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Indicators addressing the impacts of climate change on marine and coastal biodiversity

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TABLE OF CONTENTS

I. The Mediterranean: potential and stakes

The Mediterranean is an ecoregion that is remarkable for its climate. First and foremost it is a sea that is common to three continents, and is outstanding for the richness of its biodiversity and its historical heritage and for the diversity of its landscapes and cultural spaces and the feeling that it belongs to the people of the three shores. It remains one of the parts of the world where the issue of sustainable development is especially sharply felt, given that climate change should be particularly acutely revealed there (UNEP-MAP-RAC/SPA, 2010).

The Mediterranean and its 22 countries and territories bordering on the sea represent approximately (UNEP-MAP-Plan Bleu 2009)

- 5.7% of the world's non-sea area, much of which is desert and mountain areas
- 10% of known species of higher plants, on only 1.6% of the terrestrial surface
- 7% of marine species on less than 0.8% of the area covered by the ocean
- 7% of the world population with 460 million inhabitants (constant)
- 2 out of 3 people who live in the Mediterranean are town dwellers
- 31% of international tourism, with 275 million visitors
- 12% of world GDP (dropping)
- 60% of the population in the world's 'water poor' countries
- 8% of CO_2 emissions (rising)
- about 30% of international maritime freight traffic every year
- 20-25% of maritime transport of hydrocarbons.

This juxtaposition of potential, disturbance and risk makes the challenge of conservation extremely difficult, and even more so when one is attempting to achieve sustainability in the use of goods and services in the Mediterranean, whence the interest of turning towards an ecosystem approach and undertaking energy-managing measures, not only in the areas under the states' jurisdiction but also in the habitats and ecosystems lying outside the waters that are under national jurisdiction.

The Mediterranean, centre of biodiversity

The Mediterranean contains a great diversity of coastal and marine habitats that stand out for their singularity and their many endemic species, sometimes of world importance. The marine areas particularly contain vital habitats that are propitious for the development of a *flourishing biodiversity: Posidonia meadows and belts of calcareous algae.*

A feature of the regional ecosystem is its exceptional biological richness, both marine and terrestrial. This area is recognised worldwide as a biodiversity hotspot. But, particularly because of its being oligotrophic, the Mediterranean's marine resources are limited and cannot support being overexploited. Now, from 2001 on an ecological deficit has been noticed in all the countries bordering on the sea – the environmental capital is being spent more quickly than it can be renewed.

Even though the coastal and marine areas of the Mediterranean have so far been the subject of intense prospection, the biological wealth of the Mediterranean basin and of its shores is without doubt even greater. Inventories are incomplete for certain groups and certain geographical areas.

Also, the Mediterranean is regularly enriched by the regular entry of new Atlantic and Eritrian species and by accidentally introduced species (ballast water, fouling, fish farming…).

Stakes linked to the conservation of Mediterranean biodiversity

Around this vast inland sea are 21 bordering states, all confronted by high development stakes. On these coastal areas the populations and economic activities are concentrated. Every year over 150 million tourists visit these states' coastal and island regions.

Demographic and economic pressure has a sometimes very great impact on the coastal areas and receiver environments, and this pressure is growing constantly from year to year.

Pollution of the marine areas is widely felt at the level of the 101 listed hotspots, particularly those near urban and industrial concentrations. It is mainly due to industrial effluent and to urban waste water, the source of many effluents that reach the sea untreated. A more diffuse pollution is caused by maritime traffic, especially merchant shipping.

Fishing is economically and socially a particularly important activity in the Mediterranean. Production varies from one country to the next, but total landings for the Mediterranean Sea are estimated to be between 1.5 and 1.7 million tonnes annually. This directly gives rise to about 300,000 jobs without counting the great amount of indirect employment, all depending on the sustainability of this activity. Fishing pressure on halieutic resources is intense, threatening stocks of traditionally fished species and others, such as species fished in deep water that are so far untouched.

Finally, today climate change constitutes an ever clearer threat. The Mediterranean is acknowledged to be one of the regions most sensitive to the effects of climate change. The man threats which arise from this will be worsened by pollution, the growing pressure of human activities and unsustainable development that will sap the resistance and resilience of the ecosystems, habitats and species both on the coastal strip and out at sea. The other threat lies in the biosphere's quickening meridionalisation and the amplification and extension of exotic species, particularly invasive ones.

The shape of the Mediterranean basin and the quality of the natural heritage contained in its coastal and marine ecosystems as well as the considerable pressure exerted on its natural resources make the Mediterranean a vulnerable place, that requires the mobilizing of all the countries that border on it, and sometimes further away from the sea itself, for it is also necessary to consider the contributions and influences of the hillside slopes.

Today the states of the Mediterranean are making a contribution to a coordinated dynamics to conserve their vital space both to protect its fragile resources and to prevent the deterioration of its biological diversity.

As the number and growing area of protected areas shows, protecting the most vulnerable species has already been commonly adopted as a protection tool. But much remains to be done to put aims into effect as regards protected areas and their distribution, setting up marine protected areas out at sea and in the deep sea, reflection on ecological corridors between protected species, and, especially, putting into practice the management recommendations that are still, for many protected areas, often at the stage of intention only. As far as species are concerned, the protected areas that constitute spearheads for zones where the integrity of the environments and species is protected could act as laboratories dedicated to monitoring the effects of climate change on the natural heritage.

II. Impacts of climate change on marine and coastal biodiversity

Today climate change represents an additional pressure threatening biological diversity. Climate change, particularly the rise in temperatures, affects the periods of reproduction and/or migration of certain species, the duration of growth phases, the frequency of parasite infestations and the appearance of new diseases. Anticipated change thus risks causing modifications in the distribution of species and population densities, by moving habitats (e.g. migration towards the pole or in altitude for cold-affinity species). Thus a change in the composition of most of the present ecosystems is probable. Similarly, the danger of species extinctions, particularly those that are already vulnerable, is likely to rise significantly, especially for species which have a restricted climate distribution area, those which have very specific needs as regards habitat and/or small populations that are naturally more vulnerable to a modification of their habitats. Finally, the introduction of new exotic species could be facilitated, a thing whose long-term consequences are very hard to anticipate.

Over the last few years, the natural evolution of the Mediterranean biome has been disturbed by the accumulation and amplification of global changes, particularly due to the effects of climate change. Today the Mediterranean's specific features appear to make it especially sensitive to climate change (UNEP-MAP-RAC/SPA, 2010).

