach that involves evaluating and comparing different alternatives or options against a set of predefined criteria or factors that are important for the decision-making process

NOTE MCDA is widely used in various fields to assist in making well-informed and balanced decisions when faced with complex situations involving multiple competing objectives or criteria.

3.1.29 nature-based solutions

actions to protect, conserve, restore, sustainably use, and manage natural or modified terrestrial, freshwater, coastal, and marine ecosystems, which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience, and biodiversity benefits

NOTE It is important to provide clarity on the crossovers and distinctions between these concepts: nature-based solutions and nature-inclusive design. Both nature-based solutions and nature-inclusive design aim to enhance biodiversity or ecosystem services while addressing societal needs, with a strong emphasis on sustainability and the integration of natural processes. Nature-inclusive design can be seen as a specific approach or tool within the broader framework of nature-based solutions. However, there are notable differences: nature-based solutions have a broader scope, addressing a wide range of societal challenges through ecosystem-based approaches, often at larger scales such as landscapes or regions. In contrast, nature-inclusive design is more focused on the built environment and infrastructure, dealing with the integration of natural elements within man-made structures. Additionally, nature-inclusive design is typically implemented at a more granular level, such as individual buildings or construction areas, whereas nature-based solutions can span larger geographical areas and encompass more diverse applications.

[SOURCE: United Nations Environment Programme, 2022 [10] – modified, note added]

3.1.30 nature-inclusive design

design targeted at the integration of ecosystems, or specific habitats and species, with man-made architecture and infrastructure, via the intentional incorporation of habitat features, and backed by scientific evidence

NOTE Alternatively, nature-inclusive design refers to the scientific approach of producing such a design.

3.1.31 nature-inclusive structure

man-made structure with a nature-inclusive design that has a documented consideration of ecosystems and environmental impact mitigation throughout its life cycle; during planning, design, implementation, monitoring and decommissioning

NOTE In the case of composite structures, the entire structure might be nature-inclusive or component structures might be nature-inclusive, for example, an entire nature-inclusive breakwater, or a breakwater with nature-inclusive armour units, could be developed. The degree of separation lies in the scope of nature-inclusive design; and ecosystem and environmental impact consideration/mitigation.

3.1.32 nature positive

halting and reversing the loss of nature measured from its current status, reducing future negative impacts alongside restoring and renewing nature, to put both living and non-living nature measurably on the path to recovery

NOTE The concept of a nature-positive future is discussed in more detail in the International Union for Conservation of Nature (IUCN) document [11].

3.1.33 nekton

actively swimming aquatic organisms that can move independently of water currents

3.1.34 optioneering

process of exploring and evaluating different design options to achieve the best possible outcomes in terms of biodiversity enhancement, impact mitigation, functionality, cost-effectiveness, and stakeholder acceptance

3.1.35 outplant

intentional relocation of habitat-forming marine organisms, such as coral, oysters, and seagrasses, from a controlled nursery environment to an external habitat

3.1.36 plankton

organisms that drift or float in water currents and have little to no ability to swim against these currents

3.1.37 pseudo-replication

use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated (though samples may be) or replicates are not statistically independent

NOTE More information about pseudo-replication can be found in Hurlbert, S.H., 1984 [12].

3.1.38 seascape

interconnected system of marine and coastal environments, encompassing both physical and biological components

NOTE 1 It includes not only the water bodies but also the associated features such as coastlines, estuaries, habitats including reefs and sea mounts, and ocean floors. The seascape concept emphasizes the dynamic and holistic nature of marine ecosystems, recognizing the interplay between different marine habitats and the organisms that inhabit them, as well as the influence of human activities and natural processes.

NOTE 2 The term in this PAS is used in reference to seascape ecology, whereby the wider seascape and interconnectedness of habitats is considered, not the visual seascape to human viewers.

3.1.39 species

group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding

NOTE The species is the principal natural taxonomic unit, ranking below a genus and denoted by a Latin binomial, e.g. Homo sapiens.

3.1.40 substrate

surface or material that provides a base for an organism to live on, grow, or derive nutrients from

NOTE A substrate is not always the seafloor; it can be any biotic or abiotic material, for example, a floating piece of rope on a mooring can act as a substrate for organisms residing on it.

