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CURRENT STATUS OF CLIMATE CHANGE IMPACT INDICATORS ON MARINE BIODIVERSITY IN THE MEDITERRANEAN MARINE PROTECTED AREAS

Delegates are kindly requested to bring their documents to the meeting

UNEP
RAC/SPA - Tunis, 2013

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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 ichthyologic 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) and climate change

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, fifty eight National Action Plans were crafted to face priority issues identified by the national process carried out in each of the countries. 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 riparian countries, 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.

V. On the need to implement CC/ Marine and coastal biodiversity indicators in the MPAs

V.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).

V.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).

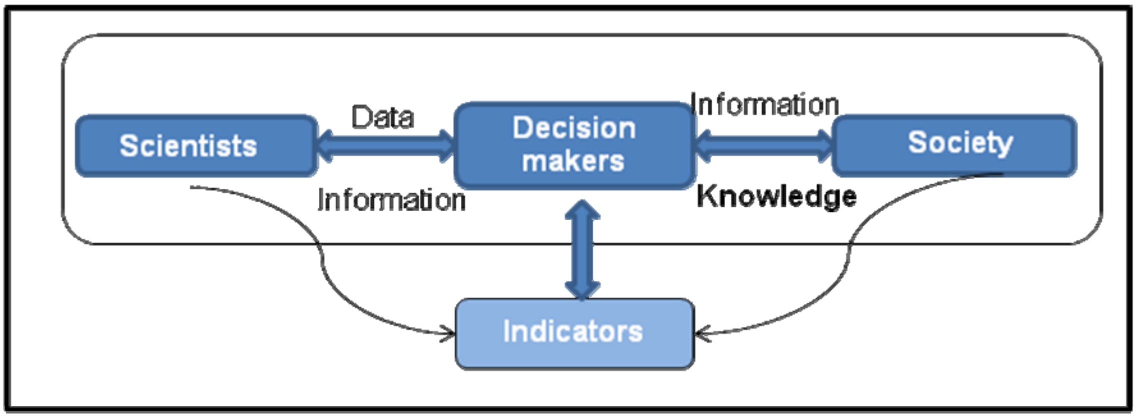
Mediterranean marine and coastal protected areas are distributed around the whole of the Mediterranean, at least those areas lying in the territorial waters of the Mediterranean (except the Pelagos Sanctuary, which encompasses a wider territory) and are representative of the diversity of the Mediterranean 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.

V.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), and 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.

V.4. Indicators, Climate Change, Marine and Coastal Biodiversity and MPAs

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).

V.5. A question of logic: Impact indicators cannot and must not be implemented in isolation.

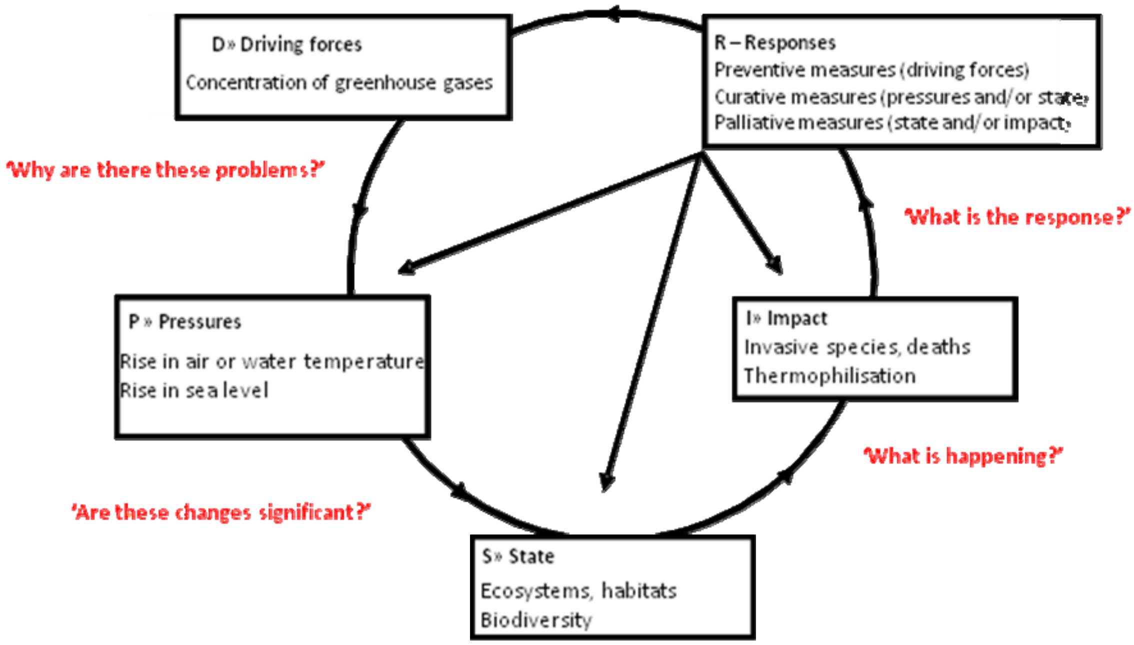
To be correctly understood, Impact indicators must be seen within a logical approach based on causal relationships. For often above and beyond the results reflected by the Impact indicator itself, it is the causal links that are the most important and allow the approaches to be better defined. And it 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

VI. Tasks carried out on the definition of indicators and follow-up

Annex I 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. It is complemented with a list of potential indicators (Table 1).

A selection among those potential indicators according to their pertinence and, especially, to the feasibility of implementing them in Marine Protected Areas, took place through a technical meeting (Malaga, Spain; 23-24 October 2012) bringing together experts from RAC/SPA and IUCN Med to discuss and harmonize results. There, most recent initiatives up to date in the Mediterranean were presented and the Prioritization of a pre-selected list of CC indicators was worked out, whosa results are depicted further below.

After this first stage, a list of pre-selected characterised indicators is presented in Annex II, 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.

VI.1 Insight on most recent initiatives up to date in the Mediterranean.

Indicators context to the of CC from the perspective of the MedPAN-North project, gives special relevance to involving MPAs into CC monitoring efforts. Particular emphasis was laid on the importance of taking relevant criteria into consideration for selecting the appropriate indicators (e.g. - easiness, scientific relevance, inexpensive & feasible, helpful, answer key questions…).

The involvement of particular MPAs and MPA managers into CC-monitoring efforts relies, from the point of view of MedPAN-North, on a series of assumptions such as the basic principle that individual MPAs should have already monitoring plans in place the selected indicators would vary across the network in time and choice of variables to be measure. In order to count on sufficient information for a better understanding the different vulnerabilities on MPA features, time series of information will also need to build up. Moreover, it would be necessary that MPAs develop a broad communication strategy on the impacts of marine CC in their protected areas.

Starting from the preliminary list of categories and indicators to track CC impacts across the MPA network as pre-selected in the Experts Meeting on Climate Change impacts on marine biodiversity in the Mediterranean MPAs, held in Malta on 22- 23 November 2011, next steps have to be further made to define these indicators, and, eventually, consider additional ones to be recommended to MPA managers and the Contracting Parties to the Barcelona Convention. This process is facing a series of challenges, such as: how to define and communicate indicators; the need to fully understand the impacts of CC and their synergistic effects; criteria to select target impacts of key biodiversity features; how to be ready for planning adaptation strategies; need to develop and adapt new ideas; and how to feedback result findings into managers.

The need to coordinate national efforts at the international level to integrate all research and monitoring efforts into a monitoring system is highlighted. Another key factor is the necessity to identifying a funding framework (specific solutions to financial support) and distinguishing between activities already funded (nationally or internationally), from those which would need further financing. Thus, for EU countries some of the proposed CC indicators should be discussed in the framework of EU Directives such as Habitat FD, WFD or MSFD, and propose the enlargement under the Barcelona Convention (to ensure that at least in EU countries they will be supported by EU regulations).

Work from the Spanish Institute of Oceanography (IEO – Grupo Mediterráneo de CC) is centered on oceanographic aspects of CC impacts monitoring in the Spanish Mediterranean. It constitutes a concrete example of long-term data series to be used for further developments. In summary, the monitoring effort in place by the IEO (which started in 1992 to the present) consists on a series of oceanographic stations visited periodically all along the year with oceanographic vessels, where they take a set of oceanographic variables. Some of the stations are in coastal areas (20-m depth) – and some are close MPAs, other on the shelf, and other in the open sea (focusing on the deep ocean).

The rationale behind this IEO monitoring program, starting from what we know to date about the oceanic response to CC and the particular conditions of the Mediterranean relies on a series of contrasts, such as: local *vs*. global; natural *vs*. anthropogenic, and, within those changes caused by humans, climate *vs*. not-climate changes. Some effects of CC are direct, but affected by other factors; so, to demonstrate that an observed biological change is caused by e.g. increase in seawater temperature, it is needed to also measure the change in temperature. The strategy followed to select CC indicators in this case followed a trophic-based hierarchy, as follows: SST (but also through the water column to the bottom), salinity, dissolved O_2, CO_2, inorganic nutrients, phytoplankton – cl.a or (more expensive) species composition and abundance, zooplankton, etc. In this hierarchy, other parameters could be more difficult to applied with the present technology (e.g. pH and alkalinity).

