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Monitoring Marine Protected Areas Network in Lebanon

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List of Abbreviations

APAC – Appointed Protected Area Committee

APANC - Appointed Protected Area Network Committee

CDFW – California Department of Fish and Wildlife

COP – California Ocean Protection

GBF - Global Biodiversity Framework

GIS – Geographic information system

GPS – Geographical Positioning System

IUCN - International Union for Conservation of Nature

MoE - Ministry of Environment

MPA - Marine Protected Areas

MPAN - Marine Protected Areas Network

MPAN – EM – Marine Protected Areas Network Ecosystem Monitoring

MPAN – MM – Marine Protected Areas Network Management Monitoring

NBSAP - National Biodiversity and Action Plan

NIS – Non-Indigenous Species

ROMS – Regional Ocean Modeling System

SDGs – Sustainable Development Goals

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I. Introduction

Marine Protected Area (MPA) Networks are systems of individual MPAs connected on multiple scales and sharing important levels of coordination amongst themselves to ensure a more effective approach in the protection of natural biodiversity and the enhancement of all its components (Nader et al., 2022). MPA networks increase the scope to optimize the costs and benefits for ecological and socioeconomic goals (Lopera, Zapata-Ramirez, & Cardona, 2023) as well as adapt and mitigate the impacts of climate change on marine ecosystems. They do not only protect marine ecosystems and species with high biological importance, but also support coastal communities and help sustain the fisheries sector. An increasing need for the evaluation and understanding of the effectiveness of MPA networks is therefore crucial (Pomeroy et al., 2005). This entails the introduction and sustainability of monitoring programs at the marine protected area network ecosystems level (biodiversity, chemical and physical parameters, etc…, hereinafter referred to MPAN-EM) and at the marine protected area network management level (hereinafter referred to MPAN-MM).

At MPAN-EM level, biodiversity is recognized as a key indicator of the health of the environment and functionality of marine ecosystems (Bianchi et al., 2022). Therefore, monitoring biodiversity within an MPA network will help scientists assess the status and health of marine organisms especially species with great biological importance such as endemic species, threatened species and non-indigenous species (NIS) including invasive species amongst others as well as their habitats in order to make sure whether conservation measures are effective or if further actions need to be taken. It is also necessary to monitor keystone species and structural species within the network, known as ecosystem engineers, due to their capacity to physically modify the environment in which they thrive. In addition, monitoring biodiversity within a network will allow the detection of changes in species abundance and diversity and helps to identify environmental changes especially due to climate change and the impacts such changes may have on marine species and their habitats. MPAN-EM will also help recording shifts in biodiversity resulting from pollution, overfishing and habitat degradation due to anthropogenic activities. However, monitoring biodiversity within the context of networks is still in its infancy where such long-term observation programs are currently conducted for individual MPAs.

At MPAN-MM level, monitoring addresses the regular observation and assessment of the activities done within MPAs in order to check whether the management of these protected areas has improved or regressed after a certain period. Information resulting from such monitoring can help MPA managers to secure political support and call for additional funding and staff if needed. Furthermore, such monitoring will certainly reveal threats/stressors that these MPAs are facing. These revelations may lead to updated versions of management plans where new actions will be introduced in order to limit these threats/stressors. Several requirements are therefore needed during MPAN-MM including spatial and temporal considerations, socio-economic considerations, science and information management as well as governance (Horigue et al., 2014).

To date, little attention has been given to the specific characteristics and management approaches for MPA networks. Although a multitude of guides on managing and monitoring individual MPAs exist, the basic principles for network management and indicators to measure the success of achieving network objectives remain unclear (Beal, Goriup, & Haynes, 2017). Several countries that have already established MPA networks are either currently working on introducing MPAN-MMs or have already established one, but no MPAN-EM programs for MPA networks have been found independent from a MPAN-MM until the drafting of the current report where all identified references integrate MPAN-EM within the MPAN-MM. For example, the Philippines has set a MPAN-MM program for its MPA networks that has improved MPA management and increased the number of MPAs. This was primarily attributed to the application of an MPA management effectiveness rating system with a focus on governance indicators (Li & Fluharty, 2017). Management effectiveness within the context of the current document is defined as the effectiveness of both the MPAN-EM and the MPAN-MM. In California for example, MPAs are managed as a network referred to as the MPA Management Program that integrates both MPAN-MM and MPAN-EM programs. The California Department of Fish and Wildlife (CDFW) and the California Ocean Protection (COP) Council are collaboratively responsible for the MPAN-EM component of the program that includes a two-phased ecosystem-based approach: a regional baseline monitoring and long term monitoring. It incorporates several activities that focus on both biodiversity and physical-chemical parameters such as intertidal and subtidal habitats and physical oceanographic conditions of the coastal ocean (surface temperature, salinity, waves and currents, etc…) (CDFW & COP, 2018) (Annex 1:). Regarding the California MPAN-MM, it adopts scientific data and expert knowledge in order to inform management recommendations to aid in management decisions. Moreover, and to ensure a proper management of the network, the responsible team of the whole MPA Management Program engages a diverse range of stakeholders in the management of the MPA Network.

II. Challenges facing MPA network monitoring

One of the key challenges for monitoring network effectiveness is establishing relationships between management actions and ecological responses. Due to the complexity of these relationships, this linkage may not be possible without significant investment. Moreover, the selection of the MPA network monitoring approaches for both the MPAN-EM and the MPAN-MM will be specific to the indicator being monitored (DFO, 2020). This is why interpretation of trends in indicators (e.g., cause and effect) can be challenging. While there may be a desire to attribute improvements in indicators to a successful network, the challenge lies in disentangling those changes from changes arising from other anthropogenic and environmental factors. Furthermore, and although many studies proposed indicators that can help assess the effectiveness of individual MPAs, indicators for measuring MPA network specific criteria, such as representativeness and connectivity, are uncommonly used in practice (Section III; Geldmann et al., 2020). In addition, social and economic dimensions are still poorly incorporated in monitoring MPA networks given the complexity of the evaluations of management effectiveness (Meehan et al., 2020). Di Minin & Toivonen, 2015 stated that missing these factors might enhance the risk of creating MPA networks that generally underperform relative to their promise. Another challenge that faces MPA network monitoring is the lack of baseline data. Many MPAs were established without thorough baseline data on the marine environment that can make it difficult to assess the impacts of management actions or changes in the environment. The lack of baseline information is also disadvantageous to the management and monitoring of certain key habitats and species because management actions cannot be undertaken on the basis of robust databases (Failler et al., 2020).

III. Criteria for MPA network monitoring

MPA networks are established by meeting several main criteria like representation, replication, connectivity, size and shape, and critical areas (Nader et al., 2022). These main criteria are defined as follows:

- Representation: MPA networks should represent the range of marine and coastal biological diversity – from genes to ecosystems – and the associated marine environment within the given area.
- Replication: MPA networks should include replicates of each representative habitat within the biogeographic region. It is highly recommended that at least three examples of each marine habitat type is protected within the MPA network as this ensures against the loss of the feature and builds resilience and adaptive capacity within the network.
- Connectivity: by connecting MPAs, the continuity of the activities and processes taking place in its ecosystem will be ensured.
- Critical Areas: it is necessary to protect areas with critical value like spawning and/or nursery grounds, and areas that provide high species aggregation. Zones that provide resilience against climate change, such as areas of upwelling, or those with organisms capable of adapting to change, must also be included to provide a higher success rate to the network.
- Size and Shape: each MPA must include a buffer zone that protects its components from the interference of forces beyond its reach. Simple shapes like squares and rectangles will maximize interior protection. Buffer zone size will be dependent on the area that needs protection, the surrounding sources of impact, and the available area for integration within the MPA. The shape of the MPA should capture the gradient from onshore-offshore or habitat-habitat shifts of species of interest.

Each of the five main MPA network monitoring criteria (Representation, Replicability, Connectivity, Critical Areas, and Size and Shape) requires specific approaches and methodologies that yield results that will allow evaluating the performance of the network.

