

Contact

Francesca Santoro, Julian Barbieri
E-mail: f.santoro@unesco.org,
j.barbieri@unesco.org
Phone: +33 1 45683952

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INDICATORS FOR INTEGRATED COASTAL ZONE MANAGEMENT (ICZM) : *Methodological Factsheets in support of comparable measurements and an integrated assessment in coastal zones*

The **ICZM Protocol for the Mediterranean Sea** (the 'ICZM Protocol'), signed in Madrid on 21 January 2008 and ratified on 24 March 2011, represents a milestone for the implementation of ICZM in the Region and can serve as a blueprint for the implementation of ICZM in other Regional Seas. The **PEGASO project** builds on existing capacities and develops common approaches to support integrated policies for the Mediterranean and Black Sea Basins in ways that are consistent with the ICZM Protocol.

The PEGASO project has developed a **core set of indicators** that are instrumental in measuring the implementation of ICZM policies and programmes. The core set of ICZM indicators addresses the specific requirement of Article 27 of the Protocol to '*define coastal management indicators*' and '*establish and maintain up-to-date assessments of the use and management of coastal zones*'. In doing so, the PEGASO project has widely built on previous and existing indicator sets developed by different institutions and projects, and which are duly acknowledged (see '*Methodological paper for the selection and application of PEGASO ICZM indicators*' for further reading and background material)

The present Methodological Factsheet is part of a set of 15 factsheets that are made available to end-users. This set of factsheets is conceived to support a harmonized approach to calculate ICZM indicators at different spatial scales in the Mediterranean and Black Sea regions.

Name of the Indicator	
Number of hypoxia events and/or extent of hypoxic areas.	
Objective of the indicator	
<p>The Water Framework Directive (2000/60/EC) aims for a good ecological status for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU by 2015. The Marine Strategy Framework Directive (2008/56/EG) in turn aims for the protection and conservation of the marine environment to achieve a good environmental status by 2020 at the latest. Levels of oxygenation are part of the physico-chemical quality elements for the assessment of the ecological and environmental status.</p> <p>Human activities accelerate hypoxia (<2 mg O₂ L⁻¹) development in many areas of the world's coastal areas and oceans by an increase in anthropogenic nutrient loading (fertilizers for crops, burning of fossil fuels, urbanization, waste water generation, ...). Additionally, warming and/or increased precipitation (climate change) both intensify stratification reducing the downward transport of oxygen through the water column causing oxygen depletion at depth. When oxygen levels drop, animals relocate, show reduction in growth and reproduction, or die. The response depends on species and hypoxia severity and spatial extent. Hypoxia also influences microbial and chemical processes at the seafloor resulting in the release of toxic substances, nutrients and greenhouse gases. In coastal areas, high nutrient levels sustain an intense production of microalgae. While degraded at the sea floor, bottom water oxygen is consumed and nutrients are recycled back in the water column, further enhancing productivity and the risk of bottom water hypoxia.</p> <p>Although the surface waters of the Black Sea are enriched by nutrients, the anoxic conditions in the central part of the Sea are considered part of its natural state. However, the state was made worse by eutrophication in the 1980s (Oguz et al., 2008). Projected increases in the frequency and the extent of hypoxia events are accompanied by increased emission of greenhouse gases, losses in biodiversity and ecosystem functions and services such as fisheries, aquaculture and tourism.</p> <p>This indicator informs about the number of hypoxic events in the area of interest as well as the geographical extent of those events. Due to the close link between hypoxia in coastal surface waters and human activities within the coastal area, the indicator can be used to assess a long-term evolution of the anthropogenic pressures and their impact on the (chemical water quality in the) coastal zone.</p>	
Policy context	
ICZM Policy Objective	To perform Environmental Impact Assessment for human activities and infrastructures
ICZM Protocol Article	Article 9: <i>Economic activities – Agriculture and industry</i>
UNEP-MAP Ecological Objective	Objective 5: <i>Human-induced eutrophication is prevented, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters.</i>
INSPIRE ANNEX I-III Data Theme (34)	Operational objective 5.2: <i>Direct effects of nutrient over-enrichment are prevented</i>
	Hydrography (Annex I – 8) Environmental monitoring facilities (Annex III – 7) Oceanographic geographical features (Annex III – 15)

CALCULATION OF THE INDICATOR

Spatial consideration

Coverage	Resolution – reporting unit
Coastal zone of the reference region.	By measurement station (monitoring network stations)

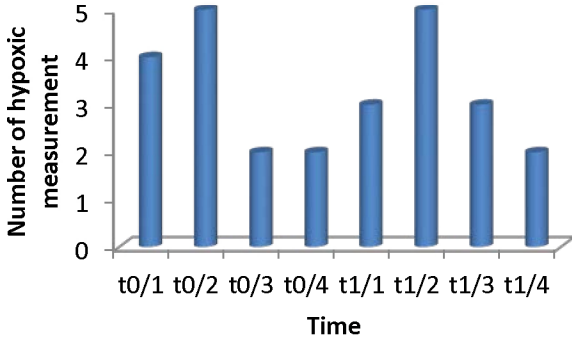
Temporal consideration

Period	Resolution (time interval or unit)
Time series should be as long as possible	Frequency of monitoring is 3 months