The existence of a set of long-term temperature records has enabled us to show, for the north-western Mediterranean, a warming trend of about 1° C over 30 years and an increase in the frequency of extreme events. Since this kind of data is often lacking in other parts of the Mediterranean, it is necessary to set up suitable strategies to develop models for predicting changes in environmental conditions (warming, circulation, nutriment content) (UNEP-MAP-RAC/SPA, 2008).

The migration of southern species, usually in a westerly and northerly direction, was the first indication of the biological effects of the warming of the Mediterranean. The most numerous reports are for the north-western Mediterranean and the Adriatic. It is believed that the short-term modifications of the ichthyological populations reflect in quasi-real time – at least on the scale of one generation – changes in the hydrological conditions. In the north-western Mediterranean, the most recent inventory lists several dozen species whose distribution area has changed significantly since the 1970s. Among these movements is the arrival of many species of fish (*sardinelles*, barracudas, coryphenes) that are gradually appearing in the regional fisheries. Above and beyond these positive effects are the collapse in stocks of small pelagics (sprats, anchovies) and/or modifications in the life cycle of some popular catch (tuna, amberjack).

The biological invasions, deemed to be an element of global change, in that they affect biodiversity, are often linked to climate change and environmental disturbance. Other factors also come into play: the intense maritime traffic carrying invasive species in ballast waters or as fouling, and the lagoons and bays that shelter quantities of fish farms which, by stocking up with spat or juveniles, permit the introduction of exogenous organisms. Moreover, recent cases of introduction of exotic dinophytes with their biotoxins, or proliferation of mucilage-producing species, have also been correlated with occurrences of climate anomalies (UNEP-MAP-RAC/SPA, 2008).

The rise in sea level, still difficult to anticipate at world level and more particularly in the Mediterranean basin, is considered to be one of those climate change-linked variables that have major effects on the coastal ecosystems. According to the 2007 projections (**IPCC**) that are considered as optimistic, the rise in sea level could reach 23-47 cm by the end of the 21st century. Many Mediterranean regions would then run a big risk of submersion and erosion, among these regions being the extreme cases of Venice, the Kerkennah and Kneiss archipelagos in Tunisia, and Alexandria and the Nile Delta in Egypt (UNEP-MAP-RAC/SPA, 2010).

The consequences to be feared are mainly the following:

- worse flooding of low-lying coasts, particularly delta areas, coasts with lagoons, maritime marshes and certain islands
- accelerated erosion of cliffs and beaches
- greater salinity in estuaries
- less fresh water in the ground water.

Among the other possible direct effects are the flooding of ‘amphibian’ caves and certainly impacts on biogenous formations made up of sessile species of the ‘vermetid platform’ kind.

III. Marine Protected Areas and climate change

III.1. Marine Protected Areas – conservation tools

The Marine Protected Areas were created to overcome the dangers and pressures caused by human activities to Mediterranean fauna, flora and habitats and to act as a brake to the erosion of biodiversity.

They were designed and set up as a tool for conservation and the sustainable management of the coast and the marine environment, with a view to protecting Mediterranean ecosystems, protected and threatened species and habitats, and natural resources.

Mediterranean Marine Protected Areas contain entities of great value such as the *Posidonia Oceanica* meadows; rare formations like the vermetid platforms; or threatened species like the red coral (*Corallium rubrum*), the noble pen shell (*Pinna nobilis*) and the limpets (*Patella furiginea*).

These special areas also help reduce the pressure on emblem or critically endangered species like the monk seal (*Monachus monachus*), the loggerhead turtle (*Carette caretta*), the cetaceans and a big variety of birds that use the MPAs as reproduction areas.

MPAs are also used today as a tool for protecting fisheries. They allow spawning grounds and nurseries to be protected, thus constituting sanctuaries for overexploited species.

Within the MPAs it has been proved that the abundance and size of both commercial and non-commercial species of fish are increasing, quite unlike what is happening everywhere else. Furthermore, the MPAs have a beneficial effect on those fisheries that lie outside the protected perimeters, for they help eggs, larvae, juveniles and adults to spread. And yet, for this beneficial effect on fisheries to be observed, the MPAs must have significant surface areas and contain diversified, quality habitats.

Suitably managed MPAs help bring about an increase in the productivity of fishing areas and generate jobs in this sector. Thus they represent a tool for the sustainable use of the sea and the coastal areas.

III.2. Marine Protected Areas – natural sentinels warning about the climate change crisis

The CBD set at 10% the areas to be protected in the Mediterranean; this aim is far from being achieved despite the extent of the effects of global change, particularly climate change, on the marine and coastal areas generally and in the Mediterranean more particularly.

MPAs are considered to be natural solutions to the climate change crisis, because:

- they can constitute superb laboratories for monitoring the CC/MCBD in the Mediterranean: they can act as sentinels where the effects of climate change can be checked via studies, inventories and monitoring, and where management strategies (adaptation and where possible mitigation) against such negative effects can be developed and possibly extended to the entire Mediterranean
- when they possess a management body, they can represent the best inventories and the best managed sites (human means, logistics, partnerships set up with scientists). Moreover, they constitute reference sites for conservation and monitoring stations that cover the entirety of the Mediterranean and its environments
- the MPA networks can help maintain biodiversity, conserve the services of the marine ecosystem, and thus help CO_2 to be absorbed, including in the deep sea
- the MPA networks respond best to climate change and other stress factors when they are effectively managed. The efficacity of an adaptative management should be enhanced
- the MPA networks respond better to climate change if the cumulative effects of stress factors and other stress factors are reduced
- the MPA networks guarantee biological and ecological connectedness and enhance the marine ecosystems' resistance and resilience to the effects of climate change.

IV. Strategic Action Programme for the conservation of Biological Diversity in the Mediterranean region (SAP BIO)

The main aim of SAP BIO is to set up a logical base for implementing the 1995 SPA/BD Protocol by providing the Contracting Parties to the Barcelona Convention, international and national organisations, NGOs, donors and all actors involved in protecting and managing the Mediterranean natural environment with concrete and coordinated actions, measures and principles at national, cross-border and regional level for the conservation of marine and coastal biodiversity in the Mediterranean, within the context of sustainable use and via the implementing of the 1995 SPA/BD Protocol.

SAP BIO was adopted in 2003 by the Contracting Parties to the Barcelona Convention to overcome the complex threats hanging over marine and coastal biodiversity in the Mediterranean. Its crafting took about three years, from 2001, as part of a wide process based on consultations at country level to make a diagnosis of the state of marine and coastal biodiversity and identify national priorities, and draw up a National Action Plan for each of the priority themes.