3.1.41 type 1 error

incorrect rejection of a true null hypothesis in scientific studies, often referred to as a “false positive”, where an effect or difference is concluded to exist when it does not

3.1.42 type 2 error

failure to reject a false null hypothesis in scientific studies, known as a “false negative,” where no effect or difference is concluded to exist when, in fact, it does

3.1.43 umbrella species

species whose conservation provides protection for a wide range of other species that share its habitat

NOTE In marine ecology and nature-inclusive design, protecting these species indirectly conserves the larger ecological community and the natural habitat they depend on. Umbrella species are selected for conservation efforts because their habitat requirements are broad and encompassing, ensuring that protecting these species and their habitats also protects a wide range of other species that share the same environment.

3.2 Abbreviated terms

BACI	before after control impact
BAG	before after gradient
BNG	biodiversity net gain
BPEO	best practicable environmental option
CA	comparative assessment
CIEEM	Chartered Institute of Ecology and Environmental Management
EcIA	ecological impact assessment
EIA	environmental impact assessment
EPD	Environmental Product Declaration
IGGI	integrated greening of grey infrastructure
LCA	life cycle assessment or life cycle analysis
PEA	preliminary ecological appraisal
MCDA	multi-criteria decision analysis
MPA	marine protected area
NEBA	net environmental benefit analysis
NNS	non-native species
RAMS	risk assessment method statements

4 Fundamental recommendations and principles

COMMENTARY ON CLAUSE 4

This clause outlines the fundamental recommendations for nature-inclusive structures and the aims to abide by in their creation and management. Subsequent clauses provide more detailed recommendations and guidance for each of the fundamental recommendations. Whilst there is no specific auditing mechanism, referring to these fundamental recommendations can help those checking nature-inclusive structures to keep a view of the whole picture. Annex B provides a list of questions that can be used to check effective practice and Annex C provides a list of proposed documentation that can be used to substantiate nature-inclusivity.

4.1 Fundamental recommendations

Nature-inclusive marine structures should be delineated specifically to separate them from regular non-nature-inclusive structures in a project. There are fundamental recommendations that should be met to define a structure as nature-inclusive (as far as is chronologically possible at the time in a project's development), as illustrated in Figure 1.

NOTE 1 *A structure including nature-inclusive design does not mean it is a nature-inclusive structure, supporting aspects are needed, as indicated in this PAS.*

NOTE 2 *A project might contain nature-inclusive structures but this does not mean all structures or the whole project are defined as nature-inclusive.*

The fundamental recommendations for nature-inclusive structures are given in a) to g).

- a) A nature-inclusive design should be incorporated, developed with the nature-inclusive design procedure and taking account of other nature-inclusive design considerations, such as low impact material selection (see Clause 5).
- b) Planning should be completed in such a manner that nature-inclusive marine structures are integrated into ethical and environmentally responsible projects, in an efficient and ethical manner (see Clause 6).
- c) Construction should be completed in a manner that does not compromise the environmental benefits of nature-inclusive design with disproportionately great additional impacts, relative to industry good practice (see Clause 7).
- d) Augmentation of structures with live habitat-forming organisms should be deemed an optional feature of nature-inclusive structures, and if performed, should be performed responsibly (see Clause 8).
- e) Monitoring should be performed to establish the success of the nature-inclusive designs, assessing success against the goals established during design (see Clause 9).
- f) Communications regarding nature-inclusive structures should be balanced to avoid the spread of misinformation and discrediting nature-inclusive design as a practice. Whether or not the structures were successful in achieving the designated goals should be shared publicly with sufficient evidence to back up any claims of success (see Clause 10).
- g) Decommissioning efforts should take into account the value of organisms growing on the structures or benefiting from their presence when deciding on decommissioning actions, so that they are not removed without due consideration (see Clause 11).

Figure 1 – The fundamental recommendations for nature-inclusive structures, illustrating the central role of nature-inclusive design and the supporting aspects throughout a structure's life cycle



4.2 Principles of nature-inclusion

The development of nature-inclusive marine structures should follow these principles, as shown in Figure 2:

- a) harmony: designs should be specified and developed with the local environment, biotope, wider ecological seascape, spatial planning and human community in mind;
- b) optimization: features beneficial to local biodiversity should be maximized and features negatively impactful to local biodiversity should be minimized;

***NOTE** For example, a practitioner of nature-inclusive design might choose to maximize refugia for juvenile fishes and to minimize loss of natural substrates.*

- c) empiricism: observation and experimentation should be utilized to develop and test designs that work towards defined goals, with measurable success criteria. Historic scientific and empirical evidence and observations should be used and built upon;
- d) collaboration: inter-disciplinary collaboration is fundamental to achieving effective nature-inclusive design. Inter-project collaboration and communication is necessary for effective accumulation of the benefits of nature-inclusive design for global marine environments and society across multiple projects; and