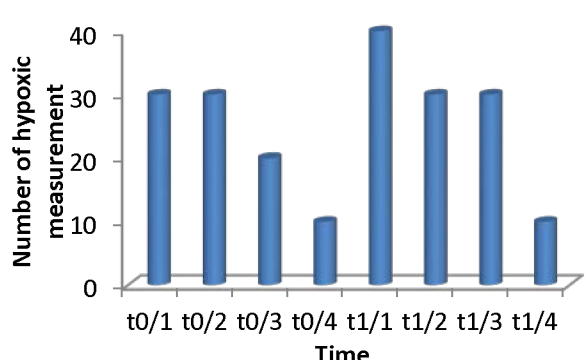
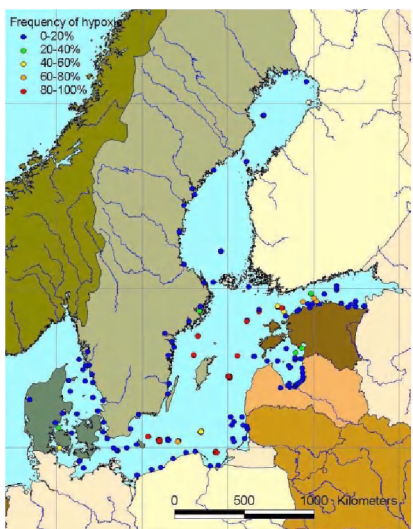
Parameter(s)

(i)	Absolute number of measurement points in which the concentrations of dissolved oxygen do not exceed 2 mg O ₂ L ⁻¹ on a yearly basis (= number of hypoxia events).
(ii)	Relative amount (%) of measurement points with dissolved oxygen concentrations less than 2 mg O ₂ L ⁻¹ on a yearly basis (= geographical extent).
(iii)	Relative frequency of dissolved oxygen concentrations below 2 mg L ⁻¹ at each sampling point (= local frequency of hypoxia)

Calculation method

Steps	Products																									
<p>1. Calculate the absolute number of measurement points characterized by hypoxia at the level of the regional sea, at the national level (EEZ), and if divisions of water bodies are available, at the subnational level.</p>	<p>Build the following table, with $t_{0/1}, t_{0/2}, t_{0/3}, t_{0/4}, t_{1/1}, t_{1/2}$ ($t_{0/1}$ = the first season of year 0; $t_{0/2}$ = the second season of year 0; ...), ... representing the periods of the measurements. Mp_i represents the different measurement points. Include for each measurement point the respective values (mg O₂ L⁻¹) in the table and calculate for each period the absolute number of measurement points with oxygen concentrations less than 2 mg O₂ L⁻¹.</p> <table border="1" style="margin: 10px auto; border-collapse: collapse; text-align: center;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 15%;">Mp₁</th> <th style="width: 15%;">Mp₂</th> <th style="width: 15%;">...</th> <th style="width: 15%;">Total Mps <2 mg O₂ L⁻¹</th> </tr> </thead> <tbody> <tr style="background-color: #d9e1f2;"><td>$t_{0/1}$</td><td></td><td></td><td></td><td></td></tr> <tr style="background-color: #d9e1f2;"><td>$t_{0/2}$</td><td></td><td></td><td></td><td></td></tr> <tr style="background-color: #d9e1f2;"><td>$t_{0/3}$</td><td></td><td></td><td></td><td></td></tr> <tr style="background-color: #d9e1f2;"><td>...</td><td></td><td></td><td></td><td></td></tr> </tbody> </table> <p>This table also enables to detect the geographical areas (Mp_i) particularly vulnerable to hypoxia (<i>see also Step 5</i>).</p>		Mp ₁	Mp ₂	...	Total Mps <2 mg O ₂ L ⁻¹	$t_{0/1}$					$t_{0/2}$					$t_{0/3}$...				
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...																										
<p>2. For each measurement period, establish a bar chart showing the temporal evolution of the absolute number of measurement points characterized by hypoxia on a (sub)national level or at the scale of the (sub)regional sea.</p>	<p>Bar chart showing the absolute number of hypoxic events at the (sub)national- level or at the scale of the (sub)regional sea with a monitoring frequency of 3 months.</p> 																									
<p>3. Calculate the relative number (%) of measurement points affected by hypoxia to make a simplified image of the</p>	<p>$x_h(\%) = (x_i / x_t) * 100$</p>																									



