Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Target 14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
Indicator 14.3.1: Average marine acidity (pH) measured at agreed suite of representative sampling stations

Institutional information

Organization(s):
Intergovernmental Oceanographic Commission (IOC) of UNESCO

Concepts and definitions

Definition:
Ocean acidification is the reduction in the pH of the ocean over an extended period, typically of decades or longer, which is caused primarily by the uptake of carbon dioxide from the atmosphere[1].
This indicator is based on observations that constrain the ocean carbon system and which are required to describe the variability of ocean acidity. The carbon system in this context mainly refers to the four measureable parameters: pH (the concentration of hydrogen ions on a logarithmic scale), DIC (CT; total dissolved inorganic carbon), pCO_2 (carbon dioxide partial pressure), and TA (AT, total alkalinity). Average, as used here, is the equally weighed annual mean.

A agreed suite of representative sampling stations are sites that have a measurement frequency that is adequate for describing variability and trends in carbonate chemistry in order to deliver critical information on the exposure of and impacts on marine systems to ocean acidification, and which provide data of sufficient quality and with comprehensive metadata information to enable integration with data from other sites in the country.

Rationale:
The ocean absorbs around 30% of anthropogenic carbon from the atmosphere annually. This carbon dioxide (CO_2) reacts with the seawater, changing its chemical composition and progressively acidifying the ocean. The observed decrease in seawater pH has been shown to affect a range of organisms and ecosystems, biodiversity and food security. Fisheries and aquaculture can be negatively affected, as can other services provided by the ocean, including tourism, transportation and coastal protection. Observations from the last 20 – 30 years have shown a clear trend of ocean acidification (decreasing pH) in open ocean locations. For coastal areas, however, the pattern is often confounded by natural processes like freshwater input, coastal upwelling, biological activities and temperature changes, among others. These factors complicate the prediction of and possible management responses to ocean acidification in the highly dynamic and productive coastal areas. Guidelines on how to improve monitoring, what to measure and what to report are provided in this methodology[2]. The associated data

[1]NOAA. What is ocean acidification? National Ocean Service website https://oceanservice.noaa.gov/facts/acidification.html, 06/25/18
[2] IOC/EC-LI/2 Annex 6

and metadata files ensure that the data collected is traceable and can be quality controlled, stored and shared in a manner that allows it to be used for better understanding and predictions of ocean acidification observations.

Concepts:
Ocean acidification is caused by an increase in the amount of dissolved atmospheric CO_2 in the seawater. The average marine acidity is expressed as pH, the concentration of hydrogen ions on a logarithmic scale. In order to be able to constrain the carbonate chemistry of seawater, it is necessary to measure at least two of the four parameters, i.e. pH, pCO_2, DIC (CT), and TA (AT). pH (the concentration of hydrogen ions on a logarithmic scale, expressed on total scale), DIC (total dissolved inorganic carbon, in µmol kg^{-1}), pCO_2 (carbon dioxide partial pressure, in ppt or µatm), and TA (AT, total alkalinity, in µmol kg^{-1}).

Comments and limitations:
The methodology for this indicator has been developed with the technical support of experts in the field of ocean acidification. It provides globally accepted and adapted guidelines and best practices established by scientists and published in peer-reviewed literature.

As this is a highly complex indicator, the technical infrastructure necessary for the correct measurement is a potentially constraining factor. The Methodology for the indicator describes how to avoid comparability issues of the data, which have been problematic in the past, measurement errors and advises on the most appropriate technical and methodological procedures to guarantee high-quality data that can be used for the global assessment of ocean acidification. The addition of metadata to the methodology for this indicator is crucial for adding traceability and transparency to the data, by providing information on the precise equipment and methodology used, as well as specifying the location, accompanying biogeochemical variables and the person taking the measurement.

Methodology

Detailed information in Attachment I IOC/EC-LI/2 Annex 6

Computation Method:
This indicator calls for the collection of multiple observations, in the form of individual data points, to capture the variability in ocean acidity. Individual data points for pH either are measured directly or can be calculated based on data for two of the other carbonate chemistry parameters, these being TA (AT), DIC (CT) and pCO_2. Calculation tools developed by experts in the field are freely available, and they are introduced and linked in the methodology. Average pH is defined as the annual equally weighed mean of multiple data points at representative sampling stations. The exact number of samples and data points depends on the level of variability of ocean acidity at the site in question. The minimum number of samples should enable the characterisation of a seasonal cycle at the site. Detailed guidelines on the minimum number of observations required are provided in the Methodology. In addition to the data value, standard deviation and the total range (minimum and maximum values measured), as well as underlying data used to provide traceability and transparency (metadata information) should be reported. If historical data is available, this should be released to enable calculations about the rate of change and to compare natural variability and anthropogenic effects.

