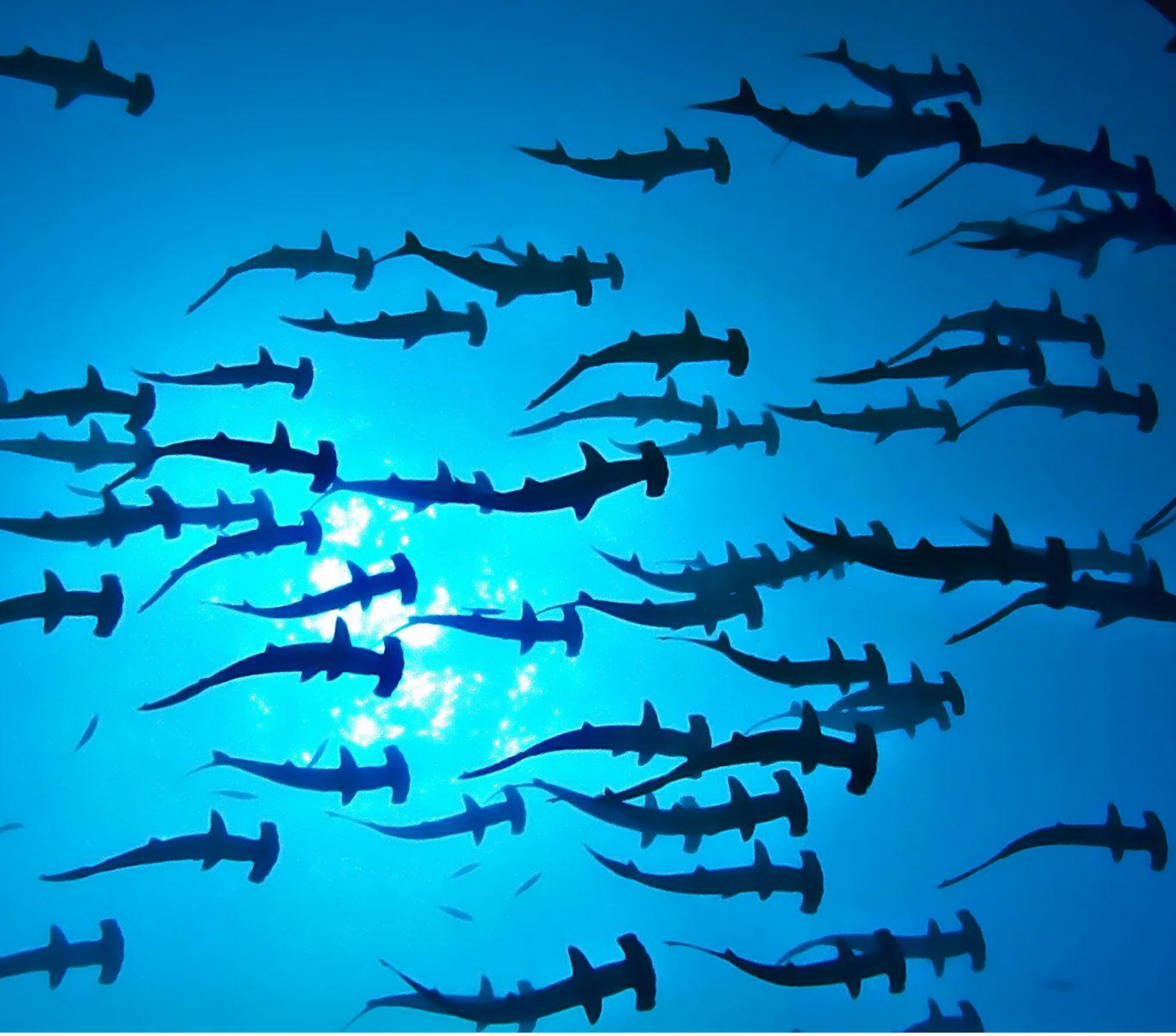

Marine Biodiversity Credits

PROTECTION CATEGORY

TECHNICAL FRAMEWORK

VERSION 1.0 | FIRST DRAFT
November, 2023

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OpenEarth

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The Open Earth Foundation is a research, innovation and deployment non-profit based in California, using cutting edge digital technologies and multi-stakeholder collaborations to advance open source platforms that help increase planetary resilience. Our approach blends: a complex-systems perspective to Earth-level solutions, emerging technologies, and an ethos of radical collaboration. *Learn more at:* **openearth.org**

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Support

The Ocean Program and its efforts, including the development of this Marine Biodiversity Credit design has been supported by the generous contributions from creative artists participating in the OceanDrop event, the Regen Network, and the OpenEarth Foundation, which includes support from the CarbonDrop.

Disclaimer

This work is incomplete and should not be used as-is under international conservation finance frameworks. Nature & Biodiversity credits are sensitive concepts & need rigorous development to ensure they are equitable, credible & achieve their purpose in environmental conservation. At the present stage, we cannot assure the proposed methodology achieves these goals as-is. Significant expert, peer, and stakeholder reviews and contributions are still required. Furthermore, a rigorous pilot will need to be undertaken to validate the hypotheses of this work.

However, this methodology significantly advances the development of Biodiversity credits in-line with the equity, credibility and purpose goal, ensuring a level of transparency and collective design by keeping the document and associated data pipeline code fully open source, so it may be 'forked' and improved.

Draft 1 | Public Request for Comments

This document was first published November 2023 as a full draft, and has an open Request For Comment version. Visit www.openearth.org/projects/ocean-program for instructions on how to provide comments and reviews

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Marine Biodiversity Credits: Technical Framework

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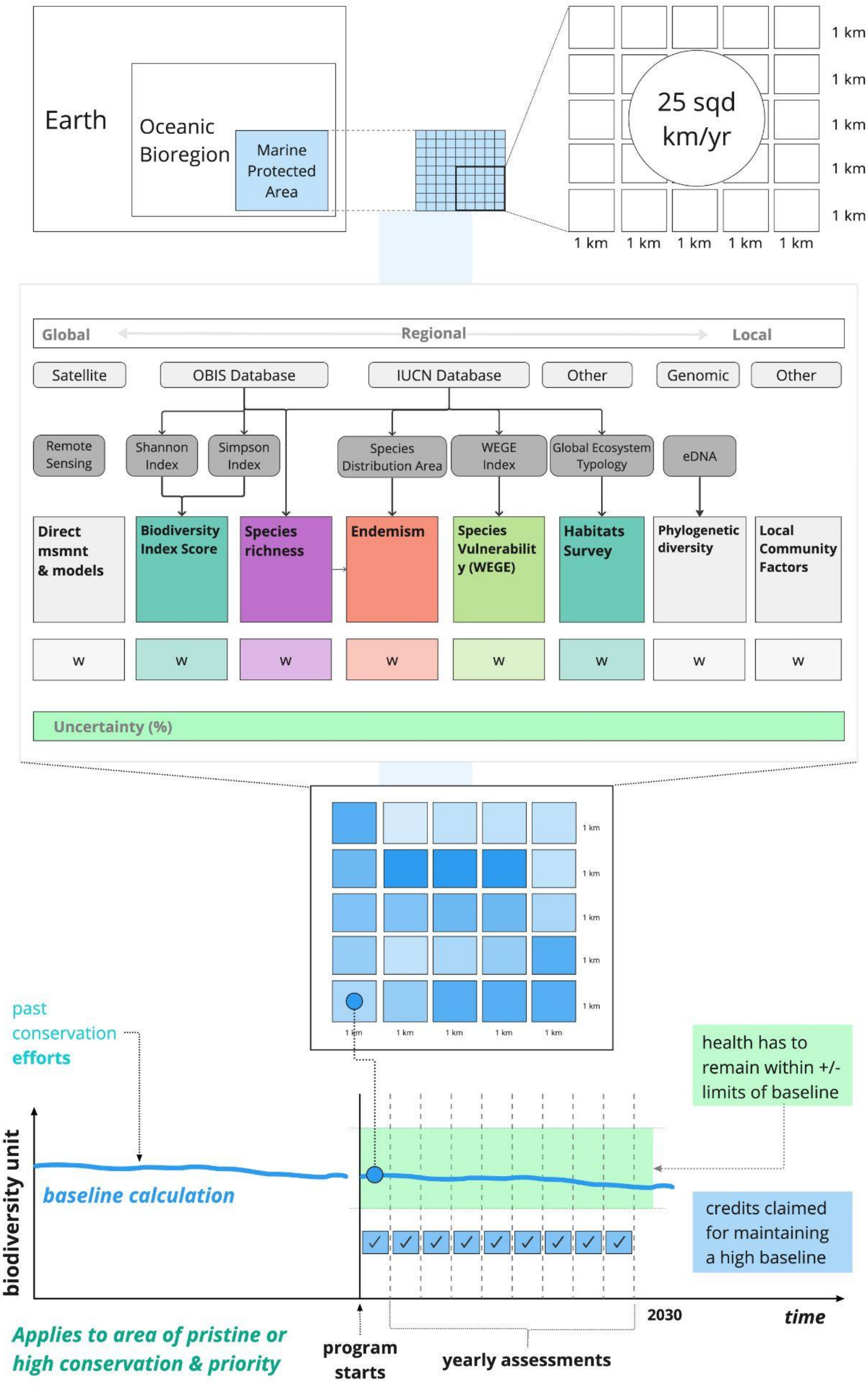
ABSTRACT

Marine Biodiversity Credits (MBCs) entail a natural capital accounting methodology that establishes comparable units of marine biodiversity value, which can be turned into credits or assets. This technical framework outlines the methodology for generating MBCs, which are designed to support both policy and financial applications. The framework is based on the concept of Biodiversity Units (BUs), which are defined as spatially and temporally coherent areas for marine biodiversity evaluation. Within each BU, Marine Biodiversity Units (MBUs) are calculated from a set of modulating factors (MFs) that capture the ecological and social value of marine biodiversity within the area of interest. The MFs are weighted and normalized to generate a single score for each MBU, which reflects its relative biodiversity value. The MBCs are generated without counterfactuals, as they reward maintaining a high baseline of biodiversity within each BU. The methodology includes a buffer that allows for some variability in the MBU scores, while ensuring that the credits are only issued to BUs that maintain a high level of biodiversity. The MBC framework is designed to be flexible and adaptable to different contexts, while ensuring scientific rigor and transparency.

Applied to policy, this accounting methodology can help governments and decision makers base conservation efforts using data-driven ecological economics. More importantly, MBCs are designed to support diverse financial mechanisms. As natural capital assets, once properly issued, they can operate in mechanisms such as guarantees in conservation finance, nature-debt swaps, tradable commodities, or as backing for environmental derivatives and other securities. By providing a market-based mechanism for valuing and protecting marine biodiversity, MBCs have the potential to unlock new sources of funding and engage a wider range of actors in conservation efforts. This paper presents the technical details of the MBC framework and discusses its potential benefits and challenges.

GRAPHICAL ABSTRACT



Base Unit

We define a Base Unit (BU) for natural capital accounting as 1 square kilometer of ocean per year. This allows a biodiversity credit to "stack" with other ecosystem credits like carbon, plastics, social etc. Geospatial definitions and griding of a Marine Protected Area (MPA) helps align data sets and nest their ecosystem value in the context of bioregions and global oceans.

Modulating Factors

Global Context
We consider factors and data approaches in a spectrum that evaluate an MPA from a global lens to local conservation priorities.

Data Sources
The methodology is designed to use existing globally accepted biodiversity datasets, as well as emerging biodiversity data techniques such as eDNA and satellite.

Indices & Metrics
Existing biodiversity indices and new metrics, calculated from the data sources are incorporated into the different modulating factors.

Factors
We present an initial library of 5 modulating factors (MF) and their methodologies, but designed to include others as they are developed and validates (eg. grey boxes have undeveloped MF methodologies)

Weights
MF are assigned weights that define how each factor influences the final biodiversity score. Weights are transparent values defined by agreed upon rules.