The results of the national consultations were compiled to craft a regional SAP BIO element aiming to back up and coordinate the National Action Plans.

The actions identified as having priority by SAP BIO concern:

- inventorying, mapping and monitoring Mediterranean marine and coastal biodiversity
- conservation of sensitive sites, habitats, and species
- assessment and mitigation of the impacts of threats to biodiversity
- developing research to improve knowledge and fill in gaps regarding biodiversity
- building skills to ensure coordination and technical assistance
- information and participation
- greater awareness.

In the SAP BIO context, abut fifty National Action Plans were crafted to face priority issues identified by the national process carried out in each of the countries.

V. SAP BIO and climate change

V.1. RAC/SPA: a key role for handling the impact of climate change on marine and coastal biodiversity

Aware of the gaps in information on the impacts of climate change on marine and coastal biodiversity in the Mediterranean, and also in line with the recommendations made by the Almeria Declaration, RAC/SPA was actively involved in helping to fill this gap and take into consideration as an important stake the effect of climate change on marine and coastal biodiversity. Thus, in consultation and collaboration with the countries bordering on the sea, a summary of national reviews on vulnerability and the impacts of climate change on marine and coastal biodiversity was crafted within the framework of SAP BIO activities for the two-year period 2008-2009. This action allowed an assessment to be made of the state of knowledge and the activities related to the impacts of climate change on biodiversity, especially marine and coastal, that had so far been undertaken. This participatory exercise also allowed future activities to be defined in response to the ‘climate change/marine and coastal biodiversity’ stakes in the Mediterranean.

Inset: Almeria Declaration, extracts

Preamble

- The Mediterranean's environmental priorities have evolved over the decades…
- Awareness of environmental problems has not been significantly expressed in sufficiently concrete actions…
- Protection and preservation of the environment has not yet been sufficiently integrated into other policies…
- Efforts at adaptation…all the countries are called on to act to reduce the impact of climate change…
- The importance of capacity-building, transfer of technology and mobilization of financial resources…
- The need to enhance regional and international cooperation in accordance with the spirit and the provisions of the United Nations Framework Convention on climate change
- The rapid rate of impoverishment of biological diversity and the ongoing degradation of the marine and coastal environment…

Conclusions

- The problem of climate change should be dealt with seriously to reduce as quickly as possible its effects on the marine and coastal environment…
- The immediate implementation in the Mediterranean region of steps to mitigate climate change…
- Climate change mitigation strategies should include methods like the ecosystem approach, risk management, strategic environment assessment, and the integral management of marine and coastal protected areas…

Decisions

- By 2011, inventorying the coastal and marine habitats and species that are most sensitive to climate change, and promoting steps to set up a vast coherent network of marine and coastal protected areas…
- Assessing the economic value of products coming from marine and coastal ecosystems and of services rendered, and the effects of climate change…
- Drafting a report, for each meeting of the Contracting Parties to the Barcelona Convention and to the Convention on Biological Diversity, on the situation of biodiversity in the Mediterranean and on the impact of climate change observed.

VI. On the need to implement CC/MCBD Indicators in the MPAs

VI.1. Marine and coastal biodiversity indicators in the context of the Convention on Biological Diversity

The request for biodiversity indicators started to emerge after the CBD was ratified in Rio in 1992. But it took the 2002 Johannesburg Conference for a costed objective and a schedule to be set to significantly reduce the rate of biodiversity erosion by 2010 (**http://www.biodiv.org**). More ambitiously, the European Union set itself the aim of stopping this erosion within the same period of time (EEA, 2007, 2009). Even though there were already some biodiversity indicators in existence at the time of the Johannesburg Conference, laying down a quantified objective really did urge the countries and international organisations to multiply the number of indicators so that there could be an assessment as to whether or not these objectives would be attained by 2010. The CBD's indicators strictly speaking were established in February 2004 at the Seventh Conference of Parties in Kuala Lumpur (**http://www.biodiv.org**).

VI.2. On the use of indicators in the MPAs, a vital tool for a regular assessment of the effects of the CC/MCBD

The bottom-up process undertaken by RAC/SPA at Mediterranean level to assess the effects of climate change on marine and coastal biodiversity allowed a regional summary to be made (UNEP-MAP-RAC/SPA, 2009a) that highlighted the following assessment:

- Concerning the CC/MCBD topic, the level of knowledge is uneven at both geographical and thematic level
  - Knowledge established on causes (greenhouse gas) and meteorological impacts
  - Little knowledge about the effects of CC on BD
  - Even less knowledge on the effects of CC on MCBD
  - Almost inexistent knowledge on adaptation and mitigation and their effects.
- Advances do indeed exist, but in a scattered order with the continuing presence of many gaps and without any guiding thread
- Need to set up a Mediterranean action plan and strategy to improve knowledge on CC/MCBD

This assessment highlighted the need to set up a common road map on the base of pertinent indicators:

- that can reflect the evolution of the state of biodiversity and of climate change
- that can reflect the evolution of the direct and indirect effects of climate change
- and then determine the evolution of attenuation and mitigation measures for climate change and its effects on marine and coastal biodiversity.

Generally speaking, well-managed Marine Protected Areas can provide a solution with a good cost/efficiency ratio for implementing strategies to improve knowledge, even response to climate change, given that the costs of setting up have already been paid off and that the socio-economic costs are offset by other services rendered by the Protected Areas. The Protected Areas' efficacity is maximal when they have good capacity and suitable management, when an agreement on their governance has been signed, and when they enjoy the firm support of the local resident population. Ideally, the Marine Protected Areas and conservation needs should be integrated within wider strategies over the marine and coastal environments (Dudley *et al*., 2010).