- Representation: Monitoring requires assessing the health and diversity of the habitats and species within it including tracking changes in species abundance and distribution, and identifying any shifts in ecosystem structure or function. A common approach to evaluating representation is to compare the proportion of each representative spatial feature within the network footprint with the representation design strategies and associated conservation targets. An MPA network-monitoring program will provide information to update spatial datasets and integrate new habitat quality indices into habitat type maps (Balbar et al., 2020; DFO, 2020). This will further improve the ability to assess whether the network is meeting its representation objectives and allows introduction of corrective measures.

- Replicability: requires the monitoring of seabed features, habitat classes, and areas of importance for priority species and how well they are replicated throughout the network. This will allow the identification of biodiversity related to these habitat patches thus informing the patch sizes appropriate for replication and the efficacy of MPA networks in protecting those habitats. In addition, monitoring replicability within MPA networks is essential to update spatial datasets and integrate habitat quality indices into the habitat type map that will improve the capacity to assess whether the network is meeting the replicability objectives (Balbar et al., 2020; DFO, 2020).

- Connectivity: is currently considered the crucial criterion for the design and management of MPA networks and relates mostly to ecological connectivity. Despite the extensive interest in research on ecological connectivity, little is known about the effectiveness of the fit of MPA networks with connectivity patterns (Lagabrielle et al., 2014). However, populations of marine organism connectivity are essential for effectively achieving the goals of protecting an adequate region, or specific species, group of taxa, or habitat (Grorud-Colvert et al., 2014). Hence, there is a need to evaluate the effectiveness of the MPA network in maintaining ecological connectivity and promoting ecological processes, such as migration patterns and nutrient cycling, within and between different areas of the network. Monitoring programs allow the assessment of the effectiveness, performance and ecological connectivity of the network. Actually, ecological connectivity could be assessed by monitoring biotic factors (studying larval dispersal, studying the movement of juveniles and adult numbers of certain focal species, studying species of high biological importance) and abiotic factors (studying variations in currents, tides, temperature, salinity and acidity, substrates and bathymetry that affect the spread of biological and non-biological material). Greater ecological connectivity increases the stability and resilience of populations hence enabling MPAs to meet their objectives. However, it might be detrimental to the stability of the network by increasing the risk of spread of NIS to key refuge areas of native species (Hermoso et al., 2015). There are several types of ecological connectivity that could be considered in network monitoring

(Carr et al., 2017) (Table 1). As climate change starts to crucially alter marine ecosystems, monitoring connectivity is becoming an important tool to reveal ecological changes within the network and ultimately help to set conservation objectives for the network as well as to inform about the network's performance. In addition, monitoring ecological connectivity across MPA networks will provide managers with the information needed to assess spatial elements (i.e. zoning and spatial network configuration).

Table 1: Types of ecological connectivity and considerations for MPA network monitoring (Balbar et al., 2020)

Type of ecological connectivity	Definition	Considerations for MPA network monitoring
Landscape connectivity	The degree to which the marine landscape facilitates or impedes movement among habitats, populations, communities or ecosystems.	• Lowest data requirements • Can address multispecies questions • Gives information about network-scale connectivity patterns • Species-specific models require field validated resistance values
Population – genetic connectivity	Movement of genes among distinct populations through the movement of organisms of a single species among distinct populations.	• Detects changes over multiple generations • Detects realized connectivity patterns • Spatial resolution is an issue and is limited/defined by sampling
Population – demographic connectivity	Movement of organisms of a single species among patchy or discontinuous subpopulations or habitats.	• In-situ measurement tools can provide real-time dispersal information (e.g. satellite tags) • Models provide network scale connectivity patterns • Models can predict changes to connectivity patterns under future climate conditions • Validating models can be challenging
Ecosystem connectivity	Movement of energy and nutrients through the movement of organisms, as well as chemicals and materials among ecosystems.	• Logistically challenging • May be suitable in specific cases

- Critical areas: monitoring critical areas within an MPA network is essential for ensuring the effectiveness of conservation efforts. This could include areas where endangered species are found, areas that are important for breeding or migration, areas with high levels of biodiversity, and/or areas that are prone to human activities. Even though monitoring of critical habitats is standard and readily available for singular MPAs, no monitoring methodologies were found in the literature for this criterion at MPA network level (Well et al., 2019 ; Charlier et al., 2009).

- Size and Shape: Even though available for single MPAs, no methodologies were found in the literature that monitor size and shape at MPA network level (Friedlander et al., 2017; Rodríguez-Rodríguez et al., 2016).

IV. Considerations for monitoring MPA networks

The aim of monitoring MPA networks is to inform the adaptive management of individual MPAs as well as the whole network (Hamilton et al., 2010). Currently, it is still difficult to identify attainable management goals for MPA networks and to design a process for evaluating whether they achieved their objectives (Grorud-Colvert et al., 2014). Thus, there is growing demand for guidance in the design of MPA network monitoring programs, especially those that exploit the opportunities provided to scientists and decision makers by the MPAs that constitute the network (Hamilton et al., 2010). While it may not be feasible to monitor all network conservation objectives, it also may not be possible to monitor all protected areas within a bioregional network (DFO, 2020). In fact, evaluating the effectiveness of the network requires monitoring the individual contribution of individual MPAs. For example, ecological benefits of individual MPAs and other factors such as size, socioeconomics and governance that influence the effectiveness of an individual MPA have been validated in MPA networks as well. This said, indicators to monitor MPA network criteria (connectivity, replicability, etc…) have been barely used in practice (Woodcock et al., 2017). Moreover, each MPA is unique and represents a specific set of ecosystems, biodiversity, environmental conditions and human uses (Otero et al., 2013).

1. Designing an MPA network monitoring program

Two types of monitoring programs exist: baseline monitoring and long-term monitoring. Baseline monitoring aims to characterize ocean/sea conditions and human activities inside and outside MPA networks, against which future changes can be measured. On the other hand, long-term monitoring, the second phase of monitoring, is very valuable for science and MPA as well as MPA network managers as scientists could further analyze the data and forward insights for management of the network. Therefore, well-designed long-term monitoring programs are scarce but beneficial for evidence-based management (Addison et al., 2014).

In addition, MPAN-EM monitoring frequency depends on factors including the goal of the monitoring program and the availability of resources. Physio-chemical parameters vary throughout the year and are likely to vary from week to week because of weather events. Consequently, weekly, monthly or quarter-annual monitoring should be decided based on availability of resources. As for biological parameters, monitoring depends on whether the species is migratory, sedentary or uses different local habitats throughout the year.

Ideally, monitoring programs for each MPA and for the MPA network should be developed during the planning phases for the establishment of the MPAs and initiated once the network is established (Agardy & Staub, 2006). The variables that are used for the MPA network monitoring programs should include the basic variables that are common to all MPAs within the network such as larvae and juveniles, nesting grounds, and habitat types, amongst others in addition to parameters that could satisfy the MPA network criteria. The International Union for Conservation of Nature (IUCN) states that MPA monitoring programs have to track performance and enforce adaptive management to be consistent across MPAs in the network to document and demonstrate management effectiveness and to report that conservation goals, objectives, and defined biodiversity conservation targets are being accomplished. Moreover, monitoring programs can improve collective understanding of climate change impacts and enforce fisheries management (Resources Legacy Fund, 2020)

2. MPA Network Monitoring Parameters

In order to assess and evaluate the performance of an MPA network, it is essential to set a monitoring program that focuses on studying various parameters that could be reflected in all MPAs constituting the network. These parameters are biological (biotic) such as larvae and juveniles, nesting grounds, habitat types, fish biomass, migratory birds, NIS, algae and seagrass species; physio-chemical (abiotic) including water quality (pH, salinity, sea surface temperature); and socio-economic such as fisheries and tourism (Table 2). In fact, the establishment of MPAs and MPA networks will protect both endangered and endemic species by providing them a shelter against predators, and breeding, nesting and nursery grounds across the network in addition to monitoring water quality.

Furthermore, monitoring programs should also assess the socio-economic impact of the MPA network on, for example, the tourism and fisheries sectors. Although some studies claim that MPAs have a positive impact on both sectors, the enforcement of restrictions on fishing and tourism activities is highly dependent on human and financial capacities. Thus, it would be essential to monitor both sectors in order to improve economic revenues, manage the sustainable use of marine resources, and protect fish biomass. When fishing restrictions are implemented to enable stock recovery, the benefits for fisheries are not instantly reached (Tranter et al., 2022). These parameters vary from one MPA to another depending on the characteristics of each MPA and should be aligned with its management objectives. The resources (financial and human) available to each MPA will determine the number of parameters to be monitored (NEASPEC, 2021) and assessments of monitoring data will identify threats and drivers of observed changes which is reflected in annual work plans and thus in responsive actions. It is essential though in the planning phase to adopt parameters that will also contribute to the monitoring program of the MPA network.