Uncertainty
Based on data quality, freshness, and level of scientific consensus, an uncertainty factors modulates the final biodiversity credit valuation calculation (eg. pricing).

Marine Biodiversity Unit Calculation

All modulating factors are then used to assign a single value score per squared km of the MPA.

Annual credit accounting & issuance to MPA inventory

The biodiversity scoring process is used to construct a baseline of at least 5 years prior to a project start time. Once a crediting period starts, 1 credit is assigned to each sqd. km if the baseline value is maintained (i.e. protected) within a 5% margin. This approach applied to the issuance of protection credits in areas with high ecological value and conservation priority.

Figure 1. Graphical abstract and process summary described in this methodology.

1. Introduction & rationale

Human activities have had a profound impact on our planet, leading to a biodiversity crisis. Protecting global biodiversity goes beyond mere fairness to other species such as plants, animals, and fungi. It is essential for safeguarding the habitats and ecosystem health necessary for human survival on Earth. In recognition of this urgent need, the scientific and global policy communities have come together to establish the Global Biodiversity Framework (GBF) during the Convention of Biodiversity in COP15. One of the key targets set by the GBF is the protection of 30% of land and oceans by 2030.

While terrestrial conservation efforts are well underway, the health of our oceans, a crucial component for human well-being, has been significantly compromised in recent decades. To align with the GBF and address this pressing issue, it has become imperative for governments to establish with legislation Marine Protected Areas (MPA)—particularly with No-Catch Zones, for as much as 30% of their Economic Exclusive Areas (EEA) (i.e. ocean areas within national jurisdictions) by 2030. Furthermore, the Treaty of the High Seas, formulated under the United Nations Convention on the Law of the Sea, aims to tackle a significant challenge in ocean conservation by focusing on the protection of biodiversity beyond these national jurisdictions.

While these global policy instruments and targets are crucial steps in the right direction, there is a lack of clear and scalable financial mechanisms to support governments and local communities in permanently protecting our oceans. To bridge this gap, the OpenEarth Ocean Program has embarked on a mission to research and design innovative financial mechanisms, starting with more advanced processes for natural capital accounting.

As part of our efforts, we have developed an overarching framework known as Marine Ecosystem Credits (MEC), which is detailed in Filippi et al. 2023. This framework serves as a roadmap for the issuance of marine biodiversity credits, outlining the technical aspects and methodology involved. Our primary focus is on the applications of these credits to MPAs and how governments, both at the local and national levels, can ensure sufficient financial resources for their establishment and maintenance.

Our work has been greatly informed and inspired by a collaboration and case study conducted in the marine protected area of Isla del Coco, Costa Rica (ACMC: Area de Conservación Marina Coco). The ACMC is home to breathtaking wonders of ocean life, such as massive congregations of hammerhead sharks. This area has recently been expanded by a significant factor of 27 to safeguard key underwater habitats that are part of the sea mounts biocorridor, an integral component of the Galapagos ecosystem[1]. However, securing the necessary financial resources for its full and permanent protection remains a challenge. This challenge is not unique to Costa Rica, even though the country has already been at the forefront of environmental innovation. Many countries in the Global South that host or are expanding MPAs face similar hurdles. Through the development of the Marine Ecosystem Credits framework and the application of our research findings in real-world scenarios like Isla del Coco, we aim to contribute to the establishment of effective and scalable financial mechanisms that will enable the permanent protection and conservation of precious marine ecosystems.

The central thesis behind this methodology is that MPAs[2] with high ecological health are unique and inherently valuable. This is also supported by the value they bring to local economies[3]. Within this framework, we aim to rigorously establish a biodiversity metric over an initial period that acts as a baseline, through the use of a set of well-established indices, conducted at a granular geographical unit such as a square kilometer. We refer to the process of combining these indices into a normalized score as *modulation*, and the inputs to this process as *modulating factors* (MF). Thereafter, over every project period, these modulating factors are recalculated and compared with its own baseline to understand if the level remains within a buffer[4]. If so, a full credit is issued for

[1] Costa Rican Presidency: Costa Rica increases the Cocos Island Conservation Area.
[2] In this document, we use the term MPA to refer to the project area of interest, even though they may not legally be a protected area.
[3] World Bank. 2021. Banking on Protected Areas: Promoting Sustainable Protected Area Tourism to Benefit Local Economies. © World Bank, Washington, DC. http://hdl.handle.net/10986/35737 License: CC BY 3.0 IGO.
[4] Buffers represent exogenous changes, measurement errors and system noise

that geographical unit, otherwise not. In this way geographic areas are compared with some stable historical notion of its own biodiversity to reward *homeostasis*, not a counterfactual. We describe this process in detail in section 2.5.

By removing counterfactuals, we do away with a comparative analysis of the biodiversity of vastly different habitats. Seagrass meadows and coral reefs should not be compared to each other per unit area for their biodiversity with the methodologies & technologies in use today[5], as they each provide a set of ecosystem services and functions that are uniquely valuable to the local ecosystem, as well as the world at large. Our methodology only works for project areas that have been traditionally protected, are well-functioning, and currently suffer from a significant funding gap to continue that protection, therefore being categorized as protection credits, as opposed to restoration credits. There are many caveats to this methodology, least of which are the effects of exogenous changes such as climate change, ocean acidification and destruction of species corridors, all of which are likely to change the global and yearly biodiversity indices. To address these issues, further research is needed, which has been highlighted in section 3.

1.1 Project context & previous work

The Marine Ecosystem Credits (MEC) design proposed by OpenEarth involves the concept of "stacking" different types of credits that represent various ecosystem services within a one-square-kilometer area, measured and accounted for over the course of one year. It is important to note that MECs themselves are not financial instruments but rather accounting units of environmental value that can be utilized to derive financial instruments.

In our MEC whitepaper, we highlight a significant distinction between conservation activities aimed at *restoring* degraded ocean habitats and those focused on *protecting* already healthy marine environments. This differentiation between Protection and Restoration is crucial due to the distinct financial requirements associated with each practice, as well as the methodologies needed to establish baselines, monitor progress, and issue credits. For the purposes of this biodiversity credit design and methodology, our focus is exclusively on the Protection category.

Among the various ecosystem services and ecological values provided by an MPA, biodiversity stands out as the most important. Pristine ocean areas that have been protected exhibit high levels of remaining biodiversity that are increasingly threatened, and the conservation of biodiversity aligns with the primary objective of ocean preservation: supporting life within its realms. Furthermore, biodiversity also serves as a proxy for ocean health.

Given the significance of biodiversity protection, our initial credit methodology primarily focuses on this aspect. However, it is worth noting that biodiversity credits and markets are still in their early stages and face a fundamental challenge, namely the determination of a common unit for measuring biodiversity. Unlike carbon credits, which have a globally standardized unit of 1 ton of CO_2, biodiversity lacks a unified measure, not necessarily due to a lack of standardized agreement but rather the practical challenges of measuring it across diverse ecosystems.

To inform our methodology, we begin by reviewing existing biodiversity credit systems that have served as sources of inspiration. By studying these systems, we aim to incorporate the best practices and lessons learned as we develop the methodology for issuing biodiversity credits within the MEC framework.

[5] For instance, counting species in deep sea habitats consistently, is an unsolved challenge, whereas the same is easier in shallow coral reefs. The same is true for our understanding of marine food webs within these ecosystems. This leads to biases in biodiversity estimations for deep sea habitats relative to coral reefs.

1.2 Biodiversity credit methodologies: State of the art

Biodiversity credits, whether for land or oceans, are still in their nascent stage of development. They are subject to change, so maintaining flexibility within their methodologies is essential to avoid being locked into rigid systems that cannot be easily optimized through iterations and consensus. By keeping the methodologies open, we can accommodate the early development and rapid evolution of biodiversity credit frameworks.

To date, only a handful of biodiversity credit frameworks have been developed, and among those, only a few possess rigorous methodologies. Furthermore, there is a notable scarcity, or even absence, of frameworks specifically focused on oceans. In this context, it is important to compare our framework with other relevant biodiversity credit and natural capital accounting frameworks that have been established. It is worth noting that the list provided below is not exhaustive, as new biodiversity frameworks are being constantly developed.

	OpenEarth MBC	Operation Wallacea	EcoAustralia Credits	UN SEEA
Application and Methodology	Applies to MPAs that require protection efforts to maintain high biodiversity	The framework outlines three categories for credits; uplift, future uplift, and avoidance of anticipated loss. (Applies mostly for land)	**Australian Biodiversity Units** (ABU), are tied to carbon offsets. Through carbon offset initiatives, habitat is protected in a project area. Eg. a wind farm with protected land	Applies to natural capital accounting at a national level. So far, only includes land-based methodologies.
Opportunity	Relevant to achieve a 30% ocean conservation by 2030 and the roll-out of the high seas treaty.	Adaptable framework covering several conservation applications. The proposed counterfactual approach of project comparison can be problematic when scaling implementations and susceptible to subjectivity.	A benefit is recognizing multiple co-benefits of offsetting projects. Additionally, the land involved is conserved in perpetuity. A limitation is that the primary offset is carbon, with biodiversity protection being a positive side effect in a protected area. Issuance of such credits can have limitations.	A global overarching framework able to incorporate new experimental methodologies for ecosystem service valuation within a common area, and compatible with national accounting principles.
Unit denomination	1 MBU per square km^2/year	1% biodiversity uplift per hectare	1.5 m^2 of protected land	Primarily using 1 km^2/year
Credit Issuance rule	Maintain baseline score within +/- 5% of the past 5 years	Measured uplift (in %) using a project with similar characteristics as a benchmark.	1 tCO_{2e} of avoided carbon emissions ***plus*** 1.5 m^2 of permanently protected habitat (government-accredited[6])	Application of UNSEEA methodologies & recorded in environmental accounts (eg. in central banks). Structured MRV are not required as this accounting relates to decision making instead of markets.
Area	Marine	Land or marine	Land based	Land (so far)

Our approach aims to be complementary to these existing credit frameworks. In areas where there is overlap, we believe that incorporating different perspectives within an open knowledge network can contribute to the robustness of the methodologies employed. It is our expectation that the field of conservation and Measurement, Reporting, and Verification (MRV) development will continue to expand in the coming years. The

[6] ABUs are a division of the larger biodiversity units used on the state-based Native Vegetation Credit Registers, termed a Biodiversity Equivalence Unit (BEU) in Victoria and a Significant Environmental Benefit (SEB) in South Australia

work presented in this paper, along with other existing frameworks, should ideally inform the development of new methodologies. Moreover, we encourage other methodology developers to contribute to this open methodology, fostering collaboration and collective progress in the field of biodiversity credit development.

2. **Marine Biodiversity Credit:** Framework & Methodology

The following section provides a summary of the framework and process flow presented in this paper. Subsequent sections will delve into each step of the process in detail, including the various modulating factors that influence the crediting system.

Our primary objective is to outline the necessary steps for practitioners to undertake the conservation and credit issuance process based on the methodology proposed in this paper. However, we also welcome suggestions from practitioners to improve the steps or provide additional details as needed. This collaborative approach ensures that the process remains practical and adaptable to real-world implementation, benefiting from the expertise and insights of those working in the field.

2.1 From biodiversity units to credits: Linking BU, MBU and MBCs

Our goal is to create a scientifically sound and equitable global scale of marine biodiversity whose implementation in a framework can support financial efforts for conservation. For the purposes of achieving global conservation targets (eg. the GBF), this means the unit must be scalable. It also needs to enable comparisons between different projects and conservation areas, with metrics that incorporate the ecological values of an ecosystem with a granularity of 1 km^2 of protected ocean area.