<p>extent of hypoxia at (sub)national/(sub)regional sea level, independent of the total number of national measurement points.</p>	<p>x_h = relative number of measurement points affected by hypoxia at (sub)national/ (sub)regional sea level; x_i = absolute number of measurement points characterized by hypoxia at national level; x_t = total number of measurement points at national level.</p>																		
<p>4. For each time series available, establish a bar chart representing the percentage of measurement points with concentrations of dissolved oxygen less than 2 mg O₂ L⁻¹ at national level.</p>	<p>Bar chart visualizing the relative number of hypoxic observations at national level with a monitoring frequency of 3 months.</p>  <table border="1"> <caption>Data for Hypoxic Measurements Bar Chart</caption> <thead> <tr> <th>Time</th> <th>Number of hypoxic measurement</th> </tr> </thead> <tbody> <tr><td>t0/1</td><td>31</td></tr> <tr><td>t0/2</td><td>31</td></tr> <tr><td>t0/3</td><td>21</td></tr> <tr><td>t0/4</td><td>11</td></tr> <tr><td>t1/1</td><td>41</td></tr> <tr><td>t1/2</td><td>31</td></tr> <tr><td>t1/3</td><td>31</td></tr> <tr><td>t1/4</td><td>11</td></tr> </tbody> </table>	Time	Number of hypoxic measurement	t0/1	31	t0/2	31	t0/3	21	t0/4	11	t1/1	41	t1/2	31	t1/3	31	t1/4	11
Time	Number of hypoxic measurement																		
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<p>5. Calculate for each sampling point the relative frequency of hypoxia on a yearly basis which informs about the geographical extent of hypoxia in the area of interest as well as about local vulnerable or sensitive areas.</p>	<p>Visualize the relative frequencies in a map. A color range scale of different hypoxia limits will harmonize the visualization and allows comparison of the results. The visualization should preferably occur in the following data format: point shape files.</p>  <p>Source: Data from OSPAR and EEA member countries</p>																		
<p>Current monitoring</p>	<p>Data sources</p>																		
<p>Water framework directive (2000/60/EC): For the surveillance monitoring period, the frequency for monitoring oxygenation is 3 months and should be applied unless greater intervals would be justified on the basis of technical knowledge and expert judgment.</p>																			
<p>Assessment context</p>																			
<p>Use of the indicator in previous</p>	<p>The 'Long-term vision 2030 for the Scheldt estuary' (crossboundary estuary management between Belgium and the Netherlands) includes a similar indicator</p>																		

assessments/initiatives	as one of the elements of interest to determine the surface water quality . This indicator however only uses the relative data, and puts the threshold at 5 mg O ₂ L ⁻¹ instead of 2 mg O ₂ L ⁻¹ . Regular Assessments in the context of the Water Framework Directive
DPSIR framework	Impact
Link to anthropogenic pressure	Human activities accelerate hypoxia development in many areas of the world's coastal oceans by an increase in anthropogenic nutrient loading by using fertilizers for crops, burning of fossil fuels, urbanization, waste water generation, etc...
Sustainability target or threshold	All measurements should evolve towards dissolved oxygen concentration exceeding 2 mg O ₂ L ⁻¹ over the entire temporal resolution
Link with other assessment tools	Link with the following descriptor of the water framework directive: Oxygenation of coastal waters (Annex 1.2.4 – physico-chemical quality elements) Link with the following descriptor of the marine strategy framework directive: (5) Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.
Example of integrated assessment	A high number of hypoxia events can be related to an increasing human activity (such as agriculture or urban developments) within the coastal area.

Scope for future improvements

The absolute and relative number of measurement points in which oxygen levels are measured is not comparable between states or (sub)regional seas due to differences in national monitoring network (measurement point) densities. This constraint can be partly evaded by visualizing the calculation of the relative frequency of hypoxia events at each sampling point in a map, which more or less allows a comparison between states and oceanic regions (coast, open ocean, estuaries). Furthermore, it will be a challenge to get access to as many data as possible in order to improve the spatial coverage and time series to strengthen the assessment.

Data Harmonization:

In order to build a common, regional view for a particular indicator, it is crucial to harmonize the data in terms of e.g. concepts, definitions, reporting units, colour codes, value class boundaries and scoring methods. For this purpose, the PEGASO consortium has developed 'Guidelines for Data Harmonization' which are available from the 'Products' section on the PEGASO project website www.pegasoproject.eu. Although agreements may exist related to the presentation of certain indicators that are legally embedded, this may be less evident for indicators which are not (yet) used as an instrument within a policy context or within a region where the policy is not applicable. The PEGASO consortium encourages contributing partners, stakeholders and end-users to consult the 'Guidelines for Data Harmonization' document, and to actively engage in this process.

Indicator references (i.e. UNEP, EEA, ...)

EEA (Frequency of low bottom oxygen concentrations in coastal and marine waters)

OSPAR (JAMP Eutrophication Monitoring: Oxygen)

References:

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy

Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

Oguz T, Salihoglu B, Fach B (2008) A coupled plankton–anchovy population dynamics model assessing nonlinear controls of anchovy and gelatinous biomass in the Black Sea. *Mar Ecol Prog Ser* 369: 229–256.