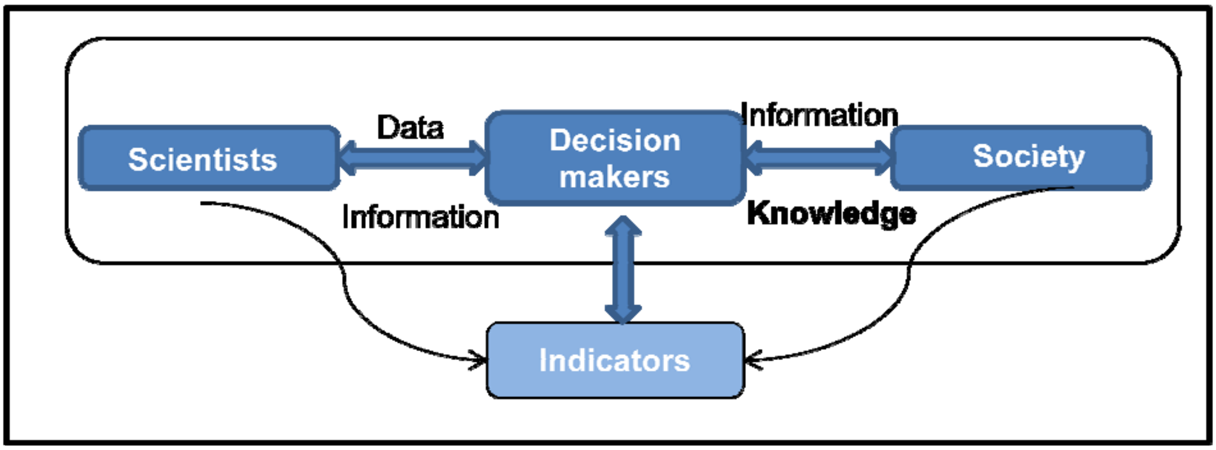
Mediterranean marine and coastal protected areas are distributed around the whole of the Mediterranean, at least those areas lying in the territorial waters of the Mediterranean (except the Pelagos Sanctuary, which encompasses a wider territory) and are representative of the diversity of the Mediterranean biome. They would certainly be more representative if other protected areas were situated out at sea or contained deep water. Thus monitoring the effects of climate change on biodiversity over these areas could allow any disturbance of habitats and species that was directly or indirectly climate-linked to be fairly rapidly defined.

Such a choice is enhanced by the presence of staff with technical skills and equipment. As part of implementing a monitoring-assessment of the effects of climate change on marine and coastal biodiversity, and insofar as simplified, cheap monitoring protocols are adopted, MPA managers can, thanks to their skills and their being on the spot, prove to be excellent contributors for improving knowledge on this still only partially understood stake.

VI.3. On the choice of indicators

An indicator is information measured over a period of time and giving information on specific changes in certain features of a MPA. It enables aspects that are not directly measurable to be assessed, like, for example, the efficacity of its management. It is, moreover, necessary to call on a battery of indicators in order to highlight the attainment (or not) of the announced aims and objectives. An indicator has to satisfy five criteria: measurability (in qualitative and quantitative terms), precision (identical definition everywhere), consistency (in time), sensitivity (variations that are proportional to changes in the measured attribute), and simplicity. Generally speaking, an indicator must be easy to understand and of obvious significance in order to be quickly accepted and deemed useful by the users.

Indicators: a synthetic tool for monitoring, informing and helping in decision-making



Indicators must meet a certain number of conditions that can sometimes be contradictory and have to be juggled:

- Pertinence: the measurement must perfectly describe the phenomenon being studied. It must be significant as to what is being measured and significant in the timing of the measurements taken
- Simplicity: the information must be easily and cheaply obtained and directly understandable without undue effort
- Calculability: the indicator must be easily calculable
- Presentability: one must be able to represent the evolution of the indicator
- Objectivity: the indicator must be unambiguously calculable over observable scales. It must result from protocols and methodologies that are ideally applied identically in time and space, or from protocols and methodologies that give rise to results that are easily comparable
- Univocality: the indicator must have monotone variation in relation to the phenomenon described in order to be able to interpret these variations unequivocally. Several phenomena can be integrated within one single indicator insofar as the share of each phenomenon is able to appear separately. If this is not so, confusion is possible
- Sensitivity: the indicator must move significantly for fairly small variations in the phenomenon. The rhythm of monitoring from which the indicator arises must be phased accordingly
- Precision: the indicator must be defined with an acceptable margin of error according to the precision of the measurements over observable scales
- Fidelity: if the indicator shows a bias regarding the concept it is expressing, it must keep that bias in time and space
- Must be able to be audited: a third party must be able to check the correct application of the rules of use for the indicators (data collection, processing, formatting, circulation, interpretation). Thus the protocols and methodologies adopted to implement the indicators must be simple and transparent

- Communicability: the indicators must enable dialogue between people who do not automatically share the same concerns. The indicators are superb communications tools in that they are quantitatively argued. This tool goes beyond the intention to accumulate knowledge and must therefore permit it to circulate as widely as possible, via adapted contents and back-up material
- Acceptability: the indicator must be saleable and must not offend the culture of the potential user. Whether this concerns the indicator or the content of the analysis documents, the message passed must not be polemical but should contain information backed up with arguments.

To sum up, the indicator must give a faithful picture of the phenomenon being studied to permit quick, simple assessment of the data to be monitored both by scientists and by all the actors, even the wider public.

VI.4. Indicators, CC/MCBD and MPA

With such complex stakes an adapted system of ecological monitoring has to be set up. Such an approach is essential for understanding how the ecosystem works and the modifications it may undergo because of climate change. And although the approach involves carrying out monitoring to give information to indicators of pertinent impacts on a Mediterranean scale, it must also be able to be perfected to be pertinent on pressure indicators in order to verify the correlation of impacts – for example, correlating the proliferation of heat-loving species with a rise in water temperature, etc. Furthermore, monitoring this indicator will have to be pertinent at the level of each protected area that constitutes a monitoring station, i.e. it must be dictated by and arise from the imperatives of management needs. This condition is necessary to justify the effort that will have to be made by managers who are often very much taken up with activities that are already planned.

Scientific monitoring is a relatively special activity that in the context of a natural environment protection system only makes sense if the site is actively, and ideally pro-actively, managed. This implies human and material means and an information base that is sufficient (inventories, other monitoring) both for carrying out monitoring on the effects of CC on MCBD and for having a sufficient documentary base for interpreting results. Unlike the routine monitoring done in a MPA, whose aim is to define the orientations of a pro-active management, the aim of a monitoring programme devoted to crafting indicators must also be to produce a synthesis of pertinent information at regional level that is intended not only for scientists and managers but also for national decision-makers, public opinion and international institutions that have power of persuasion and are able to define strategies and action plans to carry out preventive, curative or at least palliative programmes. These are the aspects that should direct future monitoring and its scientific basis.

Impact indicators must enable the evolution of the ‘CC effects on MCBD’ phenomenon to be assessed without being ‘polluted’ by other factors, unless the share of other factors in the evolution of the phenomenon is itself measurable and the evolution of the phenomenon is not amplified or modified by the interaction or synergy of the factors in question.