We define a Base Unit (BU) for marine conservation credits to be 1 square kilometer of protected ocean over one year (Fig. 2). This allows multiple ecosystem credit types to be “stacked” over the same area, as described in the Marine Ecosystem Credit whitepaper. For data analytics and calculations when dealing with large bodies of conservation area, the Base Units can be scaled up to orders of magnitude (ex. 100 or 1000 units). To initially setup the BUs for a whole MPA, one must first perform a ‘gridding’ of the ocean area so each BU has its own spatiotemporal boundary (Fig. 2, Step 2). Spatial gridding of km^2 for common data analysis can be done in squares or hexagons. In summary:

$$1 \text{ Base Unit (BU)} = 1 \text{ km}^2/\text{yr}$$

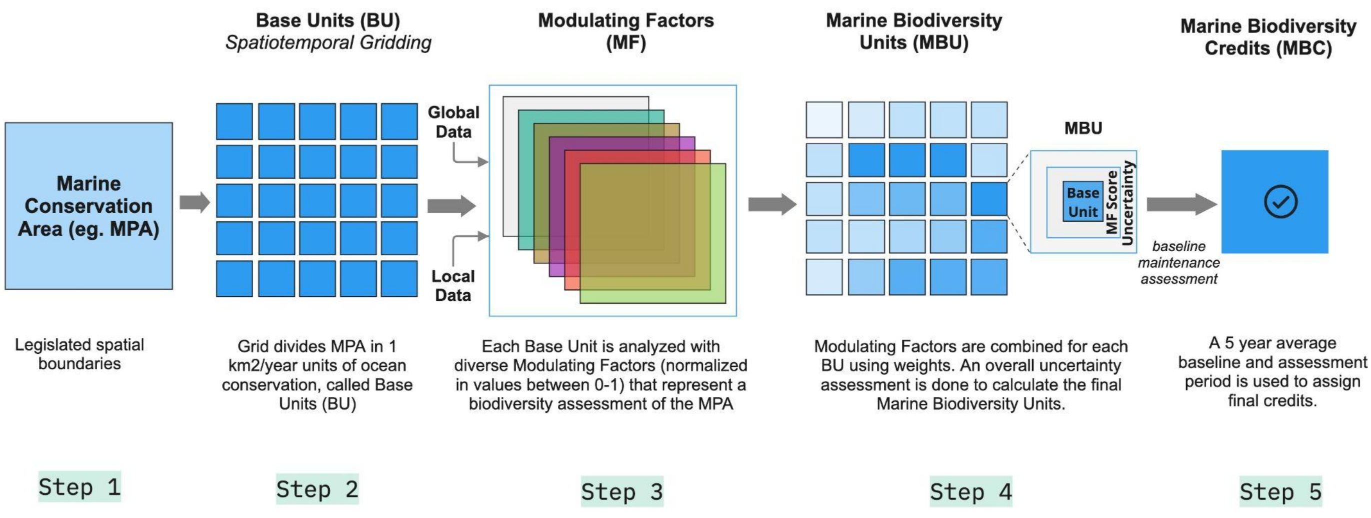


Figure 2. Process summary explaining the relationship between Base Units, Marine Biodiversity Units and Marine Biodiversity Credits.

This Base Unit of ocean conservation, is then 'modulated' by biodiversity assessment factors (called Modulating Factors, see section 3, visualized in Fig. 2: Step 3) to calculate Marine *Biodiversity* Units (MBU), which represent a unit of biodiversity health and ecosystem value within a conservation area (Fig. 2 Step 4). MBUs are subject to an uncertainty assessment which influences the total level of scientific confidence. MBUs have values between 0 and 1, and can be added to calculate the total MBUs for an MPA (for a specific year). As such, the maximum total of MBU that can be achieved is equal to the total of BU within the area. In summary:

1 Marine Biodiversity Unit (MBU) = 1 Modulated BU

Marine Biodiversity Units are calculated over a 5 year period[7] to establish a **baseline**. The average of the total annual MBUs calculated over that period is used to establish the baseline, per BU, and the total eligible Marine Biodiversity Credits (MBC) that can be issued. Credits are issued if the biodiversity conservation efforts and MBUs calculated in yearly assessments maintain the baseline within an allowed modulation window, chosen to be +/- 5[8]% (see section 25, Fig 2: Step 5). Importantly, this approach does not require counterfactuals, and is mostly applicable to MPAs with high baselines (i.e. ecological health) that require protection. This process is repeated for every BU within the project area. A complete example is detailed in Section 2.7.

2.3 Modulating Factors

The concept of Modulating Factors (MF) serves to account for the distinct components that contribute to the level of health and biodiversity richness within a marine ecosystem. These factors are designed to translate commonly used indices and metrics for biodiversity into a standardized and/or normalized value that can be employed to determine MBUs.

When considering the modulating factors, indices, and metrics, our aim is to encompass key indicators of health and change within a marine ecosystem. The selection of these factors takes into account the ecological value associated with each square kilometer of the ocean (km^2/y), reflecting the granularity of ecosystem health. This ecological value is determined by the habitats encompassed within that area and the biodiversity it can support.

Furthermore, we consider a range of modulating factors that can cover assessments and prioritization at various scales, from local to global. This comprehensive approach recognizes the interconnectedness and nested nature of complex adaptive systems within the ocean and biodiversity dynamics. By accounting for these factors at different scales, we can capture a more holistic understanding of the marine ecosystem's health and resilience.

[7] A period of 5 years has been initially chosen to provide a wide enough temporal window to average out inter-annual and intra-annual effects. However this may need to be shortened, depending on the urgency of credit initiation and available priors. On the other hand, a duration of 5 years may be too short compared to global processes such as El Niño cycles.
[8] 5% has been chosen under the hypothesis that natural fluctuations in biodiversity and observation errors can be contained within this window, and this number will need to be adjusted according to known ground truths.

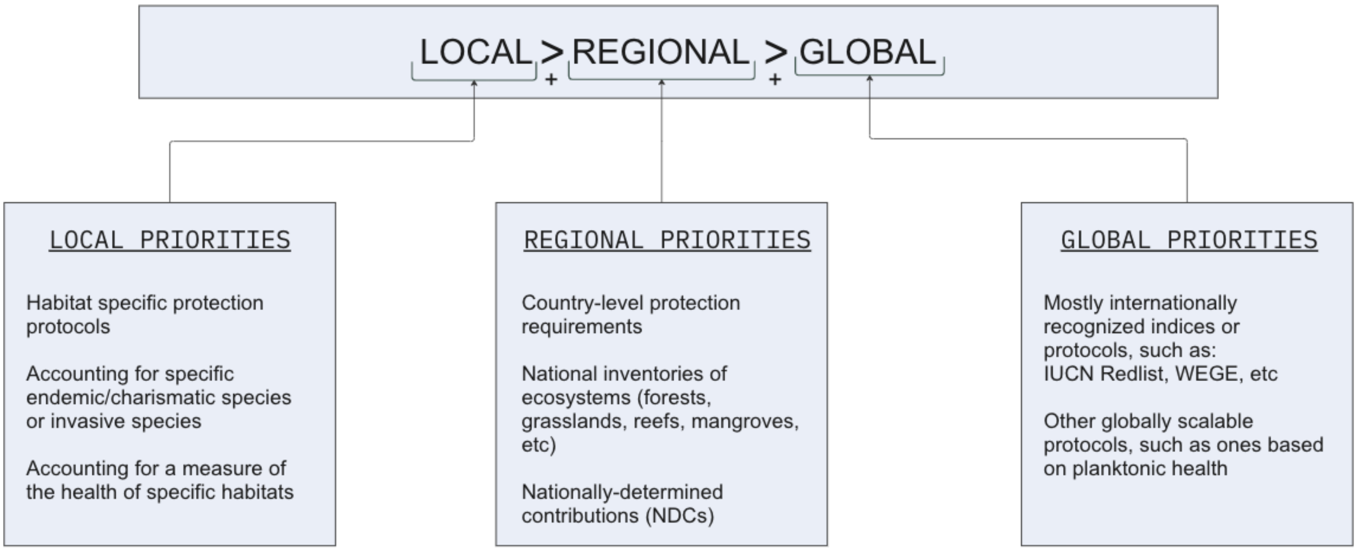


Fig 3. Use of local and global scales to determine an array of modulating biodiversity factors.

In this section, we introduce an initial set of MF along with their respective methodologies. It is important to note that additional MF can be developed and incorporated into assessments as needed. The MF presented here serve as a starting point and are based on:

1. **Shannon index**
2. **Simpson index**
3. **Species Richness**
4. **Endemism**
5. **Habitat Survey**
6. **Species Vulnerability (based on WEGE Index)**

These MF represent key components of biodiversity assessment and contribute to the calculation of Marine Biodiversity Units (MBUs). We anticipate that MF will evolve into comprehensive libraries of factors that can be applied in projects based on their relevance. Each factor can be refined methodologically, and new factors can be developed as our understanding of biodiversity science advances.

It is worth noting that advanced MF incorporating emerging measuring practices, such as satellite-based calculations and environmental DNA (eDNA) techniques, are mentioned and incorporated conceptually, but their methodologies are not yet provided in this paper. Section 3.7 elaborates on additional MFs that we believe should be included and their corresponding methodologies.

The MFs play a crucial role in modulating the value of **1 BU**, which represents 1 square kilometer per year of protected ocean area, based on data, evidence, and biodiversity science. Each index is normalized to a range of **0 to 1**. This normalization is achieved by dividing the Index or Metric score for each Base Unit (BU) by the maximum score achieved among all BUs for that MF, also known as min-max normalization. Thereafter, the normalized index is multiplied by a weight (w_i) uniquely assigned to each index.

The formulas below define these relationships for a single BU referenced as BU_k:

$$MBU_k = \frac{1}{\sum_{i=0}^{M} w_i} \sum_{i=1}^{M} MF_i(k)$$

Equation 1. Marine Biodiversity Unit calculation specification using modulating factors

Where:

$$MF_i(k) = w_i NORM(I_i(k))$$

Equation 2. Modulating Factor specification. NORM() refers to a normalizing function; w_i is the weight assigned to the ith MF; M are the total number of MFs; I_i is the i-th index for the k-th BU; k is the index of the BU

As a result, the MFs essentially dictate the MBU value for each Base Unit. The equation ensures that each MBU will have a value between 1 and 0, with 1 representing the maximum and 0 indicating the lowest level of biodiversity within each square kilometer per year. The MF also impacts the total number of MBUs within a MPA over an assessment period, thus influencing the baseline and the annual credits issued (Section 2.5). Note that throughout this document we have utilized max-normalization for consistency, i.e. dividing the value by the maximum possible value across the MPA, but other methods such as min-max normalization and standardization are perfectly reasonable alternatives.

To account for variations in the importance of different indices (such as Shannon or WEGE) when assessing the level and state of marine biodiversity, we assign weights to each index. These weights reflect the relative significance of each index in contributing to the overall biodiversity assessment. This entire modulation step is what we call the MF. The logic behind the assignment of these weights is explained in detail in Section 2.4.1.

Additionally, it is important to consider anthropogenic and natural factors that can impact the ocean globally, but are beyond the control of conservation activities within a specific region. Climate change and increased atmospheric and dissolved CO_2 are examples of such global interlinkages that affect the entire ocean and cannot be entirely mitigated by a single MPA.

To address these global interlinkages in the credit system, Integrated Assessment Models can be utilized to represent the complex relationships involved. Furthermore, global normalization can be employed by ranking local biodiversity values based on a global maximum. For further details on these suggestions, refer to Section 3 of the paper.

The remainder of this section provides a description of each of the 6 suggested MFs, their methodologies and steps to calculate them.

2.3.1 Shannon Index

The Shannon Index refers to the Shannon-Wiener index (Shannon 1948) to quantify marine species diversity and richness in an area. The Shannon index takes into account the number of species living in a habitat (richness) and their relative abundance (evenness). The higher the index value (H), the higher the diversity of species in a particular community. Shannon is also an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled.

METHODOLOGY

1. Here we show the use of the [OBIS Database](#) to calculate the Simpson and Shannon Index for the conservation area being analyzed[9] (eg. MPA). Calculate the Shannon Index[10] for the conservation area, using this formula :

$$Shannon\ Index\ (H)\ =\ \sum_{i=1}^{s} p_i ln(p_i)$$

   a. Calculate the index per species, where p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species.

   b. Sum all the values of H inside each BU

$$H_{BU} = \sum_{i=1}^{x}$$

2. Normalize the calculated index value and establish its normalized score for each BU within the area analyzed

   a. Take the calculated value (H)

   b. Search for the maximum value calculated index in all BUs within the entire project area (max H)

   c. Normalize H by BU using the maximum value found

$$Normalized\ H_{BU} = \frac{H_{BU}}{max\ H\ value\ found}$$

Considerations in Methodology

Please refer to this section in 2.3.2 below.