Table 2: Categories of MPA monitoring parameters (adapted from Cardoso-Andrade et al., 2022)

Category	Parameter
Biological	● Habitat types ● Bird species during breeding seasons. ● Non-indigenous species (NIS). ● Fish biomass. ● Larvae and juveniles ● Endangered species. ● Migratory species. ● Algae and seagrass species.
Physio-chemical	● Water quality (temperature, salinity, pH, turbidity). ● Chemical contaminants. ● Organic waste on seasonal basis.
Socio-economic	● Economic added value of the MPA. ● Eco-tourism. ● Fisheries.

3. MPA Network Monitoring Techniques

Since there has been an increasing need for the evaluation and understanding of MPA networks and their contribution to marine ecosystem health, numerous parameter-specific evaluation techniques have been used (Table 3). Usually, MPA network monitoring techniques are not feature-specific but are normally applied to monitor a diversity of features within the MPA network in addition to the five criteria for establishing the network. For example, monitoring the spatial and temporal variations in marine biodiversity using non-destructive techniques is crucial to ensure proper understanding of the ecosystem and to assess conservation strategies within MPAs (MedPAN & RAC/SPA, 2014). Some parameters require only visual census techniques such as fish along a certain length of transect and depth, birds, and/or mammals and can be supplemented by photographic identification. Concerning NIS, involving citizens (fishermen, divers, tourists, …) in recording and monitoring invasions, also referred to as citizen science, could be an effective method to survey these species in order to avoid or limit their introduction and control their spread. On the other hand, physical-chemical parameters require equipment such as multiparameter sondes that could be used to record temperature, salinity, pH and turbidity. Moreover, water sampling involving laboratory analyses and/or field water quality kits will allow the identification of the level of contaminants present. Monitoring physical-chemical parameters and species with rapid potential response to climate change (such as coastal marshes and seagrasses that are important habitats for carbon sequestration and storage) are essential for understanding climate change impacts. Results will therefore constitute a basis for establishing a database through which local situations could contribute to introducing mitigating measures at a regional level (Otero et al., 2013).

Table 3: Categories and techniques of MPA network monitoring parameters (adapted from MedPAN & RAC/SPA, 2014 and NEASPEC, 2021)

Category	Technique	Parameter
Biological	● Visual census and periodic surveys ● Photographic and laboratory identifications ● Diving surveys ● Fish traps and cameras	● Bird species ● Macroalgae and seagrass species ● Fish Biomass
Physical-chemical	● Multiparameter sondes ● Seawater sampling and laboratory analysis	● Water quality ● Chemical contaminants
Socio-economic	● Surveys and questionnaires for stakeholders (sector dependent) ● Carrying capacity estimation ● Stakeholder workshops (presentation of activities and discussing progress)	● Tourism sector ● Carrying capacity ● Local stakeholder involvement. ● Improvement in well-being

4. MPA Network Monitoring Indicators

Individual MPA effectiveness relies on adequate and sufficient performance indicators to assess the impact of conservation measures and evaluate whether objectives of the MPA are being accomplished therefore allowing improvement in its management. Systematic monitoring and the selection of key indicators to monitor MPA networks require the application of appropriate scientific skills, personnel, training and partnerships based on identified needs. Such indicators can be quantitative or qualitative variables obtained from field measurements or mathematical models and linked to the MPA network objectives (MedPAN & RAC/SPA, 2014). These indicators should report on the effects of three main categories: 1) the environmental state; 2) the socio-economic conditions; and 3) management and governance response (Table 4) in order to assess the impact of conservation measures and evaluate whether the network objectives are met (Cardoso-Andrade et al., 2022). Indicators should be specific enough to be measured consistently and flexible enough to adapt to changing circumstances (IUCN-WCPA, 2008). For effective MPA network monitoring and management as well as integrated evaluation, the assemblage of a core list of indicators has to be prioritized (Pendred, Fischer, & Fischer, 2016).

Table 4: Environmental, socio-economic and governance MPA network monitoring indicators (Cardoso-Andrade et al., 2022; Rodriguez-Rodriguez et al., 2015)

Category	Indicator
Environmental	**Biological**
	• Sea birds and mammal numbers. • Relative abundance of NIS, fish, invertebrates, and macroalgae. • Extent, species and biotope composition of intertidal features. • Extent and distribution of subtidal features. • Species and biotope composition of subtidal sediment habitats.
	Physical-chemical
	• Sea Surface Temperature. • Water quality. • Density of marine litter. • Chemical pollution assessment.
Governance	• Existence of adequate legislation for the management of MPAs and its objectives. • Material and human resources capacity allocated to MPA management. • Production of scientific knowledge that meets the needs detected by management.
Socio-economic	• Existence of an efficient, comprehensive, and adequate surveillance of the MPA. • Socio-economic advantages and disadvantages of MPAs to the fisheries sector. • Socioeconomic advantages and disadvantages of MPAs for maritime and touristic activities.

V. Proposed methodology for MPA network monitoring in Lebanon

MPA networks are nested structures aiming to conserve and protect marine biodiversity and ecosystems and this requires substantial knowledge, planning and monitoring to become effective (Stratoudakis et al., 2019). In Lebanon, establishing an MPA network requires a scenario where the main criteria (Connectivity, Replicability, Representation, Critical Areas, Size and Shape) are adopted and form the basis for the establishment of the network. This requires medium to long term investment in human, material and financial resources to ensure that all criteria are met (Nader et al., 2022a). Based on the **"Effective Marine Protected Area Network In Lebanon"** (Nader et al., 2022a) and

"Assessment of Lebanon's Marine Protected Areas" (Nader et al., 2022b) reports and the current document, following is a proposed methodology that takes into consideration both ecological and management monitoring based on the five main criteria for establishing a MPA network.

1. Proposed methodology for ecological monitoring of a MPA network in Lebanon

The field of ecological monitoring of MPAs is dynamic, as seen by the variety of approaches and methodologies available in the literature. As clearly stated though, monitoring the performance of MPA networks and their impacts on marine ecosystem resilience and associated biodiversity and is a nascent science. It is therefore crucial to remember that the approaches and methodologies described in the following sections are in constant state of development, are adaptable and can be tailored to meet the unique goals of the monitoring objectives.

1.1. Monitoring representation

Monitoring representation of MPA networks can be achieved through the application of several methodologies (*Table 5*). Methods such as habitat mapping and visual surveys (diver-based surveys and underwater photography and videography) could be adopted. While selecting habitats to monitor, a special focus should be given to the habitats of indicator species (species of prime interest for ecosystem conservation and management) such as species of economic importance and endangered species that could benefit from the network (CDFW & COP, 2018).

As for seabed mapping, *in situ* and remote mapping are considered important tools to determine the level of representation of the different habitat types inside and outside MPAs and the network (Young and Carr, 2015). Its application is based on established species, community or ecosystem associations with combined geomorphological (e.g., substrate type) and oceanographic features (e.g., water depth, currents, wave exposure). The generated maps are used to help identify essential habitats for many important species, commercial and other, and for the design of new or evaluation and monitoring of existing MPAs and MPA networks. Some habitats within the network may face severe and rapid changes while others may remain relatively stable. The frequency of habitat mapping within MPA networks depends on several factors such as the size and complexity of MPAs. Larger MPAs or MPAs with diverse habitats may require more frequent monitoring to capture the variability across the entire area. Furthermore, the frequency of habitat mapping may depend on the monitoring program, regardless whether it is short term or long term.

Water quality is another essential parameter to be taken into account while monitoring representation. Monitoring habitat quality through water quality monitoring will contribute to better achieving the representation criterion. Multiparameter sondes, remote sensing (satellite imagery) and water quality field test kits can be used in different points within the networks at the same time and for the exact same depths which will allow the study of several parameters such as temperature, pH, salinity, turbidity, dissolved oxygen amongst others. More specifically, sondes measure and record the main physicochemical water parameters that can be directly downloaded. As for remote sensing satellite imagery, they can provide valuable data on specific water quality parameters such as sea surface temperature, chlorophyll-a concentration, and turbidity.