This requires a rigorous choice of indicators and the monitoring from which they derive. It will have to be made by scientific experts who must also be able to insert them into the DPSIR system and verify the pertinence of the indicators selected at local and regional level.

Although the Driving Force indicators and their relationship with the Pressure indicators can be deemed to be known (GES), the Pressure indicators and their relationship with the State and the Impact indicators are less clear, and thus one must be vigilant before stating that there are direct correlations, and verify the suitability of the monitoring of pressures either existing or that could be set up as part of this initiative, with impact monitoring.

The scientific experts will also have to identify the protocols to be implemented and sometimes choose between two or more protocols leading on to the same results; this will permit standard monitoring protocols to be found that can be applied over the entirety of the Mediterranean and thus ensure that the results obtained are comparable from one station (MPA) to the next. To do this, the ‘simplicity’ of execution, costs etc. criteria will be decisive. Associating managers in the selection of protocols is recommended.

Choosing the timing of the monitoring is also important, both to avoid and understand seasonal or short-term variations and to permit significant variations to be noted when the phenomena evolve slowly. This applies equally to monitoring devoted to Impact indicators and that informing the Pressure indicators and the relationship between them.

Lastly, the choice of stations (MPAs) must also be rigorous, for all MPAs do not face the same stakes and the same level of pressures, these depending on their geographical situation and the ecological and biological values that characterise them – for example, one would not advocate monitoring the effects of CC on the coralligenous in a MPA where there is none, nor would one place on the same level the evolution of heat-loving species on the southern and the northern coasts of the Mediterranean, or the evolution of 'Lessepsian' species in the east and west of the basin.

The choice of stations will also take into consideration the past or future availability of information characterising the State of biodiversity and more generally of the ecosystems (inventories and monitoring). All or part of this information will form the base on which efficient measuring of the effects of CC on MCBD will be erected. Verification of the available human resources and their skills, of the means and equipment they possess, and of their scientific background will be other selection criteria, or at least parameters that must be borne in mind in the context of a specific capacity-building plan.

Joint work involving scientists, managers and people working in institutions will be necessary to identify the Protected Areas that will become stations under this initiative. One can foresee that involving managers and countries (institution staff) in such an initiative will only be effective if an argument can be made based on real needs at local level that constitute a motivational element for making best use of the results and for analysis of these indicators at local and regional level. To answer questions about efficiency, another line of argument that can involve these actors still further will be to envisage connecting these indicators to actions that can permit mitigation of or adaptation to the effects of CC on MCBD (but this is certainly to be anticipated in the mean term).

A question of logic

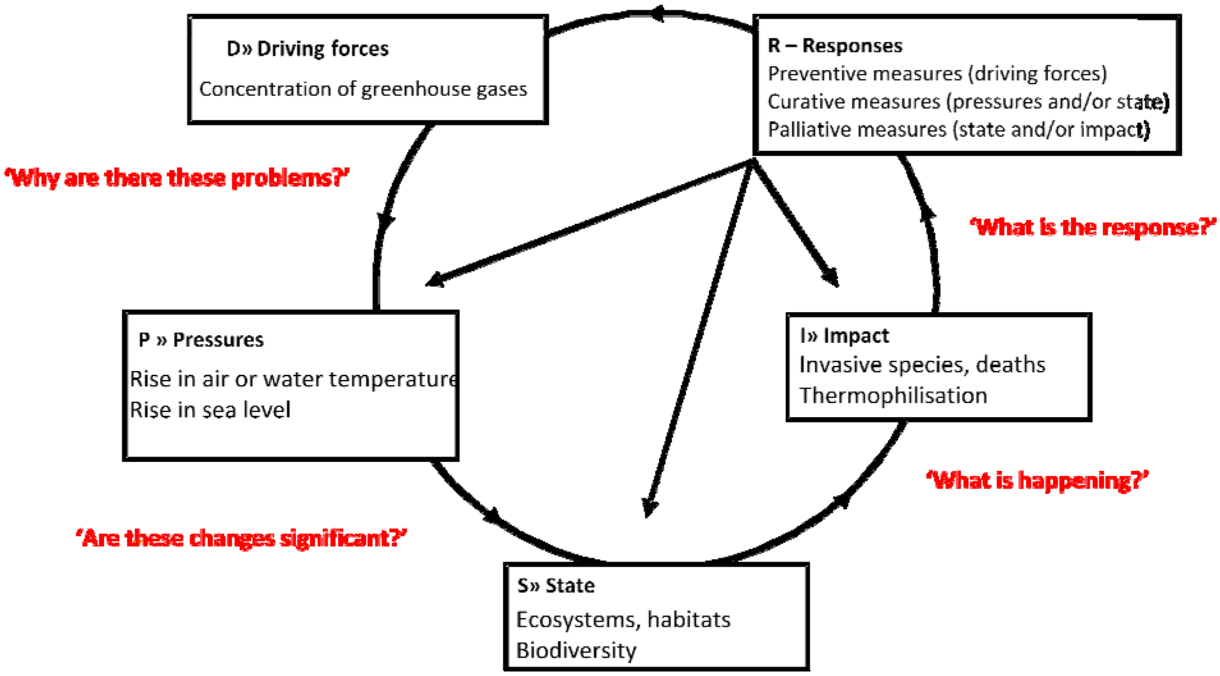
Impact indicators cannot and must not be implemented in isolation. To be correctly understood, they must be seen within a logical approach based on causal relationships. For often above and beyond the results reflected by the Impact indicator itself, it is the causal links that are the most important and allow the approaches to be better defined. And it is an understanding of these cause-effect relationships on the basis of a rigorous scientific approach that will ground the approach and allow possible steps to be taken, whether preventive or curative.

In order to build these systems of indicators logically, one can use the **DPSIR** approach. This efficient tool, developed for the use of decision-makers, can act as a basic framework when indicators are being identified, characterised or implemented, and can very well apply to the indicators that inform on the effect of climate change on marine and coastal biodiversity.

The DPSIR (Drivers-Pressure-State-Impact-Response) model allows a link to be made between the causes or **drivers** of the phenomenon (*i.e. concentration of greenhouse gases*) and the **pressures** it gives rise to (*rise in air or water temperature, rise in sea level*…) which affect the general **state** of the environment (*ecosystems, habitats, biodiversity*…) via **impacts** (*invasive species, deaths, thermophilisation*…). The **response** is the society's reactions to the phenomenon to be curbed either through ***preventive*** measures directed at the driver/s of the phenomenon, or ***curative*** measures directed at the pressures and/or the state, or ***palliative*** measures directed at the state and/or impact.