2.3.2 Simpson Index

The Simpson index (Lande 1996) emphasizes dominance and the probability of selecting individuals from the same species, highlighting the potential impact of a few abundant species. As a dominance index giving more weight to common or dominant species, the presence of a few rare species with only a few representatives will not affect the diversity value.

1. Calculate the Simpson Index for the conservation area. Simpson Index methodology can be found [here](#).

   a. Using this formula:

$$Simpson\ Index\ (D)\ =\ \frac{1}{\sum_{i=1}^{s} p_i^2}$$

   Where p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species.

---

[9] The column named "'individualCount" in the OBIS database was considered as the source for abundance information

[10] A detailed methodology can be found at https://www.itl.nist.gov/div898/software/dataplot/refman2/auxillar/shannon.htm

b. Calculate D for each species

c. Sum all the values of D inside each BU

$$D_{BU} = \sum_{i=1}^{x} D_n$$

2. Normalize the calculated index value and establish its normalized score for each BU within the area analyzed

a. Take each calculated value (D)

b. Search for the maximum value calculated by index in all BUs within the entire project area (max D)

c. Normalize each D by BU with the maximum value found

$$Normalized\ D_{BU} = \frac{D_{BU}}{max\ D\ value\ found}$$

Considerations in Methodology

The combination of the Shannon and Simpson indices provides a better level assessment of marine biodiversity, taking into account overall diversity, evenness, dominance, and the significance of different species within the ecosystem. However, both these indices emphasize the importance of species diversity, over other salient factors, including species composition, functional diversity, or genetic diversity. Moreover, these indices can be sensitive to differences in sample size, especially when comparing biodiversity across different sites or when dealing with uneven sampling efforts. This means that sites with larger sample sizes tend to have higher index values, regardless of the actual species richness or diversity. In such cases, other indices that account for sample size or rarefaction methods may be preferred.

Furthermore, Shannon and Simpson indices consider species abundances but do not explicitly account for species identities or ecological roles. This means that two communities with different species compositions but similar abundances may yield similar index values. Finally, these indices make certain assumptions about the data, such as species independence and proportional abundances. Violations of these assumptions, such as the presence of strong species interactions or highly uneven species abundances, can affect the reliability and interpretability of the indices.

However, these indices are relatively straightforward to construct and use with data that is easier to collect. To balance these considerations, we advise the use of smaller weights for these indices.

2.3.3 Species Richness

Species richness refers to the number of unique species present in a given area or ecosystem. It is a simple count of the number of species and does not take into account the abundance or distribution of each species. The difference between the Shannon and Simpson Index scores and Species Richness is that the former takes into account species abundance and other factors, whereas richness just considers the number of different known species present. We include this as a separate MF because of its importance and variation over time, but recommend using a low MF weight since the sheer number of species doesn't correlate highly with ecosystem function, and is generally considered to be a low quality proxy for biodiversity.

We present a methodology that is flexible with respect to the available data sources, so that a species richness value can be calculated directly via eg. environmental DNA methods.

METHODOLOGY

1. Assess the available datasets, e.g IUCN, OBIS, local species inventories, or self-collected datasets. These datasets have to contain spatial information at a species level, i.e. contain either ranges for each species, such as the IUCN, or more likely point estimates for species observations. CLean the data appropriately to remove extinct species, observation dates too far in the past, etc.
2. Count the number of species within each BU by conducting an intersection analysis of each BU over the available spatial datasets. This provides the number of unique species per BU, i.e. the species richness.
3. Normalize this value by using the maximum total value of any individual BU in the project area.

Considerations in Methodology

1. Evaluate if the data sources are updated regularly, and if not, incorporate this in the Uncertainty factor
2. If the availability of species-level data is not very granular, consider performing an assessment of family diversity, i.e. a higher level of taxa.
3. This MF can be compatible with eDNA methodologies for data acquisition.

2.3.4 Endemism

Endemic species are those that are exclusively found in a particular geographic region and nowhere else in the world. It is crucial to understand endemic species in order to maintain the planet's biodiversity, inform conservation efforts, advance our knowledge of evolutionary processes, and recognize the cultural and economic significance of these species. Endemic species in the ocean are difficult to find because they have more freedom of movement than species on land (sparsity), and the limited modalities we have for observing them, such as manual surveys, eDNA, etc which can lead to considerable observation biases. Consequently, endemism is an important factor to consider when evaluating the importance of protecting a specific place in the ocean.

We construct a MF based on *weighted endemism* as defined by Crisp et. al 2001, which is calculated per BU, as the ratio of area over which species (i) is found to its global distribution, summed over all species in the MPA (k):

$$Endemism_k = \sum_{species} \frac{\text{Area over which species}_i \text{ is found within BU}_k}{\text{Global species distribution area for species}_i}$$

Equation 3. Endemism

Figure 4 explains the significance of this MF for the entire MPA.

METHODOLOGY

We can use the species richness information for the MPA to perform an Endemic Factor analysis for each species present using the following steps:

1. For each species present, establish their global Species Distribution Area (SDA) as a geographical extent (e.g. represented by a shapefile or spatial polygon derived from the IUCN Red List[11]).
2. For every species in the conservation area (eg. MPA) boundary, calculate its local SDA per BU by comparing each SDA's extent with that BU and its global extent.

[11] IUCN Red List: https://www.iucnredlist.org/

a. Find the intersection between each BU and the overall SDA[12], SDA_i .

3. Divide the SDA area within each BU (SDA_i) by the global SDA area by applying the following formula for species i:

$$distribution\ factor\ (i)\ =\ \frac{SDAi}{Global\ Species\ Distribution\ Area}$$

4. For each BU, add all distribution factors per species to establish a single MF per BU.
5. Normalize this MF value with the maximum value among all BUs in the MPA.

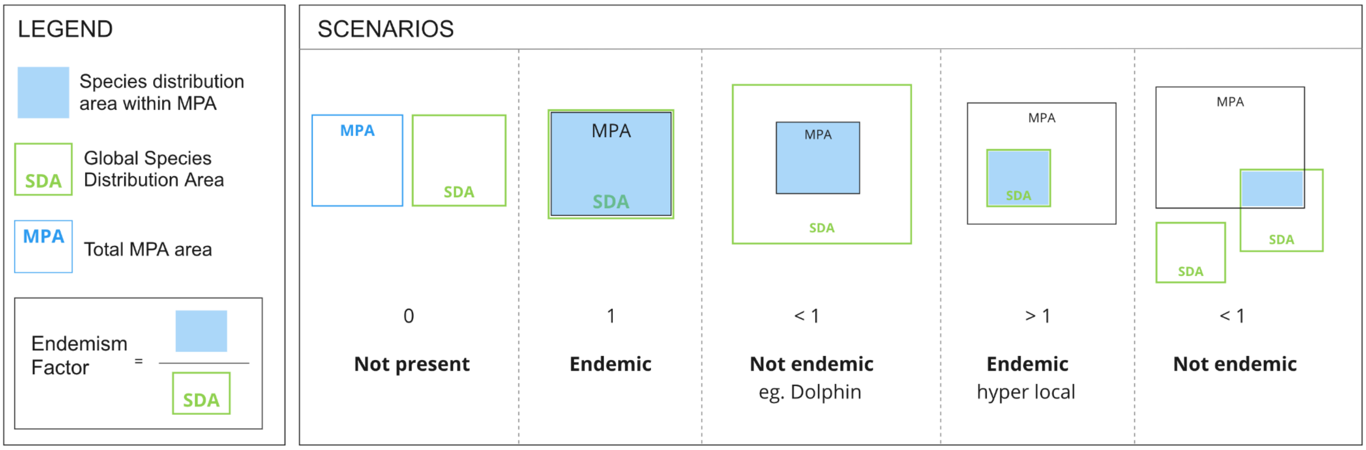


Figure 4. Endemism Factors: calculation using geospatial information of each Species Distribution Area.

When the Endemism Factors is close to *1*, the species aren't endemic to the MPA but they could be local species . When the factors are very low, i.e. *<< 1*, the species are probably migratory; they might visit conservation areas seasonally and they can travel long distances. When values are higher than 1, it means the species not only are endemic, but hyper-local to the region and thus may require extra conservation effort.

We consider species endemic if their endemism factor is within 0.8 and 1.2, in order to include a 20% variance to the conservation area range.

Considerations and Issues in this Methodology

1. It's possible that some local resources (eg. regional ecology textbook) or survey of local experts, may describe an endemic species present in the conservation area, but global databases either don't have records of it, nor have spatial distributions to describe its SDA.
   a. If so, an SDA should be conducted for the species and proposed to the IUCN.
2. Some species can be hyper local and may require special conservation efforts and monitoring. The methodology needs to prevent a dilution of from a low count in high endemism factors, with a high count of low EF value.

[12] In python, the geopandas package provides a "clip" function that could be used to extract and preserve only the intersecting parts of a geometric object based on a specified geometry, discarding any portions that fall outside. It allows for precise cutting and extraction of relevant features from a geometry by utilizing another geometry for clipping.

2.3.5 Habitat Survey

The diversity of marine habitats greatly influences species diversity and richness in marine ecosystems. Different habitats offer unique ecological niches and resources, attracting a wide range of species. More complex and diverse habitats provide various microhabitats for shelter and sustenance, supporting diverse marine communities. MPAs with multiple habitats hold ecological value as they serve as essential nurseries and feeding grounds for marine species, while also contributing to carbon sequestration, nutrient cycling, and shoreline protection, benefiting overall ecosystem functioning and marine life. Diverse marine habitats are biologically valuable, hosting species with unique adaptations. Having multiple habitats within MPAs promotes ecological connectivity, allowing species to move and maintain gene flow, thus increasing the resilience and adaptability of marine populations amid environmental challenges such as climate change and habitat degradation. Then, this modulating factor considers both ecological habitats (eg. coral, seagrass, seamounts, knolls, etc) as well as the different physical pelagic regions (i.e. epipelagic, mesopelagic, abyssopelagic. etc).

METHODOLOGY

In our particular implementation, we conduct a survey of the number and types of habitats per sq. km in the conservation area using the IUCN Global Ecosystem Typology[13]. This typology is a hierarchical taxonomy of ecosystems at various scales. We conduct our analysis on the level of *Ecosystem Functional Groups (EFG)*.

1. The IUCN Global Ecosystem Typology provides geospatial information in the form of coverage of different EFGs globally. We begin by extracting the overlaps of EFGs and the MPA.
    a. Find the intersection between each EFG and the MPA.[14]
2. Count the unique number of EFGs that are contained within the MPA.
3. Normalize every total value of habitats/ecosystems per BU with the max total value among all BUs.

Considerations and Issues in this Methodology

- This methodology is highly sensitive to the temporal and spatial accuracy of the IUCN Global Ecosystem Typology dataset and may introduce errors over space and time. Some ways to ameliorate this would be to conduct local assessments at higher frequencies to augment the IUCN dataset.
- This modulating factor is only an accounting of the different habitats present per BU; the more habitats present, the higher the BU score. Since this is a presence based score and does not necessarily correlate with the health, vigor and resilience of the ecosystems, we recommend a lower relative weighting for this MF.