The experiences gather from these monitoring stresses the importance of integrating meteorological information (air temperature, winds, precipitation, atmospheric pressure, etc.) with oceanographic variables. At last, a proposal would be to distinguish between a basic set of variables common to all MPAs, and the possibilities for each place to develop locally particular indicators. Regarding oceanographic parameters, the monitoring system could start with the basic variables (O_2, nutrients, cl-a), and widen the variables as possible (depending on funds and human resources), including e.g. pH and alkalinity measures, phyto- and zooplankton, etc. Automatic measuring systems (cheaper and less person-demanding), such as oceanographic buoys, could be used as alternative to reduce costs and efforts on this monitoring.

Internationally coordinated oceanographic monitoring initiatives could be put in place, using as mirror the meteorological monitoring system, which is coordinated worldwide for a long time. Independently of CC effects, the interest to extend MPA monitoring in the long-term becomes evident, to set up baselines and reference points in order to estimate the actual magnitude of the effects of other anthropogenic risks.

RAC/SPA present initiative is in line with past efforts devoted to evaluate the direct and indirect threats due to CC on marine and coastal biodiversity[1], and in the framework of other programs promoted by RAC/SPA. Special emphasis was put on the project aiming at providing support to the Barcelona Convention for the implementation of the Ecosystem Approach (ECAP), including the establishment of MPAs in open seas areas, including deep sea[2]. In this context, MPAs, as a concrete realization of the ECAP (both from the conceptual and practical point of view), are ideal sites to promote the long-term monitoring of a set of CC indicators.

Tasks performed to date to develop a preliminary list of CC indicators for MPAs by RAC/SPA, has been first, to make a deep review of the scientific literature, in order to build a wide list of all indicators potentially useful to measure causes and consequences of CC on marine biodiversity. From this list, and starting from the preliminary list of categories and indicators to track CC impacts across the MPA network as pre-selected in the Malta experts meeting, and using an informal set of criteria, an extended list was prepared for discussion in the Malaga experts meeting (see below). In parallel, a reflection document was produced on the expected features of CC indicators in MPAs and the desirable criteria to be met in order to prioritise indicators.

[1] http://www.rac-spa.org/climate_change

[2] http://www.rac-spa.org/ecap

VI.2 Prioritizing of a pre-selected list of CC indicators: a proposal

Works of the Malaga meeting included agreeing on a set of explicit criteria to build a "dashboard" table, in order to offer a prioritized list of indicators based on a series of objective criteria. Once this list was elaborated, each indicator was subsequently developed, following a standardised factsheet table.

Following sections of the present document will be devoted to describe the results of such tasks.

Starting from a list of potential indicators (table 1 in Annex I), the participants in this meeting discussed pros and cons, and finally agreed on a pre-selected list of indicators of CC in MPAs (Box 1). This list takes into account the recommendations of the above mentioned Experts Meeting on Climate Change impacts on marine biodiversity in the Mediterranean MPAs, held in Malta, and adds other indicators following the advice of RAC/SPA external consultants and that of the experts present in the meeting in Málaga.

The extended list of pre-selected indicators was built as a result of an informal (implicit) application of a series of criteria, as discussed in the document, such as pertinence, simplicity, calculability, sensitivity, precision, etc.).

The indicators were then assessed, using an expert panel methodology elaborated *ad hoc* to build a formal assessment dashboard, based in part on the proposal of Beliaeff & Pelletier (2011)[3]. This methodology consists on (1) evaluating the indicators based on a set of criteria, (2) scoring each indicators based on each criterion, measured in a semi-quantitative scale (from 1 to 5, representing a scale from low to high performance), and (3) ranking the indicators as a function of their performance (score). The final rank will provide an objective way to prioritise the pre-selected indicators, from more to less degree of competent.

Box 1: List of pre-selected CC indicators in MPAs

SST and thermal stratification
Basic parameters (O_2, salinity, nutrients, cl.a)
Acidification (pH, alkalinity, DIC, pCO_2)
Phytoplankton abundance
Flowering of *Posidonia oceanica*
Seasonality of benthic algae species (*Cystoseira*)
Seasonality of hydrozoans and colonial ascidians species
Reproduction and breeding date of selected species
Phenology of fish early life history stages
Migration date of seasonal species
Mortality and bleaching events
Episodic species outbreaks (blooms)
Range shift of alien / temperature-sensitive species

[3] Beliaeff B, Pelletier D (2011) A general framework for indicator design and use with application to the assessment of coastal water quality and marine protected area management. *Ocean Coast. Manage*. 54: 84-92.

The criteria used in this process were simplified from the ones discussed in sections V.3 and V.4, and were divided into four groups: indicators of relevance (sensitivity, univocity), indicator of effectiveness (precision/accuracy), indicators of feasibility in the context of MPAs (calculability/metrics, methodology, data analysis, cost, relevance for MPA management), and geographical interest (local/sub-regional interest, regional interest). The criteria for the selection set of indicators was the following:

- **Sensitivity:** Sensitivity reflects the indicator's ability to respond to variations in pressure, i.e. to move significantly for fairly small variations in the phenomenon.
- **Univocity[4]:** This refers to the direct relationship of the shifts in the values adopted by the indicator with CC (i.e. its diagnostic significance)
- **Precision / Accuracy:** Precision refers to the dispersion of the metric estimates. This definition holds whether or not the mean value around which the dispersion is measured approximates the "true" value. Precision is to be differentiated from accuracy, which is the property of being close (on average) to some target or true value. The precision of a metric is affected by various sources of variability: measurement errors, temporal variability (e.g., between seasons and across years) and spatial variability at several scales. Both features affect statistical power, which is the probability of detecting a change of a given magnitude (effect size) when it exists, distinguishing it from natural variability ("white noise").
- **Calculability / Metrics:** Metrics refer to the existence of the relevant variables observed or calculated at a given scale to measure the phenomenon. To become a good indicator, the metric should devise unambiguous rules to interpret the values taken by the metric.
- **Methodology:** This feature refers to the existence of the appropriate estimation method (sampling technique, measurement device, etc.) to compute the metric.
- **Data analysis:** It refers to the feasibility of handling databases and analysing the whole dataset at the regional scale.
- **Cost:** Economic cost (of sampling devices, human effort, training initiatives, intercalibration and validation exercises, etc.).
- **Relevance for MPA management:** This criterion refers to the interest of measuring the indicator for assessing expected effects of protection other than CC influences
- **Geographical interest:** It refers to the extent to which the indicator could be both of local/sub-regional interest (i.e. only applicable to a sub-region within the Mediterranean basin), and regional interest (i.e. applicable in the whole Mediterranean).

From this assessment, a ranking of pre-selected indicators was produced (Table 1). The result of such assessment dashboard discussion is presented in Table 2.

[4] Univocity is a 'barbarism' (i.e. non-standard word), derived from the French term 'univocité', and the Spanish 'univocidad', used here as a synonym of the expression 'univocal nature' (or 'unambiguous').

Table 1 Ranking of performance for the indicators to monitor CC in MPAs. In yellow, the top-six indicators to be further prioritised.

Rank order	Indicator type
1	SST and thermal stratification
2	Mortality and bleaching events
3	Range shift of alien / temperature-sensitive species
4	Flowering of *Posidonia oceanica*
5	Reproduction and breeding date of selected species
6	Episodic species outbreaks (blooms)
7	Basic parameters (O_2, salinity, nutrients, cl.a)
8	Seasonality of benthic algae spp (*Cystoseira*)
9	Phenology of fish early life history stages
10	Migration date of seasonal species
11	Acidification (pH, alkalinity, DIC, pCO_2)
12	Phytoplankton abundance
13	Seasonality hydrozoans and colonial ascidians species

Table 2 Result of assessment dashboard for the 13 pre-selected indicators of CC in MPAs

		Relevance		Effectiveness	Feasibility / MPA					Geographical interest		
Nº	Indicator type	Sensitivity	Univocity	Precision / Accuracy	Calcul. / Metrics	Method.	Data analysis	Cost	Relevance for MPA management	MPA	Regional	Final score
1	SST and thermal stratification	5	5	5	5	5	5	4(1)	5	5	5	49
2	Basic parameters (O_2, salinity, nutrients, cl.a) (2)	5	2	5	5	5	5	2(3)	5	5	5	44
3	Acidification (pH, alkalinity, DIC, pCO_2)	5	5	5	5	2	3	3	1	3	5	37
4	Phytoplankton abundance (4)	3	2	2	4	5	1	2	2	3	5	29
5	Flowering of *Posidonia oceanica*	5	5	5	4	5	5	4	4	5	5	47
6	Seasonality of benthic algae spp (Cystoseira)	4	4	5	5	5	4	3	4	4	5	43
7	Seasonality hydrozoans and colonial ascidians species	4	2	1	3	5	1	2	2	2	3	25
8	Reproduction and breeding date of selected species (5)	4	4	5	5	5	5	3	5	5	5	46
9	Phenology of fish early life history stages	4	4	3	5	5	3	3(6)	5	5	5	42
10	Migration date of seasonal species	5	5	5	5	3	3	3	4	4	5	42
11	Mortality and bleaching events	5	5	5	5	5	5	4	5	5	4	48
12	Episodic species outbreaks (blooms)	4	4	5	5	5	5	4	5	5	4	46
13	Range shift of alien / temperature-sensitive species	5	5	5	5	5	5	3	5	5	5	48

1	2	3	4	5
Worse				Best

Notes to the dashboard table:

(1) Cost of temperature measures include the instruments and personal costs (e.g. of going twice a year to recover data loggers)

(2) Only relevant for offshore MPAs

(3) Includes cost of instrumentation (multiparameter sensors) and calibration, as well as validation exercises

(4) Phytoplankton abundance refers to qualitative or quantitative estimation of community structure (species composition, species abundances) of the whole phytoplankton or a part of it (e.g. *Ceratium* group), to be studied by vertical or oblique plankton tows in a bi-monthly basis.