The DPSIR approach

Example of the DPSIR analysis applied to climate change:



These links and relationships must be understood and duly set out in order to understand the phenomena, even in the case where there is a focus on Impact indicators. This will enhance the indicators' information and communication role

VII. Content of the assignment, tasks carried out and follow-up

In the following Appendix a preliminary work appears that reproduces the state of the art regarding the effects of climate change on marine and coastal biodiversity. It shows the main pressures exerted on species and habitats and their impacts, all quantifiable and measurable.

This work will be rounded off by a selection of these potential indicators according to their pertinence and, especially, to the feasibility of implementing them in Marine Protected Areas. Next September a technical meeting will bring together experts from RAC/SPA and from the IUCN Med to discuss and harmonize the results of their respective assignments.

After this first stage, a list of pre-selected characterised indicators will be submitted to the countries for discussion and amendment with a view to setting up a monitoring system to be extended to the Mediterranean MPAs which will give information on regional and local trends in the effects of climate change on biodiversity, in order to come up with adaptation and mitigation solutions.

ANNEX I
Impacts of climate change on marine and coastal ecosystems, potential indicators

Impacts of climate change on marine and coastal ecosystems

Abiotic changes

Driving forces

- Overall rise in marine surface temperatures (about 0.4° C since the 1950s)
- Expansion of world oceans and rise in sea level
- Increase in re-emergences due to eastern currents, speeding up the availability of surface nutriments. (Iberian re-emergence? small Mediterranean re-emergences (Almeria-Oran), Golfe du Lion, etc.?)
- Strong thermal stratification and dive in thermocline, impeding the cooling of the surface water and its enrichment in nutriments via re-emergences
- Increase in recurrence of storms
- Influence on models of rainfall that could affect the salinity, turbidity and telluric contributions (nutriments and pollutants) of the coastal water
- Disturbance of wind and ocean circulation models
- Frequency of El Nino-type phenomena

Chemical changes

- Drop in pH (due to growing CO_2 emissions)
- Amplification of UV radiation (due to the deterioration in the ozone layer)
- Dwindling concentrations of oxygen in the subsurface water and increasing episodes of hypoxia
- Complex interaction mechanisms between the cloud cover, UV radiation, productivity of plankton, and freeing of **DMS** by marine algae

ECOLOGICAL RESPONSES TO CLIMATE CHANGE

Perceptible ecological responses

Responses to temperatures

- The physiological, morphological and ethological effects of the rise in surface water temperatures affect the performance and survival of marine organisms (variations between species and different ontogenic stages of marine organisms: larva plankton stages, demersal or benthic juvenile stages and adult stages) e.g. in the Mediterranean: growth rate of *Cladocora caespitosa, Oculina patagonica, Madracis pharensis*; mass deaths of *Corallium rubrum, Paramuricea clavata, Eunicella singularis*, etc. (See Table 1 in Lejeusne *et al.*, 2010)
- Duration of ontogenic and phenologic transitions, e.g. in the Mediterranean: flowering of *Posidonia oceanica* (prevalence and intensity), dates of seasonal migrations, egg-laying seasons (**http://www.springerlink.com/content/d6044j80137616r1**/), distribution and residence periods of pelagics (*Thunnus thynnus, Seriola dumerlii*), phenological changes for phytoplankton species (*Ceratium*)
- Changes at community level (pressure of predation, distribution and density of habitats)

Responses at sea level

- Vertical displacement of species distribution
- Reduced availability of habitats, mainly at depth

Responses to changes affecting circulation

- Increased vulnerability of shallow intertidal and subtidal systems (harm caused by the increased frequency of storms, plus turbidity etc.)

- Variations in availability of nutritive elements in re-emergences
- Effects on dispersal and recruitment in marine systems, affecting the balance of recruitment of larvae/mortality of adults (likely to lead to local population extinctions)
- More complex effects on the community at process level (predation, competition, etc.)

Responses to changes in CO_2 and pH concentrations

- Physiological effects (e.g. reductions in sub-cellular processes such as protein synthesis and ion exchange) affecting growth and survivorship of marine organisms, likely to be more pronounced for invertebrates than for fish; loss of phenolic substances in seagrasses
- Impact on many marine invertebrates and algae that build carbonate structures (decreased calcification rate)

Responses to UV

- Negative effects on larvae of invertebrates and algae (likely to be dependent on the presence of species that can interact, for example, phytoplankton + invertebrate marine viruses graze benthic algae

Emerging ecological responses

Changes in distribution: zoning models

- Changes in the average depth distribution of marine organisms (sessile invertebrates and fishes) because of rise in temperature, hydrodynamic disturbance, increased UV and/or rise in sea level
- The 'shearing effect': abiotic stress changes the vertical distribution shelf of an organism compared to a predator or a competitor

Changes in distribution: biogeographical affinity

- Latitudinal movement of the geographical distribution of marine species, which leads to the expansion (or contraction) of their distribution limits, or to changes in the relative abundance of marine species in one single place – for the Mediterranean, see **http://www.ciesm.org/atlas/appendix1.html** on fishes, **http://www.ciesm.org/atlas/appendix2.htlm** on crustaceans, and **http:///www.ciesm.org/atlas/appendix3.htlm** for molluscs; e.g. *Serranus atricauda, Parapristipoma octolineatum, Mycteroperca rubra, Sparisoma cretense, Pseudocaranx dentex, Acanthurus monroviae, Plecthorinchus mediterraneus, Sphyraena viridensis, Thalassoma pavo, Sardinella aurita, Coryphaena hippurus, Astroides calycularis, Scyllarides latus* (increasing), *Homarus gammarus* (dwindling), replacement of the cavernicolous mysidacean *Hemimysis speluncola* by *H. margalefi*

Changes in composition of species, diversity and structure of communities

- Consequences for the community and ecosystems of the loss of one or several species – e.g. for the Mediterranean, the jellyfish (*Pelagia noctiluca, Cothylorhiza tuberculata*, others) and proliferation of thaliaceans
- Establishing and deliberate or accidental spread of introduced species – e.g. for the Mediterranean: *Percnon gibbesi, Dyspanopeus sayi, Caulerpa taxifolia, C. racemosa* var. *cylindracea, Lophocladia lallemandi, Asparagopsis armata,* and production of palytoxin by the dinobionta *Asterodinium* and *Ostreopsis ovata* (Dinophyceae), *Stypopodium schimperi, Ruditapes philippinarum, Siganus rivulatus, Siganus luridus*
- 'Climate forcing' of interspecific interactions – e.g.
  ° Behavioural change from competition to facilitation
  ° Amplification of the negative effects of diseases: *Bonamia ostreae* in *Ostrea edulis; Gambierdiscus toxicus* (causing cigateria), *Vibrio* in marine invertebrates e.g. *Paramuricea clavata, Astropecten jonstoni*)
  ° Variation in the strength of trophic interactions (e.g. 'match-mismatch' hypothesis, etc.)