2.3.6 WEGE

WEGE is the acronym for the Weighted Endemism including Global Endangerment index as it is described in Farooq et al. 2020, and is an adaptation of the EDGE (Isaac et al. 2007) score (Evolutionarily Distinct and Globally Endangered). WEGE allows the ranking of any set of locations according to the Key Biodiversity Areas (KBA) guidelines and on a continuous scale. WEGE is calculated as:

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[13] The IUCN Global Ecosystem Typology is a comprehensive classification framework for Earth's ecosystems that integrates their functional and compositional features. This new typology helps identify the ecosystems that are most critical for biodiversity conservation, research, management and human wellbeing into the future. https://doi.org/10.2305/IUCN.CH.2020.13.en

[14] The "clip" function in the python geopandas package was used to extract and preserve only the intersecting parts of a geometric object based on a specified geometry, discarding any portions that fall outside. It allows for precise cutting and extraction of relevant features from a geometry by utilizing another geometry for clipping.

$$WEGE = \sum_{i=1}^{N} \sqrt{WE_i} \times ER_i$$

WE_i : weighted endemism for species i (See Crisp et al. , 2002); ER_i: probability of extinction of species i (Using the IUCN50 transformation for the ER from Davis et al., 2008) and N is the number of

Where weighted endemism (WE_i):

$$WE_i = \frac{\text{Area over which species i is found within target area}}{\text{Target area}}$$

Crisp et al. 2001 describes weighted endemism in terms of grid cells, stating:"...a single-cell endemic has the maximum weight of 1, a species occurring in two cells has a weight of 0.5, and a species occurring in 100 cells has a weight of 0.01. To obtain an endemism score for a cell, these weights are summed for all species occurring in the cell. We term this measure weighted endemism". Instead of counting grid cells, we can define the endemism weight for each species as a ratio of areas.

Where extinction probability (ER_i) is a mapping:

$(DD, LC, NT, VU, EN, CR, EW, EX) \Rightarrow (5.13\%, 0.09\%, 0.71\%, 5.13\%, 42.76\%, 96.88\%, 100\%, 100\%)$

Where:

- DD = "Data Deficient"
- LC = "Least Concern"
- NT = "Near Threatened"
- VU = "Vulnerable"
- EN = "Endangered"
- CR = "Critically Endangered"
- EW = "Extinct In The Wild"
- EX = "Extinct"

ER is defined by Farooq et al. 2020 as the extinction probability for the species IUCN Red List category, using the transformation from Isaac et al. 2007. Other transformations exist in the literature, such as Mooers, Faith, and Maddison 2008. However, we follow Farooq et al. 2020 and use the Davis, Faurby, and Svenning 2018 transformation. We also set the extinction probability of data deficient (DD) species to the extinction probability of "vulnerable" species following Bland et al. 2015. This is based on the idea that DD species may be more threatened than some data-sufficient species (Bland et al. 2015). Here, the transformation used is for each IUCN Red List category.

METHODOLOGY

Our methodology follows Farooq et. al's consistently, where the 'grid cells' in their methodology are BUs in ours. The steps are as follows:

1. Per BU, find the weighted endemism (WE_i) score
    a. Use the range maps for every species in that grid cell to calculate the WE_i using the formula above
2. Per BU, find the extinction probability (ER_i) score
    a. Use the mapping above to apply to every species; for species not listed, use 'DD'
3. Construct the WEGE score by taking the square root of WE_i and multiply by ER_i
4. Normalize the score of each BU by dividing it by the maximum value across all BUs in the MPA.

2.3.7 Other Modulating Factors

While the initial set of Modulating Factors presented in this methodology provides a foundation, it is important to acknowledge that other MFs can be developed and incorporated into the framework. Additionally, advancements in direct measurements and data sources can lead to more robust and dynamic calculations of the MF outlined above, providing more accurate and granular data.

Three important aspects that could be included in future development of this methodology are:

1. Satellite Data Sources: Dynamic direct measurements and data sources from remote sensing approaches, such as satellite imagery, especially multispectral and hyperspectral imagery. These technologies can provide more comprehensive data on factors that influence biodiversity health within an area, including shipping patterns, extractive practices, pollutants, and biological activity. Satellite-based data sources could be considered as a separate MF or as improved data sources for existing indices.

2. Environmental DNA (eDNA) assessments offer another promising approach to establish robust biodiversity information. eDNA refers to the DNA shed by organisms into the environment, which can be detected in water samples. This technique enables the detection of phylogenetic diversity, abundance as well as species richness. They can provide consistent measurements of biodiversity changes across space and time within a conservation area. Development of eDNA techniques for ocean biodiversity require further research, but could potentially enhance the direct data sources for the MF of endemism, species richness, and Biodiversity Index Score.

3. Local community role: The role of indigenous communities and local marine communities in the governance, conservation management, and Monitoring, Reporting, and Verification (MRV) process of Marine Protected Areas (MPAs) is an important consideration. These communities often become de facto stewards of biodiversity and play a crucial role in ensuring sustainable practices and benefiting directly from conservation efforts. While methodologies can be developed to represent local community factors as a separate MF within the biodiversity framework, they can also be evaluated as a separate ecosystem service credit within the Marine Ecosystem Credit (MEC) framework.

In terms of the MF, they should be viewed as a 'library of options for assessments', with the potential of the MF options to grow and improve over time.

Two possible pathways for ensuring reproducibility and compatibility across projects, sites, and credits are suggested:

1. Defining a final set of acceptable MF and methodologies as a rigid standard to ensure comparability.

2. Dynamically recalculating MBU values based on the specific MF and weights used in each project, allowing for relative comparisons while using different MF and weights.

By incorporating these advancements and considerations, the methodology can evolve, adapt, and provide a more comprehensive framework for assessing marine biodiversity credits.

2.4 Calculating Marine Biodiversity Units

To determine the MBUs assigned to a conservation area within a year, all Modulating Factors (MF) need to be harmonized into a single value per Base Unit (BU), representing the level of biodiversity. This is achieved by first normalizing each index, assigning weights to and finally combining the weighted indices values for each BU and normalizing them again, to generate the MBU for each BU.

2.4.1 Assigning weight values to generate modulating factors

This methodology allows for assigning weights to each index to further modulate their influence on the calculation of MBUs and final credits. Unlike traditional practices such as ESG metric determination or scoring financial instruments, the weights used in this methodology should be transparently disclosed through open data practices. This ensures *transparency* and helps address subjective considerations, and allows for comparative analysis of crediting methodologies across projects.

Weights can be subjective, acknowledging that different cultures and scientific perspectives may assign different values and equity to the different aspects represented in the MFs. To embrace this subjectivity and promote comparability, weights are designed with comparability in mind, allowing for recalculating MBU values using the same weight factors for different projects to enable relative comparisons. Different equity and scientific frameworks can be used to establish predetermined weight factors, simplifying the comparison process.

The process of determining the weight of each MF and achieving comparability calculation is still incomplete, and the methodology invites researchers, standard setters, and experts to propose mechanisms for this. The current default weight is an evenly distributed value thereby averaging the proposed MFs.

2.4.2 Harmonizing all Modulating Factors for MBU calculation

Normalized MF scores are multiplied by their weights, and the weighted values are then summed up. This process is applied to each BU, resulting in a single MBU value for each BU. The MBU values for all BUs within the conservation area are added together to calculate the final MBU for the entire area.

The diagram below provides a visual representation of the process using sample values for the MF scores, and the default use of the evenly weighted values:

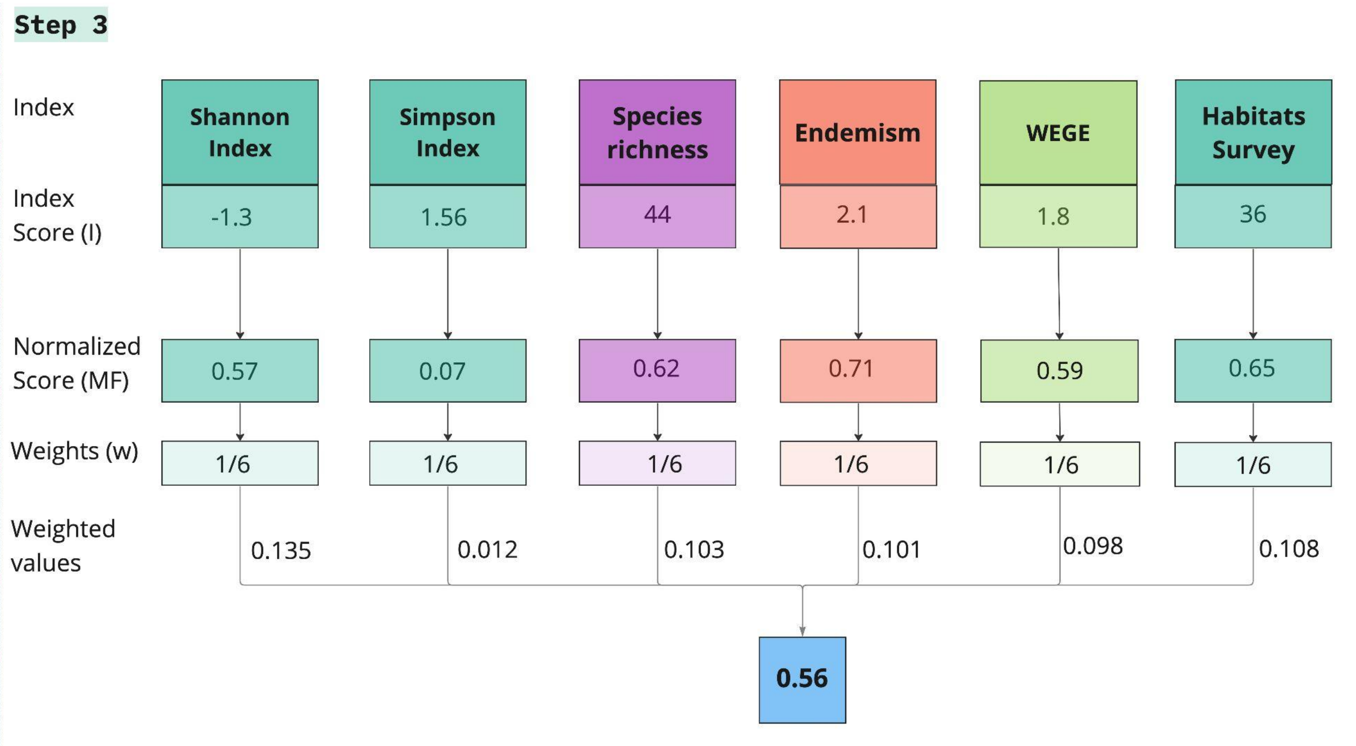

Figure 5. MBU Calculation for a single BU using modulating factors comprising index scores, normalization and weights. Refer to Equation 1 for the specifications of the MBU calculation.

2.5 Baseline & Credit Issuance

The previous section describes the method to calculate the annual MBU for each BU and the total conservation area. This process is repeated over a 5-year period to establish the initial baseline before the project can start issuing credits, as shown in Figure 6. Alternatively, if past data is available, the previous 5 years are considered for establishing the baseline. This initial baseline is the 5-year average MBU value per BU.