(5) Referring to fishes (groupers, labrids), turtles and seabirds

(6) More costly in terms of training than technical facilities

VII. Conclusions and future works

A pre-selected set of 13 indicators of CC for putting into practice in MPAs has been built (Annex II), from which 6 have been considered of priority interest, so as to advice their implementation to MPA managers and countries. These top indicators are the following:

- SST and thermal stratification
- Mortality and bleaching events
- Range shift of alien / temperature-sensitive species
- Flowering of *Posidonia oceanica* (if present)
- Reproduction and breeding date of selected species
- Episodic species outbreaks (blooms)

Following steps need to include the development of the description set of CC indicators by completing the filling of the corresponding fact-sheets (Annex II). Further analysis could include their potential assessment for some of these variables to be implemented with participatory methods, involving e.g. the use of volunteers. Special emphasis will be done on methodological issues, such as the level of standardization, specialization needs, economic costs, and natural, material and mathematic constraints, etc., as well as their policy relevance at the regional level.

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)
		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)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
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)
		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)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
	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)
		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 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	Mortality and illness	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)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
		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)
		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)

Level of organisation	Category of response	Indicator type	Indicator example	Methodology	Reference
		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)
	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

ANNEX II

Impacts of climate change on marine and coastal ecosystems; ongoing description tables of selected indicators

<table>
<tr><td><u>CODE</u>:</td><td>SST and thermal stratification</td><td><u>Category(ies)</u>: Physical – chemical indicators</td></tr>
<tr><td colspan="3"><u>Definition</u>:

Main temperature indicators: T anomalies, T_{max}, % of time above different temperature thresholds. These indicators can only be obtained from high resolution temperature series.</td></tr>
<tr><td colspan="3"><u>Rationale</u>:

Gaining robust data sets on temperature conditions in the coastal areas is key for the analysis of climate change effects on biodiversity. Temperature series will allow the characterization of thermal regimes (T_{max}, mean temperatures, stratification patterns, etc…), detect temperature anomalies and contribute to the tracking of warming trends in Mediterranean coastal areas.

Currently there is an enormous knowledge gap on temperature regimes in coastal areas, more particularly in the first 50m of the water column where variability in the temperature regimes can have strong effects on the biological communities. In fact, long term sea temperature series (>30 years) have only been collected in a few coastal sites mainly in the North-western Mediterranean over the last 30 years. With the knowledge gathered from the analysis of these series, a clear warming trend in the NW Mediterranean (ca. 0.3º C per decade) is already visible, demonstrating the warming trend at different depths. However, we are still lacking information for the rest of the Mediterranean Sea.

Additionally, high resolution temperature series will also allow evaluation of the role and the impact of temperature conditions on marine communities.

The acquisition and analysis of high resolution temperature series will be crucial to build up the capacity to anticipate climate change impacts in the different Mediterranean MPAs.</td></tr>
<tr><td colspan="3"><u>Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)</u>

In the NW Mediterranean, changes in species distribution and mass mortality events reported during the last decades have been related to the warming trend observed in this region. In particular, large scale mass mortality events (MME) of long-lived benthic species during 1999 and 2003, have been related to the anomalous temperature conditions registered in coastal waters (0-40 m depth). However, in other areas the lack of data sets and information on temperature variability has prevented analysis that may lead to a direct correlation between temperature and impacts onto the marine communities. At present, large scale sea surface temperatures obtained through satellite images and the use of few time-resolved T series allow the characterization of the spatial and inter-annual variability of the coastal water column in only a few Mediterranean sites.

Given actual warming trends and projections in NWM, the repetition of new mass mortality events over the next decades is extremely likely.

In such context, the acquisition of high resolution Temperature series is crucial for increasing our detection, understanding and forecasting abilities of possible impacts. These abilities will be the key to implement appropriate conservation and management plans for the conservation of the rich Mediterranean biodiversity, The acquisition of this high resolution temperature series is especially urgent in MPA since they can provide information on the risk associated to climate change.</td></tr>
<tr><td colspan="3"><u>Methodology and sampling concerns</u>:

Deploy temperature data loggers every 5 m from 5 to 40 m depth at MPA by fixing them to</td></tr>
</table>

<table>
<tr><td colspan="2">the rocky substrate or along the buoy lines/chains. Temperature data loggers should be setup to collect hourly measurements and recovered annually or semi-annually by divers usually before and after the summer period.

Alternatively, other type of temperature sensors currently used by research institutions and other organisations are oceanographic buoys (Stowaway Tidbits, Stowaway Tidbits v2 and HOBO Water Temp Pro v2). These sensors usually take measures of oceanographic, meteorological and water quality data. Specific information from these sensors is the collection of sea surface temperature and temperature profiles. Although there are more expensive, it could be an alternative of source of information if in close proximity to MPAs.</td></tr>
<tr><td><u>Representation</u> (quantitative, graphical, cartographic, GIS):</td><td><u>Geographic relevance</u>:

Mediterranean</td></tr>
<tr><td colspan="2"><u>Target or threshold objectives (if applicable)</u>:</td></tr>
<tr><td colspan="2"><u>Policy relevance</u>:

The acquisition of temperature records will allow assessment of the climate change risks for the different Mediterranean areas. This will permit adoption of management and conservation actions depending of the degree of the risk.</td></tr>
<tr><td colspan="2"><u>Other data sources (existing Mediterranean/National monitoring programs)</u>:

• National observatory services
• http://www.t-mednet.org/</td></tr>
<tr><td colspan="2"><u>Relevant modelling programs</u>:

• ClimCares project
• Tmed-net</td></tr>
<tr><td colspan="2"><u>Possible lead responsible person for collection of data, validation and analysis</u>:

J. Garrabou ()</td></tr>
<tr><td colspan="2"><u>Possible lead responsible person for communication-feedback to managers</u>:

J. Garrabou ()</td></tr>
<tr><td colspan="2"><u>Relevant references</u>:

• T-Mednet web site: www.t-mednet.org
• Bensoussan N, Romano JC, Harmelin JG, Garrabou J (2010) High resolution characterization of northwest Mediterranean coastal waters thermal regimes: to better understand responses of benthic communities to climate change. Estuarine, coastal and Shelf Science 87: 431-441
• Crisci C, Bensoussan N, Romano JC, Garrabou J (2011) Temperature anomalies and mortality events in marine communities: insights on factors behind differential mortality impacts in the NW Mediterranean. PLoS ONE 6(9): e23814. doi:10.1371/journal.pone.0023814</td></tr>
</table>

CODE:	**Basic parameters (O_2, salinity, nutrients, chlorophyll a)**	**Category(ies)**: **Physical – chemical indicators**

Definition:

Long-term, periodic measurement of dissolved oxygen, salinity, inorganic nutrients and chlorophyll a values in the water column.

Rationale:

The effects of rising CO_2 do not act in isolation. Additional regional pressures on ocean ecosystems include intensive use of fertilizers, coastal and benthic habitat degradation, overexploitation of fish stocks, rising aquaculture production, and invasive species. Ecosystem deterioration is intense and increasing, particularly for coastal systems.

Coastal hypoxia, defined as the depletion of dissolved oxygen (DO) to concentrations <2 mg O_2 l^{-1}, has been increasing in frequency, duration, and extent worldwide over the last 5 decades. Increased prevalence of coastal hypoxia is most often the result of increased production of organic matter associated with excessive nutrient input. Low DO results from an interaction between physical and biogeochemical processes. Two basic mechanisms causing coastal hypoxia are (1) eutrophication due to land and river based nutrient input leading to local microbial oxygen consumption, and (2) upwelling of oxygen depleted, nutrient rich water from bathyal oxygen minimum zones where deep microbial oxygen consumption occurs. Projected declines in ocean oxygen levels reflect the combined effects of reduced oxygen solubility from warming and reduced ventilation from stratification and circulation changes. Depending on the physical processes, such as stratification and mixing, this increased organic loading alters the balance between oxygen supply through physical forcing and oxygen consumption from organic matter decomposition. Thus, in the absence of stratification, or in the presence of intense mixing, hypoxia is not generally expected to occur, regardless of organic matter loading rates.

Therefore, routine measurements of basic oceanographic parameters (dissolved O_2, salinity, dissolved inorganic nutrients – nitrate, nitrite, ammonium, phosphate, etc., chlorophyll a) are crucial to link observed changes likely due to CC, to the environmental conditions, in order to distinguish them from other potential sources of disturbance, not necessarily related to CC.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Further expansion of hypoxic zones will depend on how climate change affects water-column stratification and how nutrient runoff affects organic matter. Climate change also has the potential to expand naturally occurring oxygen minimum zones into shallower coastal waters, damaging fisheries and affecting energy flows in the same way that eutrophication-driven hypoxia does production.