Moreover, monitoring contaminants within MPA networks contribute to monitoring representation since it allows monitoring the health of habitats across the network. This usually requires seawater sampling and laboratory analysis. Seawater and sediment sampling should take into account knowledge of the physical and biological oceanography of the area and requires consideration of temporal sources of field variance, such as seasonal factors, spatial factors, changes in location and water depth within the survey area (Noble-James, 2023). The choice of sampling equipment depends on the physical-chemical properties and expected concentrations of the analytes (the substance that is being studied or measured), on the depth and location of the sampling site, and on the available infrastructure. As per the equipment used for sampling, whether sample dredges, physical collection of sediments, containers, tubing, connectors, valves, pumps or filters, they should neither absorb nor release the target analytes, or any non-target substance that interferes with the chemical analysis. Moreover, since concentrations of organic contaminants and metals in seawater are usually very low, large volumes of sediments and/or water must be sampled. Regarding organic contaminants, the materials used for the sampling equipment depend on the target contaminants. Sampling equipment for organic contaminants in seawater and sediments is preferably made of glass or stainless steel. Analytical methods are specific to the target analytes and sufficiently sensitive to allow analyses of samples that generally have low concentrations of contaminants.

Regarding diving surveys, these surveys could be conducted regularly to monitor benthic habitat health and composition. Trained divers can visually identify and describe underwater habitats, including coral reefs, rocky substrates, seagrass beds, and sand flats. They note the dominant species, substrate composition, and structural features. Moreover, still and video cameras are used to document and characterize underwater habitats. Images and videos can be analyzed to identify habitat types and monitor their condition. In addition, camera traps could be deployed to capture images or videos of marine life providing valuable data on species presence and diversity.

1.2. Monitoring replicability

Replication is the inclusion of multiple samples of habitat types in individual MPAs and MPA networks. Representation and replication, within MPA networks, are considered as measures of resilience and adaptive capacities facing conditions such as anthropogenic activities and climate change (Balbar et al., 2020). Changes in marine ecosystems due to climate change can have severe impacts on species distribution, dynamics and habitat ranges. Monitoring replication helps identifying the biodiversity associated with habitat patches at varying scales and informing the patch sizes appropriate for replication as well as showing the efficacy of MPA networks in protecting those habitats (Balbar et al., 2020). This type of monitoring focuses on seabed features and critical areas for priority species (*Table 5*). For these reasons, water quality, subtidal sediments as well as monitoring contaminants within the habitats of the network is essential to determine whether the protection and conservation of marine species are being achieved by providing them a healthy environment. As regards water quality, the same methodologies recommended for "Monitoring representation" are to be applied (Chapter V; Section 1; Sub-Section 1.1).

In order to monitor subtidal sediments within MPA networks, several methodologies exist. Sediment grabs or cores can be used to collect samples from the seabed. These samples can be analyzed for sediment composition, grain size distribution, organic matter content, contaminant concentration, and infauna. Sediment samples are sieved to determine the distribution of particle sizes, which can provide insights into sediment stability and habitat suitability. In fact, collecting and analyzing sediment data over extended periods is essential for detecting trends and changes in sediment characteristics and benthic communities.

Adding to this, monitoring contaminants within the habitats of MPA networks requires, at minimum, monitoring areas of importance for species of priority (endangered species, endemic species, and migratory species, amongst others) based on seawater sampling and laboratory analysis methodologies (Chapter V, Section 1, Sub-Section 1.1).

1.3. Monitoring connectivity

Effectiveness of MPA networks relies on connectivity (Lu et al., 2023). Hence, there is a need to assess and monitor this criterion within the network. In fact, there is a lack in connectivity between Mediterranean MPAs (Abalo-Morla et al., 2022). Monitoring several parameters such as larval dispersal, migratory species, movement of juveniles, number of adults of certain species of high biological importance, NIS and their abundance as well as abiotic variations (currents, tides, temperature, salinity, etc.) can contribute to the monitoring of this criterion (*Table 5*). Several factors affect larval dispersal within the network including MPA sizes, MPA locations, fishing restrictions and the enforcement of regulations (Sala et al., 2012). For example, larval dispersal can vary seasonally and annually requiring long-term monitoring to capture these variations across the network. To monitor larval dispersal, several methods exist such as larval labeling, otolith micro-chemical analysis, genetic parentage methods and biophysical modeling. These methods are considered popular methods to assess and monitor connectivity of the network. However, these methods, except for the biophysical modeling, require intensive sampling and are usually expensive (Lu et al., 2023). In addition, biophysical models are the preferred methods to be used to study MPA connectivity at larger temporal and spatial scales such as the Regional Ocean Modeling System (ROMS). A nearshore habitat model could be applied to ROMS to "convert" particles into simulated larvae using a pelagic larval duration (PLD) period. This model then tracks the larval production from a given location to the settlement location within the modelling domain (the MPA network) (CDFW & COP, 2018). Sites (Source and Sink) could be classified based on their level of larval connectivity to areas both inside and outside the network. Areas that are highly connected (both sources and sinks) across habitats are usually prioritized.

To specifically monitor migratory bird species, visual census methodologies are used by ornithologists and ecologists to study bird populations in their natural habitats. These methodologies involve the systematic visual observation of birds within a defined area or along predetermined transects. A long-term monitoring program for bird species should be developed in order to track changes in migratory bird populations over time within the network and assess the effectiveness of conservation strategies. There are various approaches to conducting visual censuses of birds, each tailored to specific research objectives and environmental conditions:

- Point Count Surveys:
  - **Stationary Point Counts:** An observer stands at a fixed location and records all bird species seen or heard within a specified radius for a set period, often 20 minutes (Ramadan-Jaradi & Ramadan-Jaradi, 2002). The observer then moves to the next survey point and repeats the process. This approach provides information on bird presence and relative abundance.
  - **Variable Circular Plot Counts:** Similar to stationary point counts, but the survey radius can vary depending on visibility conditions. Birds are recorded within the circle, and the area is used to estimate bird density.
- Transect Surveys:
  - **Line Transect Surveys:** This technique may be applied both at sea and on land. For both, a straight line is laid out across the study area, either randomly or systematically. Observers, equipped with binoculars, then record all the bird species they encounter that intersect with the line. The perpendicular distance from the line to each individual or group of birds is often measured.

    At sea, observers on a moving vessel scan at a 90° angle from either the port or starboard side, and record all individuals or group of birds seen or heard on either side of the transect line (Ramadan-Jaradi, G., 2021).

    On land, the observer walks along a line transect of 400m or more ideally up to 1km in slow paces and records all individuals or group of birds seen or heard from each side of the transect. At regular intervals, the avifauna expert remains in one place and turns to look in all directions to record the species of the birds heard singing, calling or making noise as well as birds observed visually. The Line Transect method provides frequencies, abundances, numbers, richness, densities, and allows several statistical tools for verification, but it does not count breeding couples with high accuracy in comparison to the Point Count Survey method.

- **Belt Transect Surveys:** This method can also be used at sea and on land, and is based on the same principles as the Transect Line method. The difference in the Belt Transect method, is that the width of the transect is predetermined, delineated and sampled. Observers, usually equipped with binoculars, move along the transect line, identifying and recording all the organisms within the defined width of the belt. At sea, a radius from the position of the observer is determined and is considered as the outer limit of the belt. In contrast with the Line Transect method, the Belt Transect method usually only allows estimation of bird density.

- Nocturnal Surveys: For nocturnal birds, such as owls, visual surveys may involve spotlighting, listening for calls, or using specialized night-vision equipment.

- Nest monitoring: For birds nesting within the network, monitoring nests and breeding success can provide insights into population health. Known nesting sites should be visited periodically.

Moreover, several marine mobile mega vertebrates display high site fidelity to specific regions on a seasonal or yearly basis (Pendoley et al., 2014). Thus, the conservation and monitoring of these habitats will definitely contribute to monitoring these species. For example, the monitoring of sea turtles (the loggerhead sea turtle, *Caretta caretta* and the green sea turtle, *Chelonia mydas, etc.*) is preferably to occur regularly on nesting beaches during the nesting/hatching season (Badreddine et al., 2020).