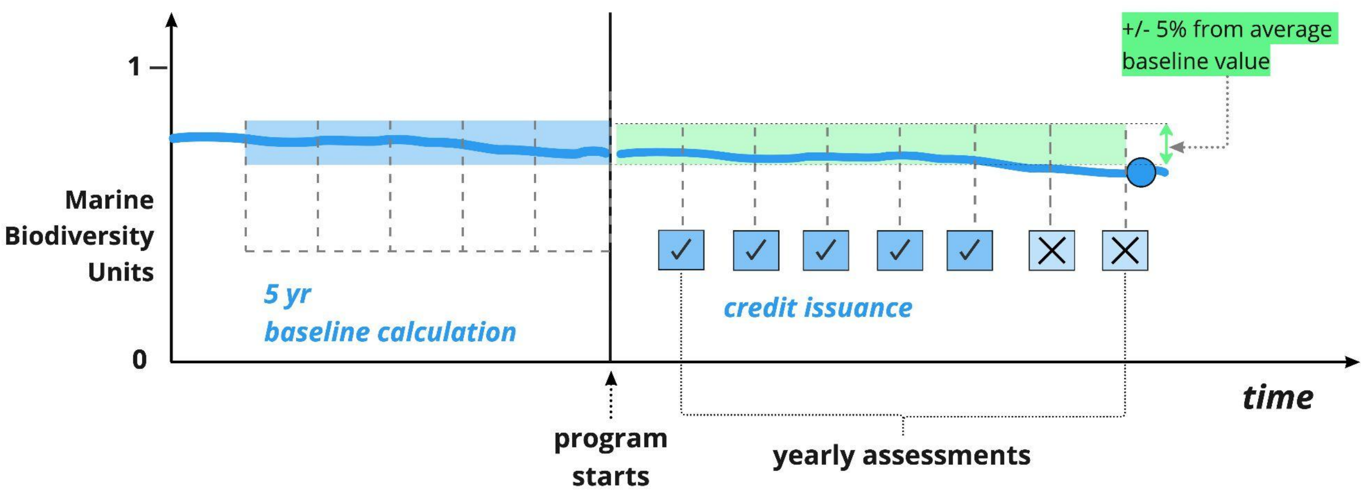

Figure 6. Final credit issuance methodology based on a 5 year average baseline and +/- 5% buffer for annual variations

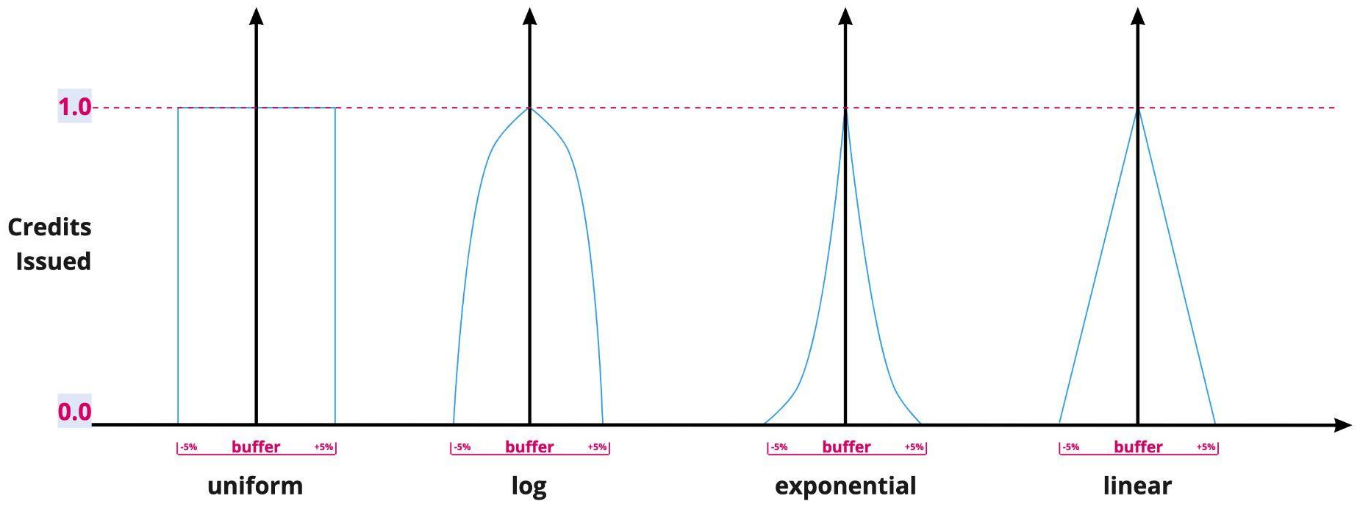

Figure 7. Possible scales for credit issuance

To determine the total number of credits that can be issued each year, a buffer is established, set at +/- 5% from the baseline value **per BU**. During yearly evaluations, the MBUs must fall within this buffer to receive the full amount of Marine Biodiversity Credits (MBC) they are eligible for (which is typically set to the same value = 1 unit). If a BU maintains biodiversity as decided by the normalized weighted sum of its MBUs, and stays within this buffer, then that BU receives 1 credit for that year. The methodology highlights the value of this approach as it does not require counterfactual scenarios, which simplifies the process of establishing baselines and issuing credits, and rewards homeostasis of the ecosystem within that BU.

Other mechanisms for credit issuance are certainly possible and variations include:

- Sliding scale credit issuance: whereby the value of the credit issued per BU is a function that produces a value between 0 and 1 (instead of either zero or one). This function could be thought of as a kernel that could be linear, exponential or of another shape, as shown in Figure 8. We have proposed the simplest version here, the uniform kernel, but other forms including logarithmic, exponential and linear mechanisms are also reasonable.
- Sliding window baselines: Here instead of using a fixed baseline constructed from the initial 5-year period, the baseline is dynamic, and could be constructed from a sliding window of the previous 5-year period. On the one hand, this design may ameliorate issues such as spillovers and boundary effects from outside the MPA, but on the other hand it may enable perverse incentives that allow the quality of biodiversity to gradually decrease over time without penalty.

2.5.1 Exceeding Buffers

A natural question that may arise, and indeed has been a difficult one to address, is - what happens when buffers are exceeded, in both directions? If the MBU value calculated is greater than the buffer (i.e. over 5% of the baseline), does that mean that the biodiversity has increased, or is it simply system noise, or perhaps the usage of better methods (such as eDNA) produces 'better' values? If it goes down below the buffer, does it mean that sufficient effort was not expended in maintaining the state of biodiversity in that BU? What if there is proof of steady or even increased protection efforts? What if there are edge effects and leakages from outside the project area; or even large scale changes in the health and wellbeing of the ocean as is visible today almost universally?

This is a multi-layered and complex topic, and comprehensive & adaptive measures will have to be undertaken to resolve such questions. This is something where further research is needed and collaborative open work needs to be done with practitioners in the field in order to arrive at an alignment on approach. We provide some simple starting points:

Scenario A: MBUs above the baseline consistently. If consistent protection actions have been taken, then it is conceivable that the health of the BUs in question have indeed risen. This could be considered a restoration effort, and pursuing restoration credits (possibly in addition to protection credits) would be an option. Having an adaptive baseline should also be considered to ameliorate such issues - e.g. the baseline is calculated over a rolling window. This comes with its own downsides, and will have to be weighed against the prevailing conditions.

Scenario B: MBUs below the baseline consistently. If consistent protection actions were proven to be taken, then it is possible that exogenous effects such as acidification, climate change, or spillover effects such as the destruction of migration corridors, etc are to blame. In such cases, thorough investigations to the cause of such declines should be reasonably conducted and documented, and an adaptive baseline should be considered for sub-sections of the project area. If, however, consistent protection actions were not taken, or could not be proved, then the system works, and the project has incentives to increase protection efforts in order to receive credits in the following cycle.

2.7 Complete Example

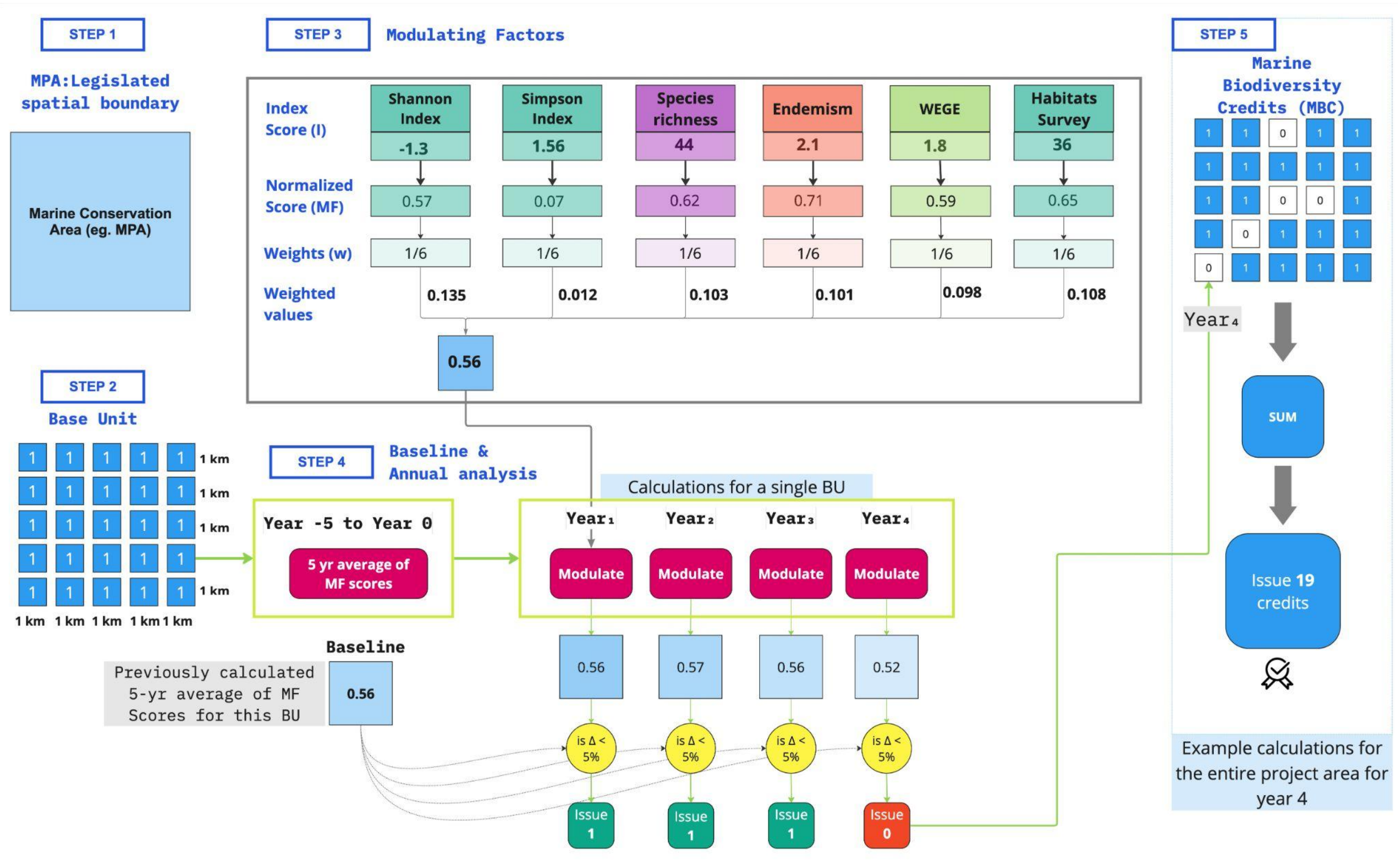

Figure 8. Complete example of generating MBUs for a project.

In the complete example depicted visually in figure 8, we show the process of calculating the MBU for a single BU. To begin with, each BU (1 sq. km) is assigned a value of 1 credit. Then the data for that BU is passed through each modulating factor and combined together (using pre-selected weights) to yield a single value between 0 and 1. This process is repeated for 5 years and averaged[15] together to provide a baseline score (0.56 in the example). This process is then repeated every project cycle (every year in this example), and the resulting MBU value of each BU is compared with its baseline. If the value is within the pre-selected buffer (here 5%), then one full credit is given to that BU, otherwise none. In this example, in year 4, the value of MBU for that BU is less than -%5 of the baseline value (0.52 < 0.532), and during that year, the BU receives no credit, having not maintained homeostasis for that geographical region.