Methodology and sampling concerns:	
Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean
Target or threshold objectives (if applicable): The oxygen content of water masses usually is characterized by DO concentration units since these are conservative with respect to the temperature and salinity and can be used for mass balances, mixing calculations, and numerical modelling. This leads to oxygen thresholds also being reported in dissolved oxygen concentration units. However, animals depend on gas exchange across membranes and tissues for critical physiological processes such as respiration and also for controlling gas exchange with the swim bladder of fishes. The appropriate thermodynamic property for this is the gas fugacity which is readily approximated by the spatial pressure. Experimental work on respiration of marine animals must thus essentially report pO_2 as the critical variable. Since the partial pressure of a gas is a function of temperature, pressure and salinity, thresholds reported as concentrations units are not universally applicable but only valid for systems with particular temperature, pressure and salinity. Oxygen thresholds in terms of partial pressure, however, are universally applicable. Table 2 in Hoffman et al. (2011) article proposes commonly used $[O_2]$ thresholds to describe various low oxygen conditions, distilled into three main “hypoxia categories”: A (“Mild hypoxia”, sensitive species show avoidance reactions); B: (“Hypoxia”, ecosystem dominated by species and communities adapted to low oxygen conditions), and C (“Severe hypoxia”, mass mortality for most species is induced and only highly specialized species are able to survive).	
Policy relevance:	
Other data sources (existing Mediterranean/National monitoring programs): •	
Relevant modelling programs: •	
Possible lead responsible person for collection of data, validation and analysis:	
Possible lead responsible person for communication-feedback to managers:	

<u>Relevant references</u>:

- Diaz RJ, Rosenberg R (2008) Spreading dead zones and consequences for marine ecosystems. Science 321: 926-929.
- Hoffmann AF, Peltzer ET, Waltz PM, Brewer PG (2011) Hypoxia by degrees: establishing definitions for a changing ocean. Deep-Sea Res I 58: 1212-1226.
- Sanger DM, Smith EM, Voulgaris G, Koepfler ET, Libes SM, Riekerk GHM, Bergquist DC, Greenfield DI, Wren PA, McCoy CA, Viso RF, Peterson RN, Whitaker JD (2012) Constrained enrichment contributes to hypoxia formation in Long Bay, South Carolina (USA), an open water urbanized coastline. Mar Ecol Prog Ser 461: 15-30.
- Vaquer-Sunyer R, Duarte C (2008) Thresholds of hypoxia for marine biodiversity. Proc Nat Acad Sci 105: 15452–15457.
- Vargas-Yáñez M, García MJ, Salat J, García-Martínez MC, Pascual J, Moya F (2008) Warming trends and decadal variability in the Western Mediterranean shelf. Glob Planet Change 63: 177-184.

<u>CODE</u>:	**Acidification**	<u>Category(ies)</u>: **Physical – chemical indicators**

<u>Definition</u>:

Total dissolved inorganic carbon (DIC; the total amount of dissolved CO_2, bicarbonate, and carbonate ions), total alkalinity (TA; the excess base in seawater), pH, or the partial pressure of CO_2 (pCO_2), measured in seawater with chemistry techniques or/and submersible data loggers.

<u>Rationale</u>:

The surface waters of the oceans are slightly alkaline, with an average pH of about 8.2, although this varies across the oceans by ±0.3 units because of local, regional and seasonal variations. Carbon dioxide plays an important natural role in defining the pH of seawater. When CO_2 dissolves in seawater it forms a weak acid, called carbonic acid. Part of this acidity is neutralised by the buffering effect of seawater, but the overall impact is to increase the acidity (that is, decreasing the pH of the oceans).

The oceans are absorbing carbon dioxide (CO_2) from the atmosphere and this is causing chemical changes by making them more acidic. In the past 200 years the oceans have absorbed approximately half of the CO_2 produced by fossil fuel burning and cement production. Calculations based on measurements of the surface oceans and our knowledge of ocean chemistry indicate that this uptake of CO_2 has led to a reduction of the pH of surface seawater of 0.1 units, equivalent to a 30% increase in the concentration of hydrogen ions.

If global emissions of CO_2 from human activities continue to rise on current trends then the average pH of the oceans could fall by 0.5 units (equivalent to a three fold increase in the concentration of hydrogen ions) by the year 2100. This pH is probably lower than has been experienced for hundreds of millennia and, critically, this rate of change is probably one hundred times greater than at any time over this period.

The scale of the changes may vary regionally, which will affect the magnitude of the biological effects. The Mediterranean Sea has certain characteristics that make it especially sensitive and vulnerable to changes in atmospheric CO_2 and gradual acidification. Recently, a first estimation of seawater acidification in the Mediterranean Sea identified a pH decrease of up to 0.14 units in the western Mediterranean Sea since preindustrial times, which is of higher magnitude than the global surface ocean decrease of ~0.1 pH units over this time period. A recent report has also listed fairly exhaustively the possible repercussions of the acidification of the Mediterranean Sea, although research in this area has just started.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts) The reduction in pH that will accompany elevated CO_2 concentrations has profound implications for physiological processes in marine organisms. In particular, increased solubility of calcium carbonate minerals used as skeleton and shell material by corals and other pelagic and benthic calcifiers generally results in a slowdown of the overall calcification process. Decreased calcification could have negative impacts on marine ecosystems, with consequent effects on local marine fisheries and coastal protection from storms. The abundance of commercially important shellfish species (i.e., clams, oysters, sea urchins) could also decline, which could have serious consequences for marine food resources. A generally unappreciated physical impact of ocean acidification is the reduction of low-frequency sound adsorption because of the pH-dependent decline in dissolved borate ions. Along with sound propagation, light propagation might also be affected. Other expected effects (e.g. change of rates of redox reactions associated with metal oxidation and electolysis, with shipping and naval consequences, particularly as it affects the integrity of ship hulls) need further research.
Methodology and sampling concerns: Seawater chemistry measurements, including total dissolved inorganic carbon (DIC; the total amount of dissolved CO_2, bicarbonate, and carbonate ions), total alkalinity (TA; the excess base in seawater), pH, and the partial pressure of CO_2 (pCO_2), from time-series stations (on a biweekly/monthly basis). Measurements of pH can also be done by using submersible data loggers. The total quantity of dissolved CO_2 and carbonate system species in seawater, or the inorganic carbon system, can be measured directly or calculated from other observed parameters. Any two of the four parameters (DIC, TA, pH, pCO_2) can be derived from two other measured parameters. Other difficult-to-measure parameters, such as the concentration of carbonate ions and the saturation state of calcium carbonate minerals (Ω), can also be derived similarly. When state-of-the-art methods, standards, and tightly controlled laboratory conditions are used, measured DIC, TA, pH, and pCO_2 have uncertainties ranging from ~0.03%~0.2% (depending on parameter). Uncertainties double if analyses are done in less tightly controlled conditions (e.g., at sea). Historically, observational campaigns have usually measured seawater DIC and TA, then calculated pH and pCO_2. Variability of pH and pCO_2 are naturally greater in coastal regions because of respiration, photosynthesis, and runoff.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Research into the impacts of high concentrations of CO_2 in the oceans is in its infancy and needs to be developed rapidly. A major, internationally coordinated effort should be supported to include global monitoring, experimental, mesocosm and field studies. MPAs are ideal sites to perform long-term data on the seawater carbonate chemistry. Special attention has to be paid to whether there is any evidence of a sustained decline in pH over the study period as predicted by scenarios with increasing atmospheric CO_2 concentration.

Other data sources (existing Mediterranean/National monitoring programs):

- The European Project on Ocean Acidification (EPOCA) – http://www.epoca-project.eu
- Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) / Surface Ocean Lower Atmosphere Study (SOLAS) Joint Carbon Working Group – http://www.imber.info/index.php/Science/Working-Groups/SOLAS-IMBER-Carbon
- International Geosphere-Biosphere Programme (IGBP) and the Scientific Committee on Oceanic Research (SCOR) Fast Track Initiative – http://igbp-scor.pages.unibe.ch/
- The Ocean in a High-CO_2 World – The Ocean Acidification Network – http://www.ocean-acidification.net

Relevant modelling programs:

-

Possible lead responsible person for collection of data, validation and analysis:

See CIESM (2008)?

Possible lead responsible person for communication-feedback to managers:

See CIESM (2008)?

Relevant references:

- Byrne RH, Mecking S, Feely RA, Liu X (2010) Direct observations of basin-wide acidification of the North-Pacific Ocean. Geophys Res Lett 37: L02601, doi:10.1029/2009GL040999.
- CIESM (2008) Impacts of acidification on biological, chemical and physical systems in the Mediterranean and Black Seas. Briand F (Ed) CIESM workshop monograph 36. CIESM, Monaco.
- Doney SC, Balch WM, Fabry VJ, Feely RA (2009) Ocean acidification: a critical emerging problem for the ocean sciences. Oceanography 22: 16-25.
- Doney SC, Fabry VJ, Feely RA, Kleypas JA (2009) Ocean acidification: the other CO_2 problem. Annu Rev Mar Sci 2009.1: 169-192.
- Fabry VJ, Seibel BA, Feely RA, Orr JC (2008) Impacts of ocean acidification on marine fauna and ecosystem processes. ICES J Mar Sci 65: 414-432.