Furthermore, if MPAs are not connected by dispersal and juveniles movement between them, then they will become more vulnerable to local species extinctions due to local perturbations (Di Franco et al., 2015). Tracking the movement of marine juveniles is a complex process because of the difficulty in tracking individuals throughout their entire life cycle. As previously mentioned, methods such as otolith chemistry as well as acoustic and radio tagging are used for studying and tracking the movement of juveniles.

Monitoring NIS is another approach to monitor connectivity. One of the methodologies is diving surveys. The number of sampling stations (that should be representative of all the habitats, depth ranges, substrates and wave exposure conditions found in the MPA network) usually depends on the size and number of habitats found within each MPA (Otero et al., 2013). Surveys should be conducted at least twice a year, one in summer and the other in winter, to detect the presence of NIS. Regarding non-indigenous algae, coverage is best monitored and quantified by using 25cm x 25cm quadrats, each subdivided into 25 sub quadrats of 5cm x 5cm (Otero et al., 2013). As for non-indigenous fishes, their abundance and size is to be recorded along transects (25m x 5m or more) at each sampling station at a fixed depth. The number of individuals for each species is recorded and approximate size estimated. Fish traps could also be a tool to monitor no-indigenous fishes. These traps are designed to passively capture fish over a specified period of time determined based on research objectives and the need to capture an adequate sample size, allowing researchers to sample a representative portion of the fish community. Fish traps are deployed in specific locations within the study area, often following a predetermined sampling plan. Traps can be placed on the seafloor, suspended in the water column, or anchored to submerged structures, such as reefs or buoys. Therefore, their design can vary depending on the target species and the habitat in which the trap will be deployed. After the sampling period is complete, researchers retrieve the traps. They carefully remove the captured fish, documenting the species, size, and number of individuals. Fish biomass is estimated by multiplying the average weight of fish in the sample by the total number of fish captured. These estimates could then be extrapolated to cover the entire population.

1.4. Monitoring Critical Areas

Monitoring critical areas include monitoring nesting and spawning grounds, areas with high level of biodiversity, habitats that are essential for the survival of key species amongst others. Monitoring nesting and spawning grounds within the network basically means monitoring migratory species and their movement across the network especially during breeding and nesting seasons. This could happen through tagging and tracking key species (*Table 5*). In addition, diving surveys could be conducted in order to monitor benthic habitats especially during breeding and nesting seasons. Moreover, a passive acoustic underwater monitoring using hydrophones could be conducted especially during mating seasons. The latter is considered as a non-invasive and non-destructive observational tool and provides unbiased data on the position and movement of the sound source in question (Putland et al., 2018). Acoustic underwater monitoring also helps in monitoring habitat range of certain species within the network during mating seasons based on the different vocalizations produced by males and females of a certain species and whether the habitat range is expanding or contracting (Putland et al., 2018).

As regards birds, they could be divided into two groups: breeding birds and non-breeding birds. Breeding birds within the network should be monitored during the mating seasons, as for the non-breeding birds, they should be monitored while migrating through or wintering in the network. This monitoring program consists of visual census methodologies (Chapter V; Section 1; Sub-Section 1.3).

1.5. Monitoring Size and Shape

To monitor this criterion, several parameters need to be taken into consideration and various techniques need to be firstly applied (*Table 5*). The movement patterns, migration routes, or habitat preferences of key species could lead to a better understanding of the size and shape of an MPA and whether it should be expanded or not. In addition, due to the monitoring of these parameters, critical areas that were not previously included in the MPA could be added and thus contribute to adjusting the boundaries of the MPA and expanding its size therefore expanding the size of the network.

Moreover, monitoring connectivity that relies on monitoring the movement and behavior of marine species will contribute to monitoring the size and shape of MPAs forming the network. In fact, this monitoring might reveal some gaps in conservation and protection of marine species that might be addressed by adjusting the boundaries or shape of certain MPAs. In addition, monitoring commercially valuable species within the network can provide perception regarding the socio-economic value of the MPA network. This will surely lead to a better understanding of how MPA networks can contribute to sustainable fisheries and other blue economy sectors hence adjusting the size and shape of certain MPAs to meet sustainable socio-economic improvements.

Table 5: The proposed parameters, methodologies and frequency needed to monitor the criteria for establishing an MPA network

Criteria for establishing an MPA network	Parameter to be monitored	Methodology	Frequency of the monitoring
Representation	Habitat types	Seabed mapping	Depending on the type of the program (short- or long-term monitoring)
		Diving surveys	Regularly
	Water quality	• Multiparameter sondes • Water Quality field test kits • Remote sensing	Depending on the type of the program (short- or long-term monitoring)
	Contaminants	Seawater sampling and laboratory analysis	Depending on the type of the program (short- or long-term monitoring)
	Marine species	Camera traps	Depending on the type of the program (short- or long-term monitoring)
Replicability	Water quality	• Multiparameter sondes • Remote sensing	Depending on the type of the program (short- or long-term monitoring)
	Subtidal sediments	Sampling techniques and laboratory analysis	Depending on the type of the program (short- or long-term monitoring)
	Contaminants	Seawater sampling and laboratory analysis	Depending on the type of the program (short- or long-term monitoring)
Connectivity	Larval dispersal	• Larval labeling • Otolith micro-chemical analysis • Genetic parentage • Biophysical modeling	Seasonally and annually (Long term monitoring program is recommended)
	Migratory birds	• Visual census methods (Point Count surveys, transect) • Nocturnal surveys • Nests monitoring	Seasonal (long term monitoring program is recommended)

Criteria for establishing an MPA network	Parameter to be monitored	Methodology	Frequency of the monitoring
	Migratory marine species	• Habitat monitoring (Nests and eggs monitoring) • GPS trackers	Regularly and during nesting/hatching season for certain species
	Movement of juveniles	• Otolith micro-chemical analysis • Acoustic and radio tagging	Regularly
	Invasive species	• Diving surveys • Percentage cover for algae • Transects and fish traps for invasive fish	twice a year in summer and winter within the MPAs forming the network
Critical areas	Nesting and breeding grounds of marine species	• Tagging and Tracking certain species • Diving surveys	Seasonal monitoring
		Passive acoustic underwater monitoring (hydrophones)	Seasonal monitoring (during mating seasons)
	Habitats of birds	Field visits	Seasonal monitoring (for breeding birds, during breeding seasons; for non-breeding birds, while migrating and/or wintering)
Size and shape	Species movements	• Otolith micro-chemical analysis • Acoustic and radio tagging	Regularly
	Habitat types	Seabed mapping	Depending on the type of the program (short or long term monitoring
		Diving surveys	Regularly

2. Proposed methodology for monitoring the management of a MPA network in Lebanon

Monitoring the management of a MPA within a network is essential to ensure that conservation goals are met and that the area is effectively protected and managed. It also allows for the assessment of ecological health, the enforcement of regulations, and the adaptation of management strategies. This is achieved through different strategies where numerous parameter-specific evaluation techniques are applied. For Lebanon specifically:

2.1. Committee creation

In order to launch any form of monitoring on an MPA network level, the Network must have an integrated committee, the Appointed Protected Areas Network Committee (APANC) which is suggested to include the following:

- Directors of each declared MPA
- Representative of the Ministry of Environment (MoE)
- At least one marine expert
- Other experts invited as needed and based on the issue being addressed (ecologist, economist, sociologist, legal, etc…)

The APANC and its bylaws, mandate, mission, objective and goal are best established by the MoE through a participatory approach involving MPA managers, marine experts, concerned public authorities and any other identified stakeholder as contributor to the success of Network. The APANC will be subject to the same reporting mechanisms as individual MPA Appointed Protected Area Committee (APACs) or as agreed and decided upon during its establishment.

2.2. Establishment of clear objectives and goals:

The APANC must establish clear and measurable objectives and goals for the MPA network in order to ensure its success through the development of an MPA Network Management Plan. These objectives and goals should include conservation targets, biodiversity preservation, sustainable resource management, and any specific objectives outlined in the plan.