2.8 Open source data pipeline and open innovation process

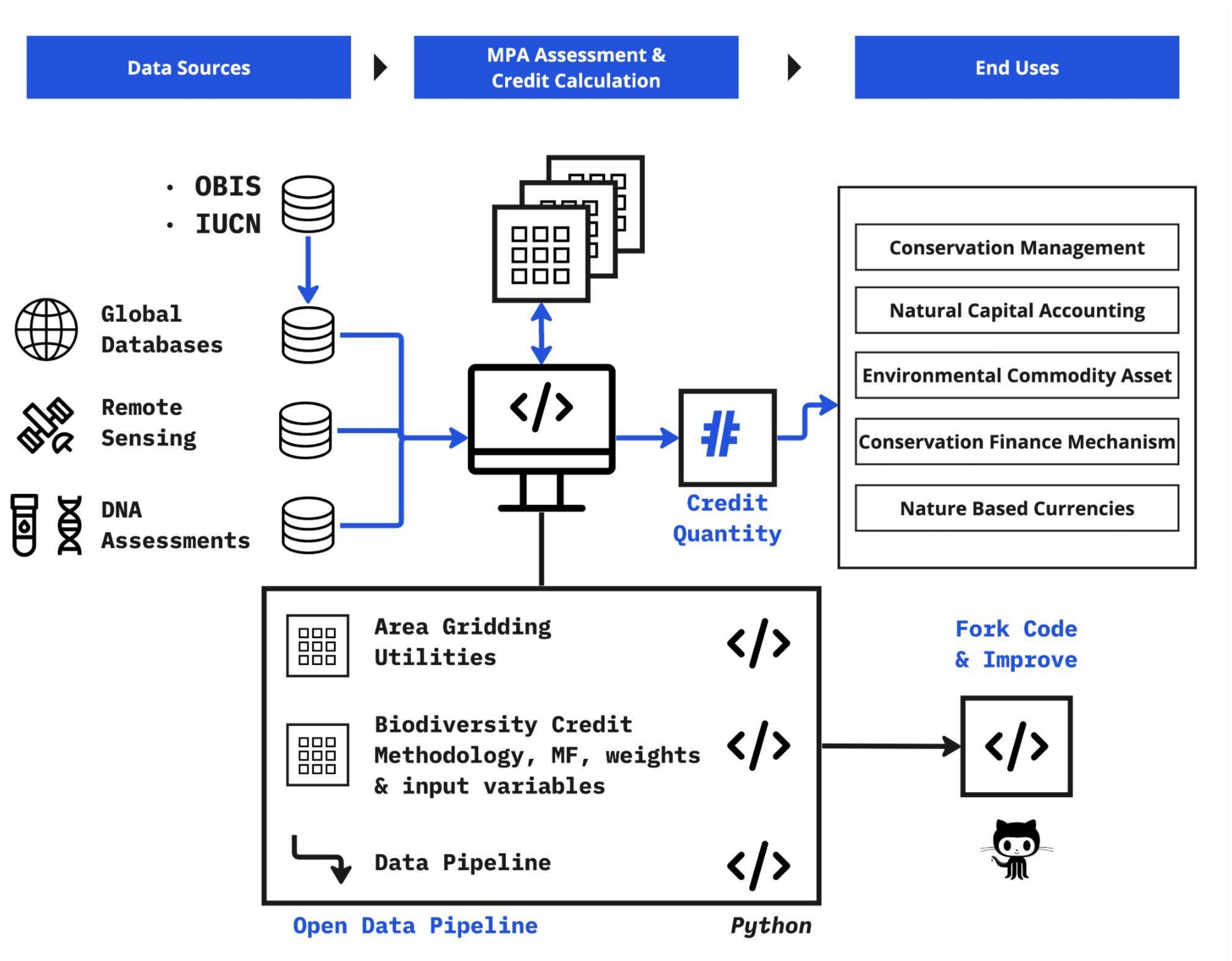

Figure 9. Illustration of the open source data pipeline for marine biodiversity credit calculation

This Marine Biodiversity Credits technical framework document is accompanied by an open source data pipeline, which enhances the open innovation process for how this methodology can be improved. The data pipeline is available on the OpenEarth GitHub repository[16]. It is written in Python code and combines all the processes laid out in this methodology, which are visualized as a process flow in Figure 1 and 2. The published

[15] Instead of averaging, using a median may be more appropriate, especially in the presence of noisy data and outliers. However, the median should not be used to cover up the source of that noise, which is an important operating parameter of the system.
[16] GitHub repository at: https://github.com/Open-Earth-Foundation/oceanprogram

data pipeline uses the marine protected park of Isla del Coco, Costa Rica as a case study example. This provides a concrete example and case study where this methodology is applicable.

The purpose of this pipeline is to provide transparency, reproducibility, and comparability across projects that are applying the methodologies. It's also designed to enable scaling the application of this credit framework, by providing automation and utility functions for the MFs described. Furthermore, it also enables a more effective way for contributions and suggestions that improve this methodology to be directly performed on the code. Finally, by making the data pipeline open source, we ensure its democratization, making it accessible to a wide range of stakeholders, including investors, governments, local communities and conservation organizations. In this way, this pipeline provides a starting point for real-world implementations.

The data pipeline is designed to be flexible, allowing for new data sources to be used in replacement of existing databases like IUCN or OBIS. This is particularly important as new advanced data sources, such as satellite remote sensing, bioacoustic loggers and eDNA, become available. The code also allows the proposal and creation of new modulating factors, or proposals to fill the gaps pointed out in the next section of this paper.

To ensure the credibility and effectiveness of a marine biodiversity crediting approach, the Open Earth Foundation and the document's authors encourage experts to provide feedback, critique, proposed revisions, additions, or deletions to the methodology. This review process can be conducted on both this text manuscript as well as on the open source code of the data pipeline, which essentially turns the described methodology into an algorithmic process for data science. Experts are invited to make a pull request to OpenEarth's GitHub repository with the open data pipeline and propose their revised version of the code, process, and calculations. Overall, this open innovation process allows for continuous improvement and refinement of the methodology in a transparent and collaborative fashion.

It is important to note that this methodology has limitations and gaps, for which further research, consultation, and input from practitioners is required. These limitations and gaps are discussed in Section 3 of this document.

3. Limitations, Gaps and Considerations in the Overall Methodology

The Marine Biodiversity Credits technical framework represents a significant step forward in the development of biodiversity credits, offering a promising avenue for marine conservation. Nonetheless, it is crucial to recognize that the methodology is not without its limitations and areas that warrant further exploration and refinement. This section aims to shed light on these aspects that necessitate additional research, consultation, and input from experts and practitioners.

3.1 Limitations & Caveats of the Crediting Methodology

The biodiversity credit methodology presented in this section presents a substantial advancement in marine conservation efforts. However, it also brings to the forefront several limitations and gaps that merit in-depth investigation to ensure the methodology's robustness and efficacy. In particular, key reviews and further work are required in the following aspects:

1. **Modulating Factor Methodologies:** Each modulating factor methodology requires careful consideration of data sources, accuracy, variations, and other relevant factors. These considerations are outlined in each Modulating Factor section. Continuous updates and optimizations to the MF methodologies through further revisions and testing, including pilot projects, are essential to enhance their precision and applicability.

2. **Integration of Next-Gen Data Sources:** The potential of next-generation data sources, such as environmental DNA (eDNA) and advanced satellite remote sensing, is acknowledged in improving the accuracy and breadth of the methodology. However, specific methodologies for incorporating these cutting-edge data sources to calculate the index score in each methodology are yet to be fully developed and validated. Further research is required to establish precise and proven methodologies for their integration.
3. **Weight Factors Methodologies:** The incorporation of weight factors is crucial for adjusting the influence of each modulating factor on the calculation of Marine Biodiversity Units (MBUs) and the issuance of credits. However, concrete methodologies or approaches for determining weight factors have not been proposed. Developing a transparent weight factor system that ensures interoperability and comparability across credits with different weight factors is necessary for the credibility and effectiveness of the methodology.
4. **Measuring Uncertainty in Credit Quantification and Claim:** The methodology proposes uncertainty as an overall Modulating Factor in valuing credits, especially if they are to be traded as financial instruments. However, a well-defined and reproducible methodology for measuring uncertainty in credit quantification and claim remains undefined. Addressing this aspect is crucial for accurately modulating credit pricing and enhancing confidence in the marketplace. Collaborative efforts are encouraged to propose technical approaches to tackle this critical aspect.
5. **Handling Baseline and Overshoots:** The simplified assumption of setting a baseline with a +/-5% buffer for 5 years may not be practical in some cases. Project owners may find it challenging to conduct 5 years of rigorous assessment without any monetary support to receive credits. The methodology should consider adopting shorter and/or adaptive baselines in such situations and provide clear guidance for handling periods when MBUs exceed or fall below the +/- 5% buffer.

Addressing these areas of further work will significantly strengthen the biodiversity credit methodology, enabling it to drive more effective conservation efforts and sustainable management of marine ecosystems. Collaborative research, consultation, and input from experts and practitioners are pivotal in refining and optimizing the methodology for real-world implementation and success.

3.2 Practical Use of Credits, Valuations and Market Considerations

In this section, we explore the valuation and market considerations for marine biodiversity credits, examining their potential applications and commercialization options.

Credits, as presented here, serve as numerical representation units within a comprehensive system of natural capital accounting[17]. They can be utilized in various ways, offering flexibility in their implementation. One approach is to maintain these credits as registered and audited accounts, providing a transparent display of environmental accounts in central banks or national/subnational conservation and environmental protection agencies, including National Park services agencies.

However, the true potential of these credits extends beyond accounting entries. They can also take the form of environmental commodities, similar to carbon credits or other commercial environmental credits, and be traded through public or private market transactions. In this scenario, they transform from accounted natural capital to tangible assets. Importantly, it is not mandatory for these credits to be "financialized" and assigned a specific financial valuation. The flexibility of the framework allows countries and organizations to decide whether to take the commercialization route based on their individual contexts and conservation objectives and needs.

Should the entitled host organization choose to "financialize" these credits, the manner in which they are used, marketed, and traded will depend on the host country and the specific application frameworks or commercial

[17] Filippi et al. 2022, "Marine Biodiversity Credits: Advanced credit class design to scale ocean conservation finance." Open Earth Foundation

mechanisms they opt for. For instance, credits could be presented as commodities available for purchase or trading by registered buyers, such as corporations, investors, or banks, within an open environmental marketplace.

Moreover, other countries could become buyers of these credits or recognize their value as assets in Nature-for-Debt Swaps. Additionally, credits might be employed as guarantees in conservation philanthropy projects or transactions adopting "Pay for Success" models, such as social impact bonds or outcome-based conservation finance schemes.

An even more innovative approach could involve considering biodiversity credits as assets held by a sovereign Treasury, potentially leading to the issuance of an entirely new Nature-Based Digital Currency. This notion is elaborated in the Nature-Based Digital Currency paper published by the Open Earth Foundation[18].

While these diverse opportunities have been designed to be compatible frameworks for the operation of credits, all with the ultimate aim of mobilizing resources for conservation activities, practical examples and case studies can illustrate how marine biodiversity credits can be applied and how they can impact conservation efforts. By maintaining an open and adaptable approach, this methodology empowers countries and organizations to leverage biodiversity credits strategically for the preservation of marine ecosystems and the sustainable management of natural resources.

4. Conclusions & Suggested Next Steps

We have presented a comprehensive methodology for calculating marine biodiversity credits, utilizing state-of-the-art techniques and existing data sources, while introducing an innovative approach through modulating factors. The incorporation of a unique index valuation for endemism further enhances the methodology's precision. As a first draft, we invite the scientific, conservation, and policy communities to actively engage in an open review process, providing valuable feedback to refine both the text methodology and the open data pipeline.

Moving forward, we propose a series of pilot programs across different Marine Protected Areas (MPAs), such as Isla del Coco, Costa Rica, to comprehensively test the methodology in real-world conservation projects. These pilots should involve collaboration with ecological credit registries (e.g. Regen Network, Verra, etc.) to issue a batch of credits using the test methodology. The credits can then be distributed to digital wallets owned by national or local governments, conservation agencies, and, importantly, indigenous or local communities, as part of their sovereign assets, if applicable.

For countries with established environmental accounts in their Central Bank, the inclusion of biodiversity credit values in natural capital calculations is recommended. This entails creating a new environmental account specifically for oceans or integrating the credits within an existing biodiversity account, if available. Additionally, exploring the incorporation of this methodology or its variations into the UN System of Environmental and Economic Accounting (UNSEEA) framework can provide a standardized approach at the international level.

Pilots should also explore various frameworks for the commercialization of credits, with credits potentially being held as assets in the balance sheets of central banks, bioregional funds, or other legitimate holders, or integrated into traditional environmental market structures, as discussed in section 3.2. This approach enables countries and organizations to leverage the economic potential of biodiversity credits while directing resources toward effective conservation efforts.