- Feely RA, Doney SC, Cooley SR (2009) Ocean acidification: Present conditions and future changes in a high-CO_2 world. Oceanography 22: 36-47.
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- Raven J (Chair) (2005) Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society, London. 60 pp.
- Touratier F, Goyet C (2009) Decadal evolution of anthropogenic CO_2 in the northwestern Mediterranean Sea from the mid-1990s to the mid-2000s. Deep-Sea Res I 56: 1708-1716.
- Wooton JT, Pfister CA, Forester JD (2008) Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. PNAS 105: 18848-18853.

CODE:	**Phytoplankton abundance**	**Category(ies): Individual / phenological – Population – Community – Ecosystem**

Definition:

Fluctuations in primary production, phytoplankton phenology, shifts in the latitudinal and/or bathymetric range of important planktonic primary producers, biomass spectra of phytoplankton

Rationale:

Recent studies have reached the conclusion that global phytoplankton concentration has declined over the past century. As regional phytoplankton trends display both short-term variation and longer-term trends, it is essential to establish long-term phytoplankton abundance series in a variety of sites in order to characterize both long-term dynamics and local specificities.

Besides the trends in the biomass and bulk activities, it is also important to consider whether there are changes in the phenology (cycles and timing) and structure of the phytoplankton communities, as exemplified by the changes observed by Tunin-Ley et al. (2009) in *Ceratium* (planktonic dinoflagellates) species. The decoupling of phenological relationships will have important ramifications for trophic interactions, altering food-web structures and leading to eventual ecosystem-level changes. Temperate marine environments may be particularly vulnerable to these changes because the recruitment success of higher trophic levels is highly dependent on synchronization with pulsed planktonic production.

Therefore, locally intensive in situ series, globally distributed platforms with biogeochemical sensors, and satellite information have been advocated to accurately quantify trends in marine planktonic primary production as well as resolve the mechanisms behind the observed changes.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

The potential effects of climate change on the biomass and productivity of phytoplankton largely depends on the littoral environmental pressure and the existing hydrodynamic regime. In nearshore waters (where most MPAs are located), local perturbations (e.g. eutrophication through coastal discharges, land mobilization and pollution) on geochemical fluxes may have a much greater influence than does climate.

Methodology and sampling concerns:

Phytoplankton surveys with vertical (e.g. 0-40 m) or surface sampling over annual cycles (e.g. bimonthly).

Regulation of phytoplankton biomass by multiple processes operating at multiple time scales adds complexity to the challenge of detecting climate-driven trends in aquatic ecosystems where the noise to signal ratio is high.

<table>
<tr><td><u>Representation</u> (quantitative, graphical, cartographic, GIS):</td><td><u>Geographic relevance</u>:
Mediterranean</td></tr>
<tr><td colspan="2"><u>Target or threshold objectives (if applicable)</u>:</td></tr>
<tr><td colspan="2"><u>Policy relevance</u>:</td></tr>
<tr><td colspan="2"><u>Other data sources (existing Mediterranean/National monitoring programs)</u>:
•</td></tr>
<tr><td colspan="2"><u>Relevant modelling programs</u>:
•</td></tr>
<tr><td colspan="2"><u>Possible lead responsible person for collection of data, validation and analysis</u>:</td></tr>
<tr><td colspan="2"><u>Possible lead responsible person for communication-feedback to managers</u>:</td></tr>
<tr><td colspan="2"><u>Relevant references</u>:
• Boyce DG, Lewis MR, Worm B (2010) Global phytoplankton decline over the past century. Nature 466: 591-596.
• Calvo E, Simó R, Coma R, Ribes M, Pascual J, Sabatés A, Gili JM, Pelejero C (2011) Effects of climate change on Mediterranean marine ecosystems: the case of the Catalan Sea. Clim Res 50: 1-29.
• Chavez FP, Messié M, Pennington JT (2011) Marine primary production in relation to climate variability and change. Annu Rev Mar Sci 2011.3: 227-260.
• Doney SC (2006) Plankton in a warmer world. Nature 444: 695-696.
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• Hays GC, Richardson AJ, Robinson C (2005) Climate change and marine plankton. Trends Ecol Evol 20: 337-344.
• Tunin-Ley A, Ibañez F, Labat JP, Zingone A, Lemée R (2009) Phytoplankton biodiversity and NW Mediterranean Sea warming: changes in the dinoflagellate genus Ceratium in the 20th century. Mar Ecol Prog Ser 375: 85-99.
• Winder M, Cloern JE (2010) The annual cycles of phytoplankton biomass. Phil Trans R Soc B 365: 3215-3226.</td></tr>
</table>

CODE:	**Flowering of *Posidonia oceanica***	**Category(ies): Individual / phenological**

Definition:

Flowering citations (reports of flowering events) and flowering intensity (FI, fractions of flowering shoots) of a given meadows, annual flowering prevalence (FP, flowering records per total records), annual average FI (estimated from the average of positive FI reports across the Mediterranean for a given year)

Rationale:

The results of Díaz-Almela et al. (2007) demonstrated a significant, positive relationship between the prevalence and intensity of flowering of *P. oceanica* meadows (thus the flowering probability for any one shoot) and the annual maximum sea-surface temperature, applicable across the entire Mediterranean, as well as the individual basins. This provides evidence for an effect of summer maximal seawater temperatures on flowering in *P. oceanica* meadows.

Hence, systematic records of *P. oceanica* flowering may provide a footprint of climate change in the Mediterranean Sea, as well as evidence of the effects of global warming and or of temperature anomalies on the life history and ecosystems therein. Whereas *P. oceanica* flowering is difficult to observe, compared to that of terrestrial plants, the growing effort to monitor these fragile ecosystems is enhancing the empirical basis to assess flowering events and, therefore, also providing an alert to the consequences of the climate change on Mediterranean coastal ecosystems.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Temperature affects seagrass at multiple levels, from physiological to life, often in opposite directions, thereby precluding predictions on the effects of global warming and temperature anomalies on seagrass meadows. Within seagrasses, there is some evidence that high seawater temperatures could constitute a source of stress for the plants either directly (physiological disruption) or through external mechanisms, such as increasing anoxia in the sediment. The observed increase in Mediterranean seawater temperatures coincides with widespread decline of *P. oceanica* meadows in the area, affecting even meadows with no evident anthropogenic impacts. Although the mechanisms responsible for an increased flowering subsequent to warming events, increased induction or increased development, remain unknown, the shoot decline associated with high temperature suggests that flowering in this clonal species could represent a response to heat stress. Flowering may be more responsive to seawater temperature anomalies than to the warming trend. However, these two effects may compound as the absolute SST reached in warm years is increasing over time, as a similar anomaly occurs over a shifting baseline. If flowering in *P. oceanica* was a stress response to high temperature, it could be expected that the absolute warming trend added to positive thermal anomalies could induce increased widespread and intense meadow flowering of this temperate species, and thus, less intense thermal anomalies would be needed to produce widespread flowerings. *P. oceanica* meadows appear to amplify the temperature footprint of global warming, as a difference of 1–2 ºC seems to induce widespread flowering throughout the Mediterranean coasts. Moreover, the prevalence and intensity of flowering increases with the amplitude of the anomaly, providing evidence of global sea climate change at a much longer scale than that possibly encompassed by the sparse or short seawater temperature time series in the Mediterranean.

Methodology and sampling concerns:

Meadow FI data is to be estimated directly in the field as percentages of flowering shoots or inflorescences densities. When records consist on inflorescence densities, FI values must be estimated dividing them by mean shoot densities.

Past flowerings of a *P. oceanica* shoot can be detected because of the base of inflorescences stalks that remain attached to the shoots decades after flowering. Annual cycles of rhizome vertical growth, which can be detected by measuring the leaf sheaths thickness or the rhizome internodal, allow the past flowerings to be dated and their time series reconstructed.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

-

Relevant modelling programs:

-

Possible lead responsible person for collection of data, validation and analysis:

Possible lead responsible person for communication-feedback to managers:

Relevant references:

- Balestri E (2004) Flowering of the seagrass *Posidonia oceanica* in a north-western Mediterranean coastal area: temporal and spatial variations. Mar Biol 145: 61-68.
- Díaz-Almela E, Marbà N, Álvarez E, Balestri E, Ruiz-Fernández JM, Duarte CM (2006) Patterns of seagrass (*Posidonia oceanica*) flowering in the Western Mediterranean. Mar

Biol 148: 723-742.

- Díaz-Almela E, Marbà N, Duarte CM (2007) Consequences of Mediterranean warming events in seagrass (*Posidonia oceanica*) flowering records. Glob Change Biol 13: 224-235.
- Peirano A, Cocito S, Banfi V, Cupido R, Damasso V, Farina G, Lombardi C, Mauro R, Morri C, Roncarolo I, Saldaña S, Savini D, Sgorbini S, Silvestri C, Stoppelli N, Torricelli L, Bianchi CN (2011) Phenology of the Mediterranean seagrass *Posidonia oceanica* (L.) Delile: Medium and long-term cycles and climate inferences. Aquat Bot 94: 77-92.
- Sghaier YR, Zakhama-Sraieb RYM, Charfi-Cheikhrouha F (in press) Patterns of shallow seagrass (*Posidonia oceanica*) growth and flowering along the Tunisian coast. Aquat Bot.