2.3. Recommended roles and responsibilities

Effective management of the MPA Network requires that the APANC determines its roles and responsibilities at both the governance and socioeconomic levels. These are best determined during the establishment of the APANC (Table 6).

Table 6: Proposed roles and responsibilities (non-exhaustive)

Governance	• Ensuring the existence of an efficient, comprehensive and adequate surveillance of the MPA Network based on a well-designed program. • Ensuring the existence of adequate legislation for the MPA Network management and its objectives. • Ensuring the implementation of the MPA Network management plans (including both ecological and management monitoring) • Maintaining communication efficiency between MPAs and resolving conflicts, if any. • Optimizing data collection processes for all MPAs and across all MPAs forming the Network. • Producing scientific knowledge (data analysis and results) for the Network that meets the needs identified by the APANC. • Adjusting goals of the Network based on its performance through scientific evidence. • Promoting adaptive management of the Network based on regular monitoring results. • Ensuring that each MPA has a management strategy that meets Network objectives and goals but is adaptable enough to also meet its own needs. • Promoting adaptive financial strategies and plans to better meet the objectives of the MPA Network and improve financial sustainability, based on monitoring results. • Promoting the inclusion of estuaries in the MPAN.
Socio-Economic	• Integrating local knowledge and practices of communities relevant to the conservation and sustainable use of biodiversity within the Network. • Ensuring sustainable use of resources in recreational, artisanal fishing and ecotourism activities. • Detecting socioeconomic benefits and harms of the MPA Network for the fisheries sector. • Detecting socioeconomic benefits and harms of the MPA Network for the maritime and touristic activities. • Effective communication and awareness strategies for the Network. • Measuring satisfaction of local communities, businesses, and other stakeholders with MPAN management efforts. • Allocating financial, material and human resources to efficiently manage the MPA Network. • Articulating responsibilities, actions and transparency between MPAs forming the Network. • Providing regular reports on the financial performance of the MPA Network to stakeholders and the public.

3. Proposed MPA Network Monitoring Indicators

Based on the set of parameters and the techniques adopted for monitoring the MPA Network as detailed in Sections 12, it is essential to select key indicators, that could be either quantitative, qualitative or both in order to report on the effectiveness of the Network at ecological and management levels. These indicators could be classified according to their target and compiled from sources under the following headings: Environmental, governance, and socio-economic indicators (*Table 7*).

Table 7: Proposed indicators for MPA network monitoring in Lebanon (non-exhaustive)

Indicators Category	Indicators*
Environmental	**Biological**
	● Number of migratory birds and marine species. ● Number of nests and eggs of certain species. ● Abundance and distribution of larva and juveniles of certain species within the network. ● Relative biomass, abundance of IAS, fish, invertebrates, and algae. ● Extent, species and biotope composition of intertidal features. ● Extent and distribution of subtidal features. ● Species and biotope composition of subtidal sediment habitat.
	Physical-chemical
	● Sea Surface Temperature ● Water quality ● Subtidal sediments characteristics ● Density of marine litter ● Chemical pollution assessment
Governance	● The MPA Network committee formed (APANC). ● Existence of adequate legislation for the MPAN management and its objectives. ● Existence of an efficient, comprehensive, and adequate surveillance of the network. ● Number of estuaries included in the MPA Network. ● Number of violations.

Indicators Category	Indicators*
Social	● Number of scientific workshops and conferences related to the network. ● Number of involved stakeholders (academic institutions, research centers, NGOs, women, youth...) ● Number of scientific reports produced. ● Level of improvement of the livelihood of target communities. ● Satisfaction level of local communities, businesses, and other stakeholders with MPAN management efforts.
Economic	● Increase in the number of blue economy initiatives. ● Number of eco-touristic entities (restaurants, diving clubs, hotels, etc…). ● Market value of ecosystem services (climate change, fishery production…) ● Number of financial reports.

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VI. Approaches for MPA Network ecological performance evaluation

Several ecological approaches to evaluate the impact of MPA network monitoring on marine life exist. These approaches require years in order to gather sufficient information for evaluating network efficacy and to inform the adaptive management process through testing species responses to the implementation of a MPA network (CDFW & COP, 2018). Such approaches focus specifically on the response of biodiversity populations over time. For example, biomass and species abundance (or density) are species metrics that could be used to track the changes of a population over time within the MPA network. Once a MPA or MPA network is established, a given fish population is expected to consist mostly of mature and larger individuals over time due to reduced mortality (Baskett & Barnett, 2015). Hence, the reproduction rate will increase because of the increased number of mature individuals and because fecundity increases with maternal age and size (Baskett & Barnett, 2015).

1. Abundance and biomass

Following the establishment of an MPA network and adoption of monitoring programs and subsequent interventions, the abundance and biomass of a given species are expected to increase rapidly at first and then level off over time. However, the expected time frame for levelling off depends mainly on the lifespan of the species, nutrient availability and competition for resources. Population level responses of species with longer lifespans will require longer periods compared to short lifespan species, hence the leveling off will take longer time to be reached. In fact, increases in abundance result from both decreased mortality and increased reproductive output as body size increases, whereas increases in biomass can arise from both increased body size and increased abundance.

2. Integrating spatial differences in fishing mortality to project population responses to MPA networks

Abundance and biomass are function of fishing mortality rates. It is therefore important to measure local fishing mortality rates within each MPA before establishing the network in order to better understand network contribution to increases in abundance and biomass (comparison between "before" and "after"). This also allows the identification of target locations (within the network and within each MPA) to prioritize monitoring activities (CDFW & COP, 2018).

3. Estimating the time frame of response for different species

The time frame to detect maximum expected changes in selected species populations vary from species to another and depends on, but is not limited to, several factors such as species life history traits, rates of fishing mortality before MPA network establishment, the ecological characteristics of the MPA network, and unexpected ecological events. The dynamics of these populations depend as well on the degree of demographic connectivity between the focal MPA and other MPAs (or fished habitats), basically the MPA network, and on the amount of variability in larval recruitment (Kaplan et al., 2019). The time frame also depends on the monitoring program adopted and its feasibility. For example, does the monitoring program have sufficient sample size and is of sufficient scale where species densities will certainly set a limit on sampling? This expected time frame could be generated for each key species using an age-structured open population model (CDFW & COP, 2018). For some species, it might take few years for density to reach the maximum while for others it might take much longer. The time required for densities to reach their maximum do not necessarily indicate that changes are needed in design of MPA networks or in enforcement actions, but it could be an indicator for deciding when further monitoring or management actions are needed in an adaptive management process (Kaplan et al., 2019). Kaplan et al. (2019) also proved that species with long lifespan with higher pre-MPA network harvest rates are expected to have a greater response to MPAs that could appear over longer time scales compared to species with shorter lifespans and lower pre-MPA network harvest. Thus, longer-lived species with high pre-MPA network harvest rates and low recruitment variability could play an important role as a reliable indicator species for long-term MPA network monitoring and adaptive management.

VII. Contribution to national and international commitments

Establishing a MPA network in Lebanon will contribute to the country meeting its environmental targets and commitments under several conventions and agreements. More specifically, such a network will meet the objectives of:

- Sustainable Development Goals (SDG) 13 and 14 (Annex 2: Sustainable Development Goals (SDGs) (THE 17 GOALS | Sustainable Development (un.org))
- The National Biodiversity and Action Plan (NBSAP) (Annex 3: The National Biodiversity and Action Plan (NBSAP) targets) targets 1, 2, 3, 4, 5, 6, 9, 11, 12, 13 and 14 (Lebanon s National Biodiversity Strategy and Action Plan (NBSAP) 2016-2030. | UNEP Law and Environment Assistance Platform)
- The Kunming-Montreal Global Biodiversity Framework (GBF) (Annex 4: The Kunming-Montreal Global Biodiversity Framework (GBF) targets targets 1, 2, 3, 4, 6, 7 and 14 (Kunming-Montreal Global Biodiversity Framework (cbd.int))

VIII. Conclusion

In addition to contributing to nations meeting their national and international obligations under the SDG and GBF, MPA networks are becoming crucial tools for conserving marine biodiversity and regulating human impacts on marine ecosystems as well as their resources. Therefore, and to ensure the establishment of a successful MPA network, it is essential to invest the effort and the time to set an effective, applicable ecological and management monitoring program based on a clear set of biological, physical-chemical and socio-economic parameters. As clearly stated though, monitoring the performance of MPA networks and their impacts on marine ecosystem resilience and associated biodiversity is a nascent science and is constant development.