Disaggregation:
Countries provide complete data sets with respective site-specific data and metadata files.

Treatment of missing values:

- At country level

Some missing values may be modelled or calculated if established methodologies exist (*see Recommendations for calculation of the carbonate system in IOC/EC-LI/2 Annex 6*).

- At regional and global levels

Regional aggregates are permissible if more than 50% of coastal nations have reported values.

Regional aggregates:

Every country or nominated IODE National Oceanographic Data Centre (NODC)/Associated Data Unit (ADU)3 will provide annually updated data sets. Aggregations across regions will require data of comparable quality and all relevant metadata with site-specific information be included in the data sets. Due to the variability of measurements and the prevalence of areas with high variability in ocean acidity, the aggregation of measurement averages (equally weighed annual mean) across coastal marine habitat and ecosystem types is difficult to interpret and is therefore discouraged.

Sources of discrepancies:

As this indicator only takes into account data submitted by Member States only, there are no discrepancies between estimates and submitted data sets. In the past differences between countries in the measurement of pH and other ocean acidification data were mainly attributable to technical difficulties and the lack of comprehensive guidelines for the best practice of measurements. The present Methodology and the guidelines contained within provide detailed instructions on the measurement, collection, treatment and quality control of data in a way that will enable countries to avoid future discrepancies.

Methods and guidance available to countries for the compilation of the data at the national level:

- The SDG 14.3.1 Indicator Methodology presented here provides guidelines for the collection of measurements towards the Indicator. Data and metadata files in which all of the relevant measurements should be compiled will be provided to the data centre or data originator. This data will be collected by the relevant national data centers, such as National Statistical Offices (NSOs) and National Oceanographic Data Centers (NODCs), and shared with the Indicator's custodian agency, the IOC of UNESCO[4].
- The Indicator Methodology comprises an overview of statements on best practice and links to several Standard Operating Procedures (SOPs). These procedures represent the best practices compiled by the leading researcher in the field and have been made freely available. A list of relevant material, as referenced in the Indicator Methodology, can be found here: http://www.ioccp.org/index.php/documents/standards-and-methods
  IOC/EC-LI/2 Annex 6
  Table 1

[3] https://www.iode.org/index.php?option=com_oe&task=viewGroupRecord&groupID=349
[4] IOC-XXIX/2Annex 14, IOC/EC-LI/2 Annex 6

*Table 1. List of standard operating procedures to measure different parameters of the carbonate system (procedures marked with * are able to attain climate quality).*

	Discrete	Underway	Fixed autonomous sensors
pH	Spectrophotometric * Potentiometric	Spectrophotometric ISFET	Spectrophotometric ISFET
CT	IR detection Coulometry *	-	-
AT	Potentiometric titration (open and closed cell; open recommended) *	-	-
***p*CO_2**	-	Equilibration, headspace * Membrane-based	Equilibration * Membrane-based

Quality assurance

Data quality control and validation processes were developed in close consultation with experts in the field of ocean acidification, amongst them members of the Global Ocean Acidification Observing Network (GOA-ON) and data management experts, like the ones at IODE. Data quality control is a critical component of the data analysis, submission and processing. Scientists and technicians who collected the submitted data will be responsible for the primary quality control of the data and accompanying detailed metadata. The metadata submitted with the data must also describe the quality control standard operating procedures (SOPs) followed for each parameter.

Primary quality control consists of:

- Quality control that is attached to the methodology (CRMs, tris buffer calibration, SOPs are provided),
- Quality control and quality assurance of the actual data (SOPs are provided) and usage of community agreed quality flags,
- Identifying and flagging of outliers,
- Making determinations regarding validity of those outlying points,
- Estimating uncertainty of the measurement,
- Identifying all the sources of uncertainty in the measurements,
- Rolling up the individual uncertainties into overall uncertainty (error propagation).

Secondary quality control:

- Harmonization of the data and ensuring metadata completeness,
- External quality control/audit – Expert QC Group applying the weather and climate levels as defined by GOA-ON (following the example of SOCAT),
- Feedback to data holders.

Following the quality control assessment described above, three categories of measurement quality will be attributed by the Expert QC Group:

- Established oceanographic climate quality (Category 1)
- Weather quality data including that from sensors and capacity building simplified pH and alkalinity measurements, with appropriate uncertainty assessment (Category 2)
- Measurements of undefined quality (Category 3) (will not be displayed in the visualization of annual weighted means and variance of pH).

Data Sources

Description:

The general IOC data collection process is described in Document IOC-XXIX/2Annex 14.