CODE:	**Seasonality of benthic algae species (*Cystoseira*)**	**Category(ies): Individual / phenological – Population**

Definition:

Seasonal dynamics of *Cystoseira* species abundances expressed as coverage in cm^2 and as biomass in g dwt

Rationale:

Algae in the order Fucales are the main engineering species in sublittoral rocky bottoms of the Mediterranean Sea. They are very important primary producers in coastal areas where they dominate structurally complex and diverse assemblages. Moreover, assemblages dominated by Fucales serve as nursery habitats for some littoral fishes. The genus *Cystoseira* is present in the northern Atlantic Ocean and in the Mediterranean Sea, and it is especially diverse in the Mediterranean (ca. 50 species). Different species occupy different habitats depending on depth, degree of exposure to wave action, and other environmental factors. Most of the species of the genus *Cystoseira* are very sensitive to pollution and to other anthropogenic pressures, and they have decreased considerably during the last decades in many areas of the Mediterranean. Local anthropogenic stressors such as direct degradation or destruction of habitat, eutrophication, sedimentation, and overfishing, as well as episodic disturbances from outbreaks of urchins, storms, disease and direct harvesting are often evident as proximate triggers of these declines. The seasonal dynamics and annual production of *Cystoseira*-dominated assemblages have been found to show marked seasonality in the abundance of the dominant species and overall species composition, with the maximum biomass in late spring and the maximum species richness in autumn.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Light intensity and temperature are usually the most important factors determining the seasonal patterns of growth and primary production of seaweeds. Seawater warming could cause shifts (earlier dynamics) in biomass seasonality of *Cystoseira* species.

Methodology and sampling concerns:

Long-term monitoring of a set of localities at different depths where *Cystoseira* spp. are present, in which replicate 400-cm^2 photoquadrats are randomly taken along transects, with a bimonthly periodicity, and algal cover estimated using image-analysis techniques. Biomass can be calculated after the appropriate calibration exercises.

Important variations in local factors, like exposure degree, morphology of the coast and nutrient concentration, may influence temporal patterns in seaweed biomass. Therefore, sampling designs have to be carefully built in order to distinguish seasonal shifts from ‘natural’ variability (i.e. those variations likely due to other sources).

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean
Target or threshold objectives (if applicable):	
Policy relevance:	
Other data sources (existing Mediterranean/National monitoring programs): •	
Relevant modelling programs: •	
Possible lead responsible person for collection of data, validation and analysis:	
Possible lead responsible person for communication-feedback to managers:	

Relevant references:

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<u>CODE</u>:	**Seasonality of hydrozoans and colonial ascidians species**	**<u>Category(ies)</u>: Individual / phenological – Population**

<u>Definition</u>:

Spatial, depth and temporal long-term variations in community structure (species composition and relative abundance) of seasonal suspension-feeder species (hydrozoans and colonial ascidians), studied in situ using direct collection or/and digital-photography techniques.

<u>Rationale</u>:

Summer is an unfavourable season for most benthic suspension-feeder species in the Mediterranean, due to water stratification, particle sinking and depletion of suspended material. The coupling of food shortage and the occurrence of high temperatures have been proposed to be the cause of the observed summer dormancy (aestivation) of most Mediterranean benthic suspension feeders. For some groups (anthozoans, sponges, colonial ascidians as *Pseudodistoma crucigaster*) the period of aestivation is rather a resting stage, which is characterized by a decrease in investment in secondary production and in feeding activity, but not in abundance. Other groups (hydrozoans, other clonal and colonial ascidians such as *Clavelina dellavallei*) undergo a decrease in abundance or disappear entirely in summer (for instance, hydroid polips can become encysted as resting hydrorhizae under adverse conditions). Therefore, great differences in suspension-feeder species composition and spatial distribution (in depth) can be found at a given place according to the season, and, consequently, the temporal (seasonal) dynamics of the community structure of this benthic fraction can be used as a proxy for detecting changes in temperature regimes throughout the year.

<u>Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)</u>

Temporal variations of Mediterranean benthic assemblages are principally linked to seasonality, which in turn implies variations in temperature, light, water stratification and food availability. Seawater warming could be favouring warm-water species and disfavouring cold-water species, and thus causing profound changes in the species composition and abundance of benthic species showing a marked seasonal trend.

<u>Methodology and sampling concerns</u>:

Monthly samplings along transects (perpendicular to the coastline) using SCUBA, collecting or photographing the selected taxa – e.g. hydroids, to determine assemblage structure (species richness and diversity, composition, relative abundance, etc.).

Factors affecting spatial variability of benthic assemblages inhabiting both photophilous and coralligenous rocky bottoms in the Mediterranean are diverse, including type of substratum, depth (which in turn hedges a complex combination of changes in light quality and intensity, and water motion due to currents, waves and tides), topographic or threedimensional complexity of the habitat (including orientation, slope and rugosity), and local variations in sedimentation rate and nutrients input, as well as biological factors –e.g. local variations in primary productivity, colonisation and recruitment intensity (which in turn depend greatly on local hydrography), and the occurrence of density-dependent biotic interactions such as competition, predation or grazing intensity. All these factors determine a mosaic of patches resulting in a high variability in species composition and benthic assemblage structure at a variety of spatial scales. This makes difficult the task of ascertaining the effect of anthropogenic impacts, as we have to distinguish between this effect from the natural variability of marine benthic communities in space and time. Therefore, appropriate sampling designs are to be implemented, involving proper replication in time and space.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

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Relevant modelling programs:

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Possible lead responsible person for collection of data, validation and analysis:

Possible lead responsible person for communication-feedback to managers:

Relevant references:

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CODE:	**Reproduction and breeding date of selected species**	**Category(ies): Individual / phenological – Population**

Definition:

Determination of reproductive seasonality of selected marine species, e.g.: fishes (groupers, labrids), turtles and seabirds

Rationale:

In recent years, numerous studies focus on the potential effects of global warming upon biological organisms and processes. As a result, a link between global warming and changes in life cycles, physiology and behaviour for a variety of organisms has been established. Phenology, defined as the timing of seasonal activities, has been suggested as an indicator of ecosystem responses to global climate change.

Physiological performance is the principal determinant of a species' tolerance to environmental variability and change. As climate or other conditions shift, organisms initially respond based on physiological and behavioural adaptations molded through their evolutionary history. New conditions may be physiologically tolerable, allowing acclimatization (an adjustment of physiology within individuals) or adaptation (increased abundance and reproduction of tolerant genotypes over generations), or may be intolerable, promoting migration (by individuals or populations), change in phenology (timing of annual events), or death and local extinction if adaptation is not possible.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

As temperature affects gonadal development of species, seawater warming would result in spawning times occurring earlier than normal conditions.

Methodology and sampling concerns:

Fishes (groupers): Monitoring of reproductive activity of groupers using SCUBA diving and videotape recording throughout the year: number of courtships, number of false rises, and number of spawns.

Fishes (labrids): *Symphodus* spp: dates of nesting (in their successive phases: nest-building, sexual activity, fanning) by visual censuses using SCUBA; *Thalassoma pavo*: dates of spawning.

[In both cases, for captured specimens, gonad and biology analyses: age (otoliths), TL (mm), weight (total, somatic, gonad, liver) (mg), histological determinations of gonad maturity stage].

Turtles: Dates of egg laying, total number of clutches, number of clutches per female, number of eggs per clutch, hatching success (percentage of eggs that hatched), hatchling emergence success (percentage of eggs that actually hatched and produced viable hatchlings that exit the nest), hatchling mortality in nest, total number of hatchlings produced, total number of emergences, adult nesting success (proportion of emergences resulting in nest construction)(all corrected by females' size).

Seabirds: Dates of arrival and the start of breeding (nesting), hatching and fledging, hatching and nestling success.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

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Relevant modelling programs:

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Possible lead responsible person for collection of data, validation and analysis:

Groupers: Bernat Hereu (UB), Olga Reñones (IEO-COB)

Labrids: Nuria Raventós (CEAB)

Seabirds: Josep Arcos (SEO-Birdlife), D. Oró?

Turtles: ??