Evolution of primary and secondary production

- Restrictions in the latitude and/or bathymetric ranges of major primary producers (like the Laminaria) leading to reduced primary production
- Fluctuations in the coastal systems' primary production due to variations in the concentrations of nutritive elements caused by changes in circulation models (ocean currents and upwellings)
- Probable replacement of the macro-algae by meadows due to the increased concentration of dissolved carbon (the marine phanerogams, which evolved during the Cretaceous, when carbon dioxide concentrations were much higher, show a carbon-deprived photosynthesis under recent concentrations, whereas today the macro-algae are carbon-saturated; see Arnold *et al*., 2012), leading to more focussed detritus-eating trophic systems (idem between the fleshy algae and the Balanus and communities where mussels predominate)
- Complex interaction between primary production and the metabolic processes and population dynamics of consumers – e.g.
  ° checking the abundance of grazers under the influence of nutriments on primary production
  ° impact of individual phenological responses between functional groups on secondary production
  ° relative responses of primary and secondary producers to re-emergence dynamics
  ° effects on sedimentation and the decomposition of the excess phytoplankton biomass on the seabed

Population dynamics and evolutions

- Influence of climate change via adaptation in the ecosystems, leading to evolutional responses
- Intense selection of one single locus leading to the dwindling variability of the rest of the genome
- Genetic drift caused by the reduced size of populations due to climate forcing
- Response of the organisms to multiple climate stress (for example, pH and temperature)
- Genetic correlations and/or arbitrages between physiological features restricting the species' ability to adapt to contemporary climate change