The proposed methodology for monitoring the ecological performance of Lebanon's MPAN, allows a comprehensive assessment of its efficacy. The ecological monitoring of representation, replicability, connectivity, size and shape, and critical areas ensures that the Network's adaptive management aligns with conservation goals, enhancing resilience and sustainability. By considering species responses over time and spatial scales, the APANC can navigate challenges, prioritize monitoring efforts, and optimize the ecological and socio-economic impact of Lebanon's MPA Network.

Monitoring the management of Lebanon's MPAN, anchored by the APANC under the oversight of the MOE, establishes a robust and long-term framework. Clear objectives, at the governance, ecological, and socio-economic levels will set the foundation for an effective and successful MPA Network. The APANC's roles and responsibilities, from surveillance to conflict resolution, will surely contribute to the network's success, fostering communication and adaptive strategies.

Thus, in Lebanon, it is recommended:

- To launch soonest the establishment of the MPA network through applied research.
- To review and amend as required and necessary Lebanon's MPA Strategy (IUCN & MoE, 2012) to meet Network requirements and criteria.
- That the Network be established based on the amended version of Lebanon's MPA Strategy (IUCN & MoE, 2012)
- That the criteria for establishing an MPA network be pilot tested to assess their validity and contribution to establishing a successful MPAN.
- That methodologies proposed in this report are validated through applied research, amended if needed, and new ones introduced.
- That resources are allocated to develop a scientifically robust ecological and management monitoring program.
- That a set of ecological and management indicators designed for the Network be developed based on available resources (human, material and financial) and properly monitored to show the contribution of the MPA network to ecological and socio-economic well-being.

In the face of all the anthropogenic negative effects on natural environments in general and marine ecosystems in particular, coupled with the ever-increasing impact of climate change, it has now become imperative that a network of MPAs be established for the protection of marine resources. Such a network though, will only be successful under a long term, adaptable and reliable monitoring program overseen by the MOE and supported by allocation of needed resources.

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Annexes:

Annex 1: Examples of the existing programs for California's MPAs network monitoring

- **Multi-Agency Rocky Intertidal Network (MARINe)[1]:** Established in the 1980s, MARINe23 is a

partnership of agencies, universities, and private research groups working together to collect data in rocky intertidal habitats. Surveys by MARINe partners follow standardized protocols and occur throughout the year at over 200 sites ranging from Southeast Alaska to Mexico, with more than 187 in California. With over 20-30 years of data at some California sites, long-term data will be invaluable to assessing MPA effectiveness, performance, and network connectivity.

- **Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)[2]:** Established in 1999, PISCO24 is a long-term, ecosystem-based scientific monitoring program involving marine scientists at four universities along the U.S. West Coast. The monitoring program was designed to enhance understanding of the California Current Large Marine Ecosystem (CCLME), with research focusing on physical oceanographic conditions of the coastal ocean (5-10 km from shore and less than 25 m deep), as well as the ecology of kelp forests and rocky shorelines. PISCO's broad scale research, monitoring, data management, training, and outreach will continue to improve the understanding of how MPAs and surrounding areas respond to long-term protections.
- **National Science Foundation (NSF) Long-Term Ecological Research (LTER)[3]:** This program has designated specific sites to represent major ecosystem types or natural biomes, with two in southern California. The Santa Barbara Coastal LTER project was established in 2000 and investigates the relative importance of land and ocean processes in structuring giant kelp forest ecosystems in the Santa Barbara Channel. The California Current Ecosystem LTER project was established in 2004, and focuses on the oceanographic mechanisms leading to changes and dynamics of the pelagic ecosystem. Both sites have the potential to contribute greatly to our understanding of long-term change because of spatial protection.
- **California Collaborative Fisheries Research Program (CCFRP)[4]:** CCFRP is a partnership of researchers and local fishing communities interested in fisheries sustainability. Established in 2007 as part of baseline monitoring on California's central coast, the program uses local charter boats to take volunteer anglers out to conduct fishery-independent, hook-and-line, catch and release surveys of offshore rocky reefs inside and outside MPAs. Volunteer anglers participate in research cruises under the oversight of scientists who are on hand to help with measurements, tagging, and fish identification. The program has now expanded statewide.

[1] https://marine.ucsc.edu/
[2] https://www.piscoweb.org/
[3] https://new.nsf.gov/
[4] https://www.ccfrp.org/

Researchers attribute the success of this program to its collaborative nature, which helps to create an open and collaborative dialogue between scientists and recreational fishermen.

- **Long-term Monitoring Program and Experiential Training for Students (LiMPETS)[5]:** It is a youth-based citizen science program that works primarily with middle and high school students to collect data from more than 60 sites across California's coast. Volunteers are taught to identify, count, and measure marine species in rocky intertidal and sandy beach habitat. Participation in the LiMPETS program help increase students' understanding of California's coastal ecology while also providing publicly accessible, long-term data.

[5] https://limpets.org/

Annex 2: Sustainable Development Goals (SDGs)

SDG number	Title
1	End poverty in all its forms everywhere
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Ensure healthy lives and promote well-being for all at all ages
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	Achieve gender equality and empower all women and girls
6	Ensure availability and sustainable management of water and sanitation for all
7	Ensure access to affordable, reliable, sustainable and modern energy for all
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduce inequality within and among countries
11	Make cities and human settlements inclusive, safe, resilient and sustainable
12	Ensure sustainable consumption and production patterns
13	Take urgent action to combat climate change and its impacts
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Annex 3: The National Biodiversity and Action Plan (NBSAP) targets

National Target	Description
1	By 2030, the status of 75% of known flora and fauna species is identified and conservation actions are implemented on 50% of threatened species.
2	By 2030, the genetic diversity of 50% of economically important fauna and flora is conserved In-situ and Ex-situ.
3	By 2030, national legislation on biosafety is enforced and operational.
4	By 2030, at least 20% of natural ecosystems are protected and all types of ecosystems are represented in the PA network.
5	By 2030, the total area of nature reserves is increased to reach at least 5% of Lebanon’s area.
6	By 2030, 50% of all natural ecosystems are sustainably managed and properly considered in land-use planning implementation.
7	By 2030, the gap between Lebanon's ecological footprint and biocapacity is alleviated to reach an equal state.
8	By 2030, the private sector has taken steps to implement plans for sustainable production and consumption to mitigate or prevent negative impacts on ecosystem carrying capacity through the use of natural resources.
9	By 2030, rehabilitation plans are implemented in at least 20% of degraded sites that will safeguard the sustained delivery of ecosystem services.
10	By 2030, the national law on access and benefit sharing is endorsed, operational, and enforced.
11	By 2030, effective measures are in place to control the introduction and diffusion of NIS into the environment.
12	By 2030, 100% of school and university students and at least 60% of the public are aware of the importance of biodiversity, its values, and the need for its conservation and sustainable use.
13	By 2030, relevant government entities consider the conservation of biodiversity, its benefits for people, the pressures that affect it, and the actions they can take for its conservation and sustainable use in their policy making processes and their implementation.
14	By 2030, vulnerable ecosystems to climate change are identified and adaptation plans are developed and implemented.
15	By 2030, research is improved in Lebanon and shared in a centralized platform (from both public and private institutions), which is updated and made accessible to the public (CHM).

National Target	Description
16	By 2030, efforts are made to preserve and document traditional knowledge, uses, and practices of local communities relevant to biodiversity and sustainable use of resources through integrating them into relevant policies and promoting them in relevant economic sectors.
17	By 2030, the institutional and legal framework and government policies are reviewed, updated and reinforced where necessary to ensure effective biodiversity conservation and sustainable use.
18	By 2030, Lebanon has developed and is implementing a robust resource mobilization strategy with a sustainable mechanism to finance biodiversity initiatives.