Possible lead responsible person for communication-feedback to managers:

Relevant references:

- Both C, Visser ME (2001) Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. Nature 411: 296-298.
- Broderick AC, Glen F, Godley BJ, Hays GC (2003) Variation in reproductive output of marine turtles. J Exp Mar Biol Ecol 288: 95-109.
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CODE:	**Phenology of fish early life history stages**	**Category(ies)**: **Individual / phenological – Population**

Definition:

Temporal (annual and inter-annual) variation in intensity of reef fish larval supply, settlement and recruitment (including the occurrence of warm-water or alien species not recorded as adults)

Rationale:

Temporal variation in reef fish larval supply, settlement and recruitment follows a clear seasonal pattern in the Mediterranean: higher abundances and species richness of post-larvae and settlers occur during late spring and summer; for its part, recruitment period is generally concentrated in late summer/early autumn. Thus, changes in seawater temperature can have as a consequence local variations in the date of first appearance, as well as the duration of settlement and recruitment events, of particular fish species. Especially, post-larvae or/and juveniles of warm-water, or even alien reef fish species, not previously seen as adults, can be observed.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Fishes are particularly sensitive to temperature during their early life history. Across a wide range of fish species, embryonic development rate increases nearly threefold for every 10 ºC increase in temperature. After hatching, increased temperature tends to increase larval growth rate, decrease the age at metamorphosis and increase swimming ability. Small increases in water temperature will generally hasten the developmental rate of larval reef fishes and decrease their larval duration, provided that ambient temperatures do not exceed optimum levels for growth and development, and the larvae can consume sufficient additional food to support the increased energetic demand of developing at a higher temperature. Although increased temperature may accelerate growth and development, it may also increase mortality rates. In consequence, even relatively small increase in temperature could have a negative effect on the total number of larvae reaching settlement. More generally, an increased risk of starvation is expected where food supply is patchy or unpredictable, highly variable and unpredictable – some locations may tend to have better recruitment and others poorer recruitment. On the other hand, reproduction of reef fishes appears to be highly sensitive to temperature fluctuations. Increased temperature could have either a positive or negative effect on reproductive output, depending on whether or not populations are currently close to their thermal optimum for reproduction. In any case, a mismatch between timing of reproduction and optimum conditions for larvae could develop.

Methodology and sampling concerns: Reef fish larvae can be sampled using plankton nets in the vicinity of MPAs. Post-larvae are to be sampled with light-traps deployed in coastal waters within MPAs. For their part, settlers and recruits can be sampled using UVC technique with snorkelling and/or SCUBA. In both cases, several sites within the MPA should be routinely monitored in a monthly basis in the long-term. A huge spatial and temporal variability in larval dispersal, post-larval supply, settlement and recruitment has been reported. Physical factors such as winds, currents, temperature, rainfall, river discharge, among others, have all been addressed as possible stimuli for dispersal and larval survival Other oceanographic events such as fronts, eddies, and topographic features had also been identified as important influences to larval supply. Post-settlement events (competition and predation), modulated by spatial variations in reef habitat structure at multiple scales, are responsible for the huge spatial and temporal variability of these processes. Therefore, appropriate sampling programs, including proper replication in space and time, is essential to try to distinguish between temporal patterns likely influenced by temperature shifts, and the effects of other environmental factors.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):
Policy relevance:
Other data sources (existing Mediterranean/National monitoring programs): • MedPLaNet network () • Sublimo Life Project (http://www.aquatt.ie/client/files/Newsletter_SUBLIMO_1_EN.pdf)
Relevant modelling programs: •
Possible lead responsible person for collection of data, validation and analysis:
Possible lead responsible person for communication-feedback to managers:
Relevant references: • Félix-Hackradt F et al. (in prep.) Environmental determinants of temporal variation in fish

post-larval assemblage in coastal areas of South-Western Mediterranean Sea.

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- Félix-Hackradt F et al. (in prep.) Effect of marine protected areas on distinct fish life history stages: a case study in a marine reserve network in the South-Western Mediterranean Sea.
- García-Rubies A, Mcpherson E (1995) Substrate use and temporal pattern of recruitment in juvenile fishes of the Mediterranean littoral. Mar Biol 124: 35-42.
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CODE:	Migration date of seasonal species	Category(ies): Individual / phenological – Population

Definition:

Date of first appearance of mature individuals of migratory species in their spawning areas, identification of new (or expansion of) spawning areas, first occurrence of juvenile individuals of southern estuarine species within northern estuaries and coastal lagoons used as nursery grounds.

Rationale:

Migration is a behavioural adaptation to seasonal environments; individuals can successfully exploit temporarily abundant resources, but can escape harsh physical conditions prevalent at other times. Typically, movements are between breeding areas (where resources are plentiful and where most reproduction occurs) and non-breeding areas, to which individuals move when conditions on the breeding grounds become inclement, or resource availability is reduced.

It is often assumed that the timing of annual migrations of marine fish to spawning grounds occurs with very little change over time. Fish migration phenology appears to be driven to a large extent by short-term, climate-induced changes in the thermal resources of their overwintering habitat. This suggests climate fluctuations and trends may have significant effects on the timing of the peak abundance of fish populations.

Pelagic species experience spawning migrations. For example, Atlantic-Mediterranean bluefin tuna spawning takes place in warm waters (greater than 24°C) of specific and restricted locations; besides the historically known Mediterranean spawning grounds in the waters around the Balearic Islands in the west, and the central waters around Malta and Aeolian Islands, the presence of a spawning area in the eastern Mediterranean, i.e., Levantine Sea, has only recently been demonstrated. Other spawning grounds, such as the Ibero-Morrocan embayment and the Black Sea, have also been mentioned in the past. Authors showed that very rapid gonadal maturity occurs between the time the migrating fish are caught in the Strait of Gibraltar and the fish spawn in the Balearic area a few weeks later, possibly influenced by increasing water temperature. Spawning appears to occur in the Levantine Sea in May, in the central Mediterranean in mid-June to early July, and in the western Mediterranean in late June-July, also depending on the sea surface temperature at the specific spawning ground.

Yet, many marine fish species are known to use coastal and estuarine habitats as nursery grounds until maturity. The effect of global warming on such marine migrant fish species can therefore be more readily observed by studying juveniles inhabiting estuarine waters, and, more specifically, using the immigration of southern rather than of northern species has been suggested as an indicator of the biological effects of warming, since it is easier to observe the occurrence of new species than demonstrate their disappearance.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change

impacts)

Temperature, along with other variables, causes active movement of mobile species to areas encompassing the preferred range of environmental variables, influencing migration patterns.

Methodology and sampling concerns:

The location of spawning sites of pelagic species (e.g. tuna) can determined by either noting the location of fish caught from commercial fisheries with the appropriate gonadal condition, by noting the distribution of juveniles by aerial surveys, by ichthyoplankton surveys for larvae, or by using tracking devices on juvenile and adult individuals, such as miniature pop-up satellite archival tags (PSAT) and implanted archival tags (IAT).

Regarding estuarine/lagoonal species, juveniles can be sampled in nursery habitats by visual censuses or catch devices (such as beach seine)

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

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Relevant modelling programs:

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Possible lead responsible person for collection of data, validation and analysis:

Pelagic fish species:

Fishes in coastal lagoons:

Possible lead responsible person for communication-feedback to managers:

Relevant references:

- Alemany F, Quintanilla L, Vélez-Belchí P, García A, Cortés D, Rodríguez JM, Fernández de Puelles ML, González-Pola C, López-Jurado JL (2010) Characterization of the spawning habitat of Atlantic bluefin tuna and related species in the Balearic Sea (western Mediterranean). Progr Oceanogr 86: 21-38.
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- Sims DW, Wearmouth VJ, Genner MJ, Southward AJ, Hawkins SJ (2005) Low-temperature-driven early spawning migration of a temperate marine fish. J Anim Ecol 73: 333-341.
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CODE:	**Mortality and bleaching events**	**Category(ies): Population**

Definition:

Occurrence and relative importance of partial and total mortality in rocky reef benthic species (sponges, cnidarians, etc.).

Rationale:

In recent years, the coralligenous community, one of the most diverse in the Mediterranean Sea, where suspension feeders are dominant, has been strongly affected by several mass mortality events. Lejeusne et al. (2010) report the occurrence of bleaching and mortality in 38 Mediterranean species (13 sponges, 10 cnidarians, 5 bryozoans, 6 molluscs, 1 sea-urchin and 3 ascidians). Engineer species, including gorgonians and sponges, have been the most affected taxa down to depths of 45 m. The causes of mass mortality events in the Mediterranean remain unknown, and our ability to predict the effects of these events depends on characterizing them and elucidating trends exhibited by potentially causative factors.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Current hypotheses about the causes of these events in the Mediterranean focus on their relationship with the occurrence of distinctive climatic anomalies in late summer and early fall. The occurrence of such climatic anomalies in late summer implies prolonged exposure of organisms dwelling above the thermocline to summer conditions (high temperatures and low food availability).

Methodology and sampling concerns:

Qualitative surveys: in each locality, lists of species showing clear-cut signs of recent necrosis, such as denuded skeletons in gorgonians, sponges, and scleractinian corals and empty valves attached to the substratum in bivalves.

Quantitative surveys:

Sponges: counting the total number of specimens and those suffering partial or total mortality.

Scleractinian corals: Photographic monitoring of a sufficient number of colonies.

Gorgonians: random (or permanent, depending on the purpose) quadrats to monitor total density, total mortality, partial mortality, contribution of each of type of injury to total injury, and colony size (height).

In all cases, photographic methods are also possible (see, e.g., Kipson et al. 2011 and Teixidó et al. 2011).