While pilot projects are crucial for validating the methodology, we recognize the immediate need for in-depth review by a sophisticated audience capable of providing critique, optimization suggestions, and constructive

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[18] Wainstein, M. Constant, A. Clippinger, J, 2023. “Nature Based Currencies: Integrating natural capital in advanced monetary systems.” Open Earth Foundation.

feedback. This collaborative effort will help evolve the methodology into a full 'beta' version, ready for rigorous testing in the field.

Ultimately, we believe that this pioneering approach to marine biodiversity credits has the potential to transform conservation efforts, fostering sustainable ocean management and preserving invaluable marine ecosystems for generations to come. By engaging the broader community in this transformative endeavor, we can collectively take significant strides towards a more resilient and biodiverse marine environment.

Data and Code Availability

All our code and associated datasets can be found on OpenEarth's Github.

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APPENDIX

I. Application of the Methodology to the ACMC, Costa Rica

We present in this section the results of applying the methodology with data and credit calculations for the Cocos Island Marine reserve in Costa Rica, or Área de Conservación Marina Isla del Coco (ACMC). The ACMC has been the primary case study and context that both inspired the need for and informed the development of this MBC methodology. This case study is particularly relevant because of its high pristine context, unique role within its bioregion (i.e. part of the Galapagos underwater mountain range) and that, while it is a legislated expanded MPA, the government still faces budget shortfalls for its full conservation.

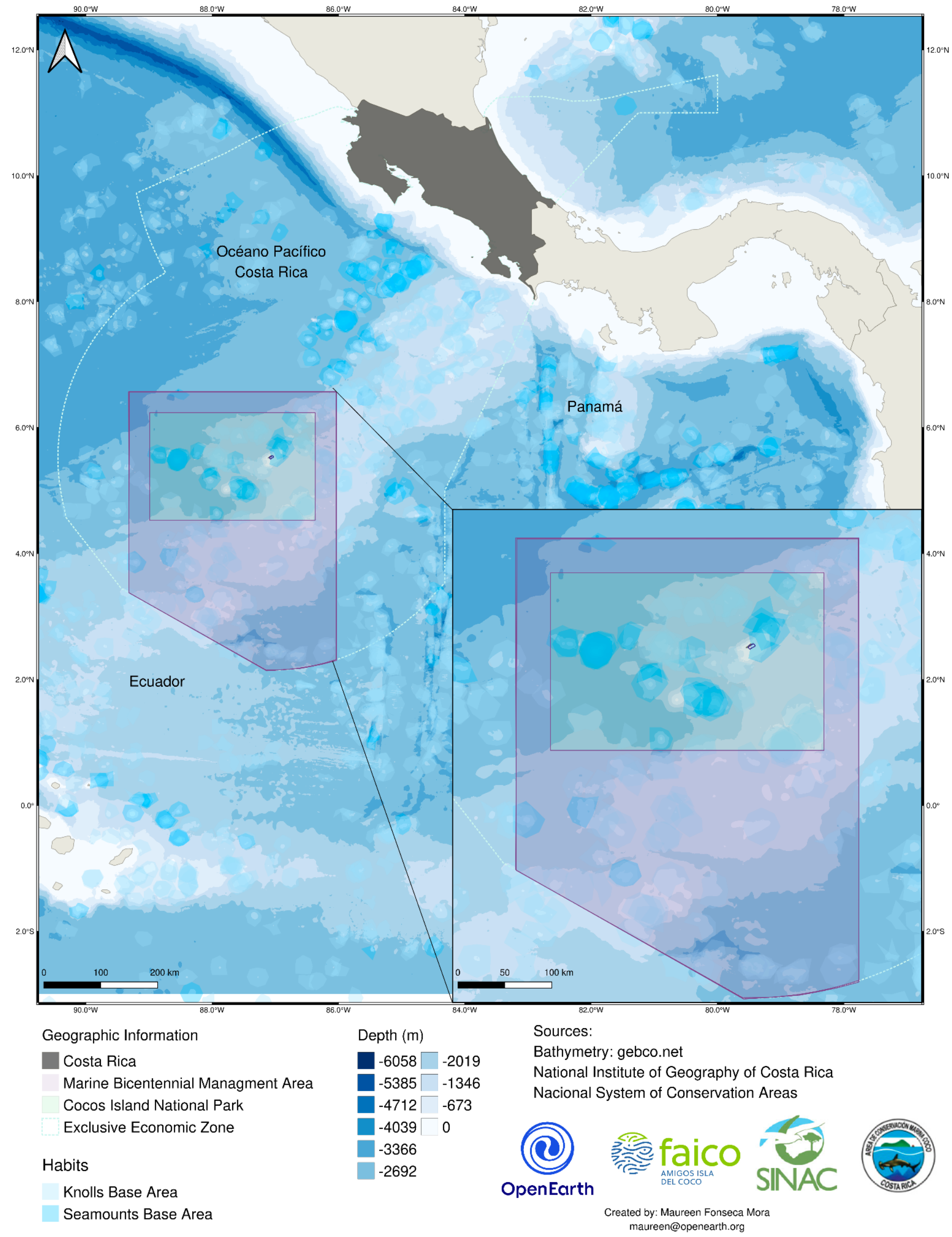

Figure A1: Open Earth has been informed by a pilot project and collaboration with the Cocos Island National Park and stakeholders. The map shows the initial rectangular size of the ACMC MPA, and the newly expanded MPA encompassing the full purple polygon. Map credit: National Geographic Society Staff; Source: Ministerio de Ambiente y Energía, República de Costa Rica. Retrieved from National Geographic.

I.1 Results: Applying the Marine Biodiversity Credit's Open Data Pipeline

The results shown in the following section are obtained using the data available from the Ocean Biodiversity Information System (OBIS), as of September 13, 2023. We use OBIS here as a primary proxy for data collected from the field by the project team. The OBIS data is fed to the open data pipeline, which includes all methodologies and calculations for the MBC process, and applied to the ACMC geospatial area.

Default assumptions:

1. For this calculation, all the modulating factors available for each data set were considered.
2. Shannon Index, Simpson Index, Species Richness were calculated with the data available from OBIS; endemism and WEGE were calculated with data available from the IUCN red list, and Habitats survey with the latest version of the IUCN Global Ecosystem Typology.
3. The same weighted value was assumed and applied to each modulating factor (w=1/6).
4. The grid size used was 0.05 degrees ~ 5.5kms at the equator, to simplify the computations.

Baseline values

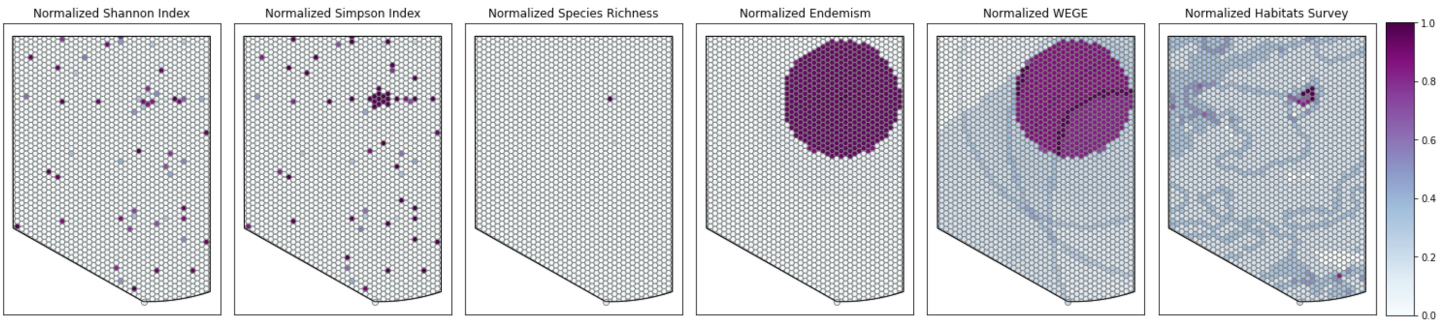

Fig I.1: Normalized baseline values for a selected set of modulating factors, using the latest data from IUCN and OBIS.

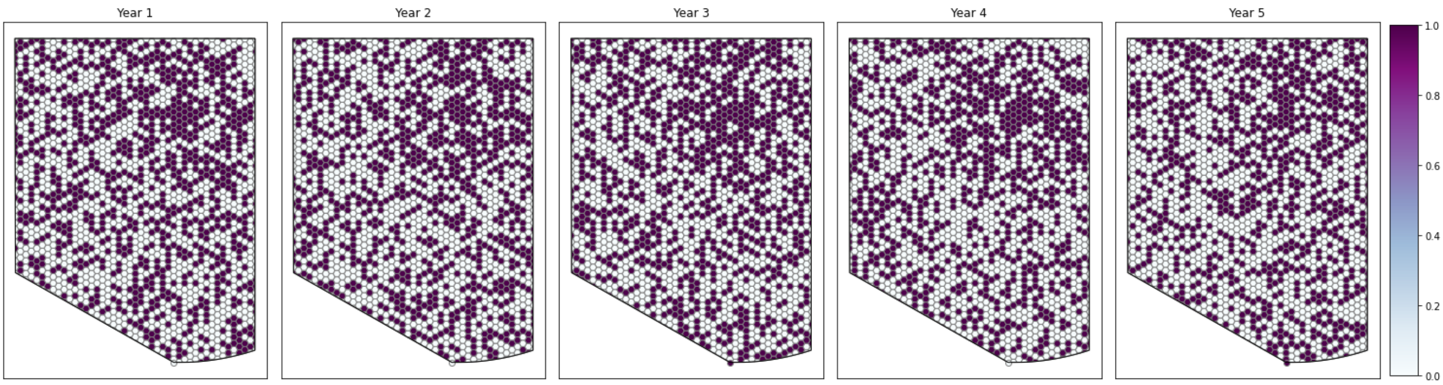

Fig I.2: Yearly values of credit assignment over each grid cell. Note, in this regime, we conduct a "hard" assignment, i.e. either 1 or 0 credits are assigned to each grid cell.

Assignment of credits over time (simulation)

We used the latest data and information from OBIS and IUCN to calculate the baseline value for each of the modulating factors. Thereafter, we **simulate** the changes over time, by 'jittering' each of the normalized modulating factors as follows:

1. Baseline values were chosen as those obtained with the data available from the IUCN and OBIS (Fig I.1).
2. Random values between -1 and 1 were generated using a normal distribution with a std deviation of 0.1 and a mean of 0.

3. These values were **added** to the modulating factors for the Shannon index, Simpson index and Species Richness to simulate a localized variation.
4. Equal weighting values were applied to each modulating factor.
5. All the modulating factors were added to obtain a total value of MBUs per grid.
6. Credits were either assigned to a grid cell (1) when the simulated value was within +-5% of the baseline values or not (0), when they were less than -5% (Fig. I.2). In this example within the data pipeline, each grid cell or base unit was not assigned 1 credit if the value increased over 5% relative to the baseline, to show variations. However, in a real situation, credits would be assigned when values are over 5%.

I.2 Results: Final credit assignment

Total # of grid cells, representing Base Units (BU): 2138

- These are less than the total sqd km/yr of the ACMC, given the units were larger to simplify the calculations.

Total marine biodiversity credits assigned to the ACMC by year (based on a total of 2138):

Y1: 926 | Y2: 962 | Y3: 956 | Y4: 939 | Y5: 958

I.3 Case Study Conclusion

This section applied the MBC methodology and calculation to a real case study in Costa Rica. This concrete application can help reviewers evaluate the numerical implications of methodology using a clear example. While the methodology still needs robust expert revisions and testing, this case study application shows that the open data pipeline published alongside this document can be effectively used to calculate MBCs in different MPAs around the world by practitioners. It also confirms the methodology is ready to advance to a pilot implementation phase. The ACMC calculations presented here, however, use standard and globally available OBIS and IUCN data with synthetically simulated variations. Under a real pilot application, the incorporation of locally sourced and measured data will be required.