Annex 4: The Kunming-Montreal Global Biodiversity Framework (GBF) targets

GBF Target	Description
1	Ensure that all areas are under participatory integrated biodiversity inclusive spatial planning and/or effective management processes addressing land and sea use change, to bring the loss of areas of high biodiversity importance, including ecosystems of high ecological integrity, close to zero by 2030, while respecting the rights of indigenous peoples and local communities.
2	Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.
3	Ensure and enable that by 2030 at least 30 per cent of terrestrial, inland water, and of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories, where applicable,and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities including over their traditional territories.
4	Ensure urgent management actions, to halt human induced extinction of known threatened species and for the recovery and conservation of species, in particular threatened species, to significantly reduce extinction risk, as well as to maintain and restore the genetic diversity within and between populations of native, wild and domesticated species to maintain their adaptive potential, including through in situ and ex situ conservation and sustainable management practices, and effectively manage human-wildlife interactions to minimize human-wildlife conflict for coexistence.
5	Ensure that the use, harvesting and trade of wild species is sustainable, safe and legal, preventing overexploitation, minimizing impacts on non-target species and ecosystems, and reducing the risk of pathogen spillover, applying the ecosystem approach, while respecting and protecting customary sustainable use by indigenous peoples and local communities.
6	Eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 percent, by 2030, eradicating or controlling invasive alien species especially in priority sites, such as islands.

GBF Target	Description
7	Reduce pollution risks and the negative impact of pollution from all sources, by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects, including: reducing excess nutrients lost to the environment by at least half including through more efficient nutrient cycling and use; reducing the overall risk from pesticides and highly hazardous chemicals by at least half including through integrated pest management, based on science, taking into account food security and livelihoods; and also preventing, reducing, and working towards eliminating plastic pollution.
8	Minimize the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation, and disaster risk reduction actions, including through nature-based solution and/or ecosystem-based approaches, while minimizing negative and fostering positive impacts of climate action on biodiversity.
9	Ensure that the management and use of wild species are sustainable, thereby providing social, economic and environmental benefits for people, especially those in vulnerable situations and those most dependent on biodiversity, including through sustainable biodiversity-based activities, products and services that enhance biodiversity, and protecting and encouraging customary sustainable use by indigenous peoples and local communities.
10	Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches contributing to the resilience and long-term efficiency and productivity of these production systems and to food security, conserving and restoring biodiversity and maintaining nature’s contributions to people, including ecosystem functions and services.
11	Restore, maintain and enhance nature’s contributions to people, including ecosystem functions and services, such as regulation of air, water, and climate, soil health, pollination and reduction of disease risk, as well as protection from natural hazards and disasters, through nature-based solutions and ecosystem-based approaches for the benefit of all people and nature.
12	Significantly increase the area and quality and connectivity of, access to, and benefits from green and blue spaces in urban and densely populated areas sustainably, by mainstreaming the conservation and sustainable use of biodiversity, and ensure biodiversity-inclusive urban planning, enhancing native biodiversity, ecological connectivity and integrity, and improving human health and well-being and connection to nature and contributing to inclusive and sustainable urbanization and the provision of ecosystem functions and services.
13	Take effective legal, policy, administrative and capacity-building measures at all levels, as appropriate, to ensure the fair and equitable sharing of benefits that arise from the utilization of genetic resources and from digital sequence information on genetic resources, as well as traditional knowledge associated with genetic resources, and facilitating appropriate access to genetic resources, and by 2030 facilitating a significant increase of the benefits shared, in

GBF Target	Description
	accordance with applicable international access and benefit-sharing instruments.
14	Ensure the full integration of biodiversity and its multiple values into policies, regulations, planning and development processes, poverty eradication strategies, strategic environmental assessments, environmental impact assessments and, as appropriate, national accounting, within and across all levels of government and across all sectors, in particular those with significant impacts on biodiversity, progressively aligning all relevant public and private activities, fiscal and financial flows with the goals and targets of this framework.
15	Take legal, administrative or policy measures to encourage and enable business, and in particular to ensure that large and transnational companies and financial institutions: (a) Regularly monitor, assess, and transparently disclose their risks, dependencies and impacts on biodiversity including with requirements for all large as well as transnational companies and financial institutions along their operations, supply and value chains and portfolios; (b) Provide information needed to consumers to promote sustainable consumption patterns; (c) Report on compliance with access and benefit-sharing regulations and measures, as applicable; in order to progressively reduce negative impacts on biodiversity, increase positive impacts, reduce biodiversity-related risks to business and financial institutions, and promote actions to ensure sustainable patterns of production.
16	Ensure that people are encouraged and enabled to make sustainable consumption choices including by establishing supportive policy, legislative or regulatory frameworks, improving education and access to relevant and accurate information and alternatives, and by 2030, reduce the global footprint of consumption in an equitable manner, halve global food waste, significantly reduce overconsumption and substantially reduce waste generation, in order for all people to live well in harmony with Mother Earth.
17	Establish, strengthen capacity for, and implement in all countries in biosafety measures as set out in Article 8(g) of the Convention on Biological Diversity and measures for the handling of biotechnology and distribution of its benefits as set out in Article 19 of the Convention.
18	Identify by 2025, and eliminate, phase out or reform incentives, including subsidies harmful for biodiversity, in a proportionate, just, fair, effective and equitable way, while substantially and progressively reducing them by at least 500 billion United States dollars per year by 2030, starting with the most harmful incentives, and scale up positive incentives for the conservation and sustainable use of biodiversity.

GBF Target	Description
19	Substantially and progressively increase the level of financial resources from all sources, in an effective, timely and easily accessible manner, including domestic, international, public and private resources, in accordance with Article 20 of the Convention, to implement national biodiversity strategies and action plans, by 2030 mobilizing at least $200 billion per year, including by: (a) Increasing total biodiversity related international financial resources from developed countries, including official development assistance, and from countries that voluntarily assume obligations of developed country Parties, to developing countries, in particular the least developed countries and small island developing States, as well as countries with economies in transition, to at least $ 20 billion per year by 2025, and to at least $ 30 billion per year by 2030; (b) Significantly increasing domestic resource mobilization, facilitated by the preparation and implementation of national biodiversity finance plans or similar instruments according to national needs, priorities and circumstances (c) Leveraging private finance, promoting blended finance, implementing strategies for raising new and additional resources, and encouraging the private sector to invest in biodiversity, including through impact funds and other instruments; (d) Stimulating innovative schemes such as payment for ecosystem services, green bonds, biodiversity offsets and credits, benefit-sharing mechanisms, with environmental and social safeguards (e) Optimizing co-benefits and synergies of finance targeting the biodiversity and climate crises, (f) Enhancing the role of collective actions, including by indigenous peoples and local communities, Mother Earth centric actions and non-market-based approaches including community based natural resource management and civil society cooperation and solidarity aimed at the conservation of biodiversity (g) Enhancing the effectiveness, efficiency and transparency of resource provision and use;
20	Strengthen capacity-building and development, access to and transfer of technology, and promote development of and access to innovation and technical and scientific cooperation, including through South- South, North-South and triangular cooperation, to meet the needs for effective implementation, particularly in developing countries, fostering joint technology development and joint scientific research programmes for the conservation and sustainable use of biodiversity and strengthening scientific research and monitoring capacities, commensurate with the ambition of the goals and targets of the framework.
21	Ensure that the best available data, information and knowledge, are accessible to decision makers, practitioners and the public to guide effective and equitable governance, integrated and participatory management of biodiversity, and to strengthen communication, awareness-raising, education, monitoring, research and knowledge management and, also in this context, traditional knowledge, innovations, practices and technologies of indigenous peoples and local communities should only be accessed with their free, prior and informed consent, in accordance with national legislation.

GBF Target	Description
22	Ensure the full, equitable, inclusive, effective and gender-responsive representation and participation in decision-making, and access to justice and information related to biodiversity by indigenous peoples and local communities, respecting their cultures and their rights over lands, territories, resources, and traditional knowledge, as well as by women and girls, children and youth, and persons with disabilities and ensure the full protection of environmental human rights defenders.
23	Ensure gender equality in the implementation of the framework through a gender-responsive approach where all women and girls have equal opportunity and capacity to contribute to the three objectives of the Convention, including by recognizing their equal rights and access to land and natural resources and their full, equitable, meaningful and informed participation and leadership at all levels of action, engagement, policy and decision-making related to biodiversity.