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

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Relevant modelling programs:

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Possible lead responsible person for collection of data, validation and analysis:

E. Ballesteros, R. Coma, C. Linares, J. Garrabou, C. Cerrano?

Possible lead responsible person for communication-feedback to managers:

E. Ballesteros, R. Coma, C. Linares, J. Garrabou, C. Cerrano?

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CODE:	**Episodic species outbreaks (blooms)**	**Category(ies): Population**

Definition:

Occurrence, magnitude and relative importance of species outbreaks (jellyfish blooms, mucilage events, harmful algal blooms)

Rationale:

Populations of gelatinous zooplankton, such as medusae, ctenophores, siphonophores, salps and appendicularians, vary much in abundance over an annual cycle in a more or less predictable manner, and tend to peak following the regular sequence of the phytoplankton spring pulse. In some years the expected plankton peak vastly exceeds the usual level and such unusual occasions are known as blooms. The term is also applied to sudden outbreaks of a particular species which comes to dominate the plankton for a period, and then resumes its normal seasonal abundance. Some blooms appear to be long-term increases in native jellyfish populations. A different phenomenon is demonstrated by jellyfish whose populations regularly fluctuate, apparently with climate, causing periodic blooms. Perhaps the most damaging type of jellyfish increase in recent decades has been caused by populations of new, non-indigenous species gradually building-up to 'bloom' levels in some regions (e.g. *Rhopilema nomadica* and other scyphomedusae, the ctenophore *Mnemiopsis leidyi* or the cubemedusa *Carybdea marsupialis*).

For its part, water column stratification under summer conditions favours the progressive coalescence of small-sized aggregates into large massive sheets, thin layers, flocs and clouds, which are collectively known as marine mucilage. Mucilage is a gelatinous evolving stage of marine snow, which can reach huge dimensions and cover areas of hundreds of kilometres of coastline. Mucilage is made of exopolymeric compounds with highly colloidal properties that are released by marine organisms through different processes, including phytoplankton exudation of photosyntetically-derived carbohydrates produced under stressful conditions, and through death and decomposition of cell-wall debris. Marine mucilage floating on the surface or in the water column can display a long life span (up to 2–3 months) and once settled on the sea bottom, these large aggregates coat the sediments, extending in certain cases for kms and causing hypoxic and/or anoxic conditions. Within this mucilage, filamentous algae can be found, such as the Pheophyceae (Ectocarpales) *Acinetospora crinita* and *Zosterocarpus oedogonium*, and the Chrysophyceae *Nematochrysopsis marina*. The mucilage can act as a controlling factor of microbial diversity across wide oceanic regions and could have the potential to act as a carrier of specific microorganisms, thereby increasing the spread of pathogenic bacteria. The number of mucilage outbreaks increased in the Mediterranean Sea almost exponentially in the last 20 years. The increasing frequency of mucilage outbreaks is closely associated with the temperature anomalies. The spreading of mucilage in the Mediterranean Sea is linked to climate-driven sea surface warming.

Finally, large accumulations of phytoplankton, macroalgae and, occasionally, colorless heterotrophic protists are increasingly reported throughout the coastal areas of all continents. Aggregations of these organisms can discolour the water giving rise to red, mahogany, brown or green tides, can float on the surface in scum, cover beaches with biomass or exudates (foam), and deplete oxygen levels through excessive respiration or decomposition. Alternatively, certain species in harmful algal blooms (HABs) can exert their effects through the synthesis of compounds (e.g., toxins) that can alter cellular process of other organisms from plankton to humans. The global increase in HABs has also included the Mediterranean, where numerous dinoflagellate blooms, especially involving the *Alexandrium* genus (have been reported). Recently, episodic toxic and non-toxic blooms forming marine aerosols generated by benthic–epiphytic dinoflagellates belonging to *Ostreopsis* spp. have been observed.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Over recent decades, man's expanding influence on the oceans has begun to cause real change and there is reason to think that in some regions, new blooms of jellyfish are occurring in response to some of the cumulative effects of these impacts. The issue is not simple and in most cases there are few data to support our perceptions. On the other hand, the increasing frequency of mucilage outbreaks is closely associated with the temperature anomalies, and it has been showed that the spreading of mucilage in the Mediterranean Sea is linked to climate-driven sea surface warming. For its part, it is generally accepted that increased frequency, intensity, and duration of HABs may be due to changes in climate. However, relatively little work has been done to characterize this link, and it is poorly understood.

Methodology and sampling concerns:

Qualitative surveys: Noting the occurrence, timing and size of jellyfish, mucilage or algal blooms.

Quantitative surveys:

Jellyfish blooms: Adult jellyfish densities offshore can be estimated periodically by combining simultaneously visual census performed from a boat and obliquely-towed zooplankton nets. Blooms affecting the beaches can be surveyed by in-land inspectors in fixed stations along the coast.

Mucilaginous events: Samples of seawater and mucilage from coastal waters by means of sterilized Niskin bottles and by 100 mL syringes operated by SCUBA divers, respectively; to characterise algal species living within the mucilage, use plastic bags to collect the mucilage present within a known surface (e.g. with the help of a metallic frame), paying particular attention to preserve the original interstitial water within the aggregates.

HABs: A reliable and rapid detection of HAB species along the coastal areas and in shellfish farms is an important component of any monitoring programme. Current methods (based on sea water samples for the investigation of phytoplankton taxonomic structure, numerical abundance and biomass) depend on microscopy, and toxin and pigment analyses, which are time-consuming and require considerable expertise and skill. Recently, Penna et al. (2007) developed a qualitative and semi-quantitative PCR-based assay for the detection of several potentially HAB species and genera belonging to Dinophyceae, Bacillariophyceae

and Raphydophyceae.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

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Relevant modelling programs:

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Possible lead responsible person for collection of data, validation and analysis:

Possible lead responsible person for communication-feedback to managers:

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CODE:	**Range shift of temperature-sensitive / alien species**	**Category(ies): Population / Communities**

Definition:

Reporting of first occurrence or/and changes in abundance/cover (in the case of benthic organisms) of warm-affinity / alien species, changes in abundance and/or distribution of cold-water species (species identity will depend on the geographic area).

Rationale:

Marine ecosystems have responded to seawater warming with changes in abundance and shifts in geographic ranges of plankton, fish and benthic species. Climate change is predicted to drive thermophilic species ranges toward the poles, potentially resulting in widespread extinctions where dispersal capabilities are limited or suitable habitat is unavailable. Less information is presently available about the responses of the cold-adapted (i.e. cool-water) component of the Mediterranean Sea and concern has been raised about the fate of these species, indeed vulnerable to regional warming and potentially further threatened by the increasing relative dominance of warm-adapted ecological antagonists.

On the other hand, the present Mediterranean biota contains an exceptionally large number of alien (or non-indigenous) species, resulting from a long history of introductions and presence of exceptional pathways of introduction. A total of 955 alien species is known in the Mediterranean, the vast majority of them having being introduced in the Eastern Mediterranean Sea (718), less in the Western Mediterranean Sea (328) and Central Mediterranean Sea (267) and least in the Adriatic (171). Of these, 535 species (56%) are established in at least one area. All are littoral and sublittoral and most are benthic or demersal species (or their parasites). Species that are classified as invasive or potentially invasive are 134 in the whole of the Mediterranean. Since the shallow coastal zone, and especially the benthos, has been extensively studied, and is more accessible, the chances that new arrivals will be encountered and identified are higher. Also, the species most likely to be introduced by the predominant means of introduction (Suez Canal, vessels, mariculture) are shallow water species.

Sensitivity to climate change and other factors (essential information from scientists explaining why the indicator is relevant and important in assessing climate change impacts)

Climate change may boost the range shift of both warm- and cool-water species, as well as enhance the ability of certain alien species to invade new regions, while simultaneously eroding the resistance to invasion of native communities by disturbing the dynamic equilibrium maintaining them.

Methodology and sampling concerns:

- Routine surveys (by snorkelling and/or SCUBA) of benthic/fish species, looking for new occurrences of thermophilic / alien species
- Quantitative monitoring of the abundance of selected thermophilic species (e.g. of fishes: *Pseudocaranx dentex, Acanthurus monroviae, Serranus atricauda, Sparisoma cretense, Thalassoma pavo, Epinephelus marginatus, Sphyraena viridensis*) and alien species (e.g.

of well established, potentially noxious species: *Caulerpa racemosa, Lophocladia lallemandii, Percnon gibbesi, Oculina patagonica, Microcosmus exasperatus, Lagocephalus sceleratus, Siganus rivulatus*)

- Colder / warmer affinity ratio; e.g. LD index – i.e. ln density ratio of both groups; for instance, Milazzo et al. (submitted) has applied this index successfully to assess the spatio-temporal patterns of geographical and vertical distribution of *T. pavo* and *C. julis* across the whole Mediterranean region.
- Estimation of temporal dynamics and emergent changes in the abundance of selected species, based on semi-structured interviews with fishermen and other users of marine resources within and around MPAs (e.g. Azurro et al. 2011). Considering the subjectivity of fishermen's knowledge, simple designs should be used, in which the variability between the different interviews is taken into account and tested against the main hypotheses.

Representation (quantitative, graphical, cartographic, GIS):	**Geographic relevance:** Mediterranean

Target or threshold objectives (if applicable):

Policy relevance:

Other data sources (existing Mediterranean/National monitoring programs):

- International basin-wide monitoring program "CIESM Tropical Signals" http://www.ciesm.org/marine/programs/tropicalization.htm

Relevant modelling programs:

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Possible lead responsible person for collection of data, validation and analysis:

Possible lead responsible person for communication-feedback to managers:

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