Table 1: Potential indicators

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
Physical/chemical		Surface temperature	Seawater temperature	Thermal captors (at different depths), AVHRR sensor (network)	Helmuth et al. (2006), Selig et al. (2010), Vargas-Yáñez et al. (2010), Calvo et al. (2011), Crisci et al. (2011), Skliris et al. (2011)
		Salinity	Salinity	Recording of salinities (at different depths)	Vargas-Yáñez et al. (2010), Calvo et al. (2011)
		Rise in sea level	Sea level, coastal map	Marigraphs/buoys (network), coastal map	Várgas-Yáñez et al. (2010), Calvo et al. (2011)
		Acidification	pH, pCO2, aragonite saturation, total alkalinity, dissolved inorganic carbon	Soundings, regular sampling	Feely et al. (2010), Hoffman et al. (2008), Byrne et al. (2010), Iglesias-Rodriguez et al. (2009), Doney et al. (2009)
		Hypoxia	Dissolved oxygen, satellite imaging	Soundings, regular sampling, satellite imaging	Diaz & Rosenberg (2008), Hoffman et al. (2011), etc.
		UV radiation	UV radiation	Extension of the ELDONET network?	Marangoni et al. (2000), Häder et al. (2007)
		Stronger upwellings	Temperature and concentration of chlorophyll a in seawater	Remote sensing, imaging	
		Thermal stratification	Depth and stability of thermocline		(cf. SST ci-dessous)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
		Nutriment contribution	Total organic, C, N, P, and other	Soundings, regular sampling of seawater	Wikner & Andersson (2012)
		Frequency of storms	Wind speed, height and energy of swell and waves, recurrence of storms	Data journal	Sheppard et al. (2005), Walker et al. (2008)
		Rainfall, run-off, turbidity	Rainfall, watercourse flow, turbidity	Data journal	Wikner & Andersson (2012)
Individual	Physiological	Thermal tolerance and acclimatization	Lab specializing in coldwater benthic invertebrates and fishes (restricted temperatures – DL50, growth rates, reproduction, oxidative stress, etc.	Lab	Pörtner (2002), Lesser (2006), Menge et al. (2008), Helmuth (2009), Peck et al. (2009), Jones & Berkelmans (2010), Pörtner & Peck (2010), Somero (2010), Valdizan et al. (2011), Huey et al. (2012)
		Tolerance of hypoxia	Ventilation, oxygen consumption, swimming performance, metabolic capacity, cardiac function, lethal and sub-lethal levels	Lab	Nilsson & Ostlund-Nilsson (2004), Vaquer-Sunyer & Duarte (2008), Petersen & Gamperl (2010), Cannas et al. (2012)
		Tolerance of acidification	Acidification/growth and rate of reproduction	Laboratoire	Orr et al. (2005), Fabry et al. (2008), Jokiel et al. (2008), Doney et al. (2009)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
		Size	Average length/weight of fishes/invertebrates	Field, data exploration	Meiri et al. (2009), Fisher et al. (2010)
		Level of calcification	Evolution of skeleton weight, % of calcium carbonate, δ11B: isotopic analysis of coral carbon-dated skeletons, X-ray densitometry, genomic functionalities	Field, lab network	Wood et al. (2008), Doney et al. (2009), Wei et al. (2009), Rodolfo-Metalpa et al. (2011), Carricart-Ganivet et al. (2012), Iguchi et al. (2012), Landes & Zimmer (2012)
		Responses to UV radiation	Survival, oxidative stress, growth of marine organisms	Lab	Lesser (2006), Bancroft et al. (2007), Häder et al. (2007, 2010)
	Ethology	Vertical migration	Vertical distribution of phytoplankton, vertical distribution of predators	Field	Dulvy et al. (2008), Rosa & Seibel (2009), Huey et al. (2012)
	Phenology	Flowering of marine phanerogams	Intensity and prevalence of flowering in Posidonia oceanica	Diving observation	Díaz-Almela et al. (2007)
		Migration dates	Dates of arrival and periods of residence of seasonal species (e.g. seasonal migration in coastal lagoons; marine turtle nesting; pelagic species)	Direct observation, tagging	Franco et al. (2006), Franzoi et al. (2010)
		Dates of reproduction and procreation	Maturity of gonads of certain species		Ling et al. (in press)
		Phytoplankton phenology	Abundance of phytoplankton	Routine sampling of phytoplankton	Edwards & Richardson (2004), Tunin-Ley et al. (2009)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
		Phenology of larvae, post-larvae, fishes and recruitment	Abundance of ichthyoplankton, post-larvae and juveniles	Routine sampling of ichthyoplankton (plankton net), post-larvae (light traps), and juveniles (visual inventory)	Genner et al. (2010), Félix-Hackradt et al. (in press)
		Period of residence of pelagic fishes	Period of residence of pelagic fishes	Tagging, acoustic monitoring	Holland et al. (1999)
		Seasonality of benthic fishes	Seasonality of hydroids	Monthly visual inventorying of hydroids	Puce et al. (2009)
Population	Mortalité et maladies	Deaths and diseases, Mass deaths	Occurrence and extent of mass deaths	Diving observations	Coma et al. (2009), Lejeusne et al. (2010), Calvo et al. (2011)
		Partial deaths and whitening	Occurrence and extent of whitening and necrosis in invertebrates	Diving observations	Ainsworth & Hoegh-Guldberg (2008), Cebrián et al. (2011)
	Dispersal and recruitment	Changes in dispersal, models of connectedness	Dispersal models, space-time mapping, models of genetic connectedness	Biophysical modelling	González-Wangüemert et al. (2004, 2007, 2009), Munday et al. (2009), Lett et al. (2010)
		Organisation/and episodes of recruitment of exotic species (not present in adult assemblages)	Presence and abundance of larval and juvenile stages in exotic species	Light traps and visual inventorying of juveniles	Félix-Hackradt et al. (in prep.)
	Distribution and abundance	Proliferation of species	Occurrence of algal blooms/jellyfish/aggregation of mucilaginous/other species	(Long-term) *in situ* sampling/network	Purcell et al. (2007), Moore et al. (2008), Danovaro et al. (2009), Gili et al. (2010), Touzri et al. (2012)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
		Changes in relative abundance	Abundance/density of a selection of species	(Long-term) *in situ* sampling/network	Hawkins et al. (2008)
		Changes in biogeographical distribution limits	Distribution limits for a selection of species	Long-term) *in situ* sampling/network	Chevaldonné & Lejeusne (2003), Perry et al. (2005), Brito et al. (2006)
		Change in average depth range	Range of depths for a selection of species	(Long-term) *in situ* sampling/network	Dulvy et al. (2008), Rosa & Seibel (2009)
		Presence and extension of exotic species	Abundance and distribution limits for a selection of exotic species	Long-term) in situ sampling/network	Izquierdo-Muñoz et al. (2009), Occhipinti-Ambrogi & Galil (2010), Coma et al. (2011)
	Reproduction	Reproduction in fishes and other groups	YCS, fecundity, state, average age/size at maturity		Pankhurst & Munday (2011)
	Genetic drift and selection	Genetic diversity and gene flow	Allelic richness, proportion of locus polymorphic, observed and expected heterozygocity		Ayre & Hughes (2004), Pérez-Ruzafa et al. (2006), Williams et al. (2008)
Community/ ecosystem	Specific composition	Cold/warm affinities	Propagation of heat-loving species, reduction (presence/abundance) of cold water species	Direct sampling (visual inventorying of fishes, benthos etc.).Long-term, wide field surveys, LEK	Francour et al. (2009), Lasram & Mouillot (2009), Azzurro et al. (2011)
		Biomass spectrum of phytoplankton	Fraction of pico-phytoplankton	Long-term, wide field surveys, LEK	Calvo et al. (2011)
		Native and exotic species	Spread of exotic species	Long-term, wide field surveys, LEK	Occhipinti-Ambrogi & Galil (2010)
		Importance of predators at the top of the chain	Proportion of predators	Long-term, wide field surveys, LEK	Baum & Worm (2009)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
	Biodiversity	Species diversity	Species richness, specific diversity	Long-term, field surveys	Gray (2000), Salas et al. (2006), Hiddink & Hofstede (2008)
		Taxonomic diversity	Taxonomic distinctions, etc.	Long-term, field surveys	Leonard et al. (2006), Salas et al. (2006)
		Functional diversity	Functional diversity indicators	Long-term, field surveys	Micheli et al. (2005), Halpern & Floeter (2008), Stelzenmüller et al. (2009), Mouchet et al. (2010), Schleuter et al. (2010), Albouy et al. (2011), Cadotte et al. (2011), Mora et al. (2011)
	Driving force of specific interactions	Force of specific interactions or competition	Structure of the community, topology of the food	Long-term, field surveys	Emmerson et al. (2004), Schiel et al. (2004)
		Mismatch between predators' needs and availability of resources	Episodes of famine caused by climate	Long-term, field surveys	Edwards & Richardson (2004), Durant et al. (2007); MacLeod et al. (2007)
		Shearing effect	Vertical modifications of distribution of intertidal species	Long-term, field surveys	Harley (2011)
	Availability of habitats	Distribution and density of habitats	Distribution and density of macroalgae, meadows, gorgonians, sponges etc.	Long-term, field surveys	Pinedo et al. (2007), Maggi et al. (2009), Waycott et al. (2009), Navarro et al. (2011)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
	Primary plankton production and secondary production	Fluctuation of primary production	Water transparency, bacterioplankton, phytoplankton biomass and zooplankton biomass, chlorophyll a	Long-term, field surveys	Hays et al. (2005), Calvo et al. (2011), Chavez et al. (2011), Vezulli et al. (2011)
		Latitudinal and depth modifications of the main primary producers	Distribution and density of phytoplankton, macroalgae, seagrass species	Long-term, field surveys	Calvo et al. (2011)
		Replacement dynamics between macroalgae (native or alien) and seagrasses	Distribution and density of macroalgae and meadows	Long-term, field surveys	Marbà & Duarte (2010), Arnold et al. (2012)
	Complex interactions between primary and secondary production	Impact of individual phenological responses between the functional groups on secondary production	Composition of epiphyte communities	Long-term, field surveys	Martínez-Crego et al. (2010

For each indicator it will be necessary to document the following terms

CODE:	**(NAME)**		**Category:**
Definition:			
Context and objective			
Methodology and sampling modes			
Calculation and units			
Representation (quantitative, graphic, mapping, GIS)		**Geographical pertinence**	
Targets and objectives, if determined and available			
Political pertinence			
Other sources (Mediterranean/country)			
Pertinent bibliographical references			

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