The novelty of assessing ocean acidification at the global level, as in indicator 14.3.1, requires the IOC secretariat to collect the data via different pathways. Future data collections are expected to be a mixture of:

- direct requests to National Statistical Offices (NSOs), as new national reporting mechanisms are now installed allowing them to provide the required information,
- annual requests to the IOC national focal points,
- collaboration with National Oceanographic Data Centres, international data centres and
- directly with data providers via the GOA-ON data portal (Figure 1).

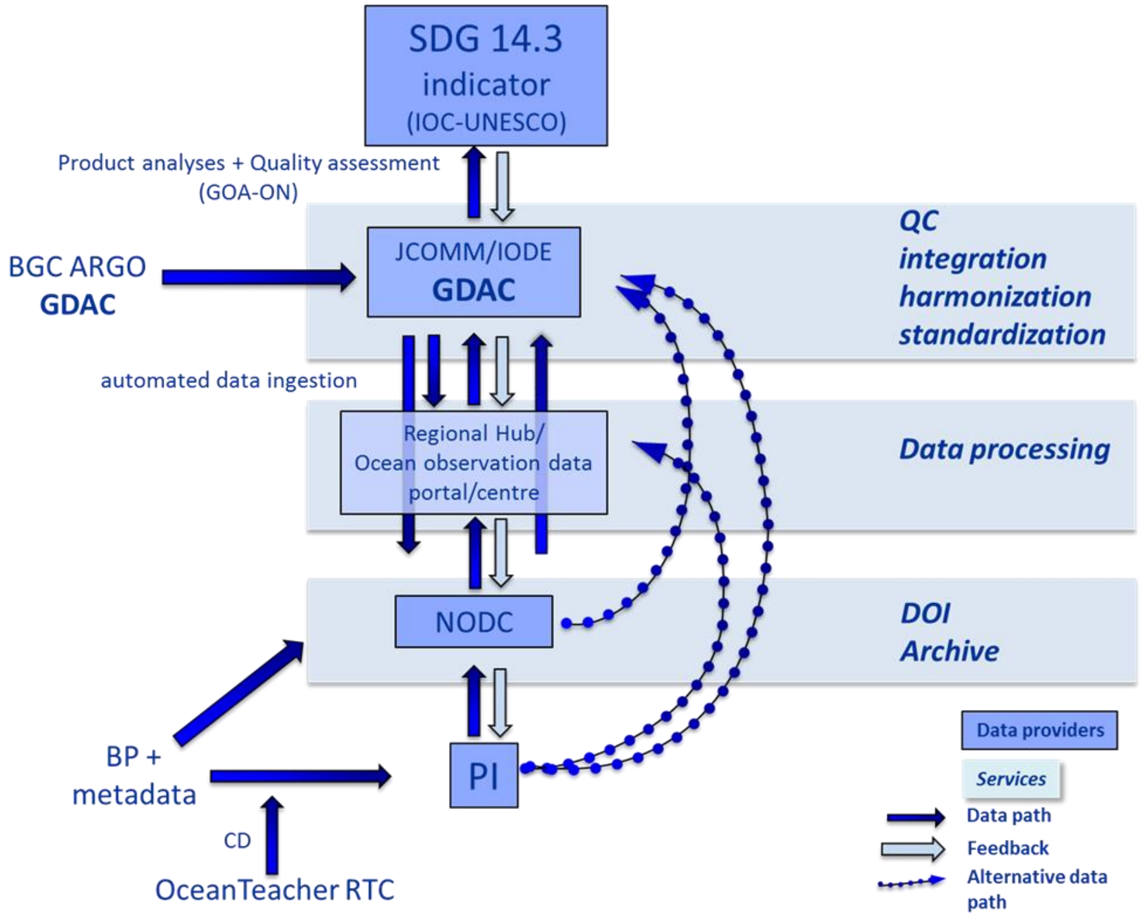

Figure 1. Scheme to illustrate the proposed data collection and publication process related to national contributions of data related to 14.3.1 (SDG: Sustainable Development Goal; IOC-UNESCO: Intergovernmental Oceanographic Commission

of UNESCO; GOA-ON: Global Ocean Acidification – Observing Network; JCOMM: WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology; WMO: World Meteorological Association; IODE: International Oceanographic Data and Information Exchange of IOC UNESCO; GDAC: Global Data Assembly Center; BGC ARGO: Biogeochemical Argo floats; QC: Quality Control; NODC: National Oceanographic Data Centre; DOI: Digital Object Identifier; BP: Best Practice; CD: Capacity Development; PI: Principal Investigator; RTC: Regional Training Centre).

Global scientific efforts (GO-SHIP, SOCAT, GCOS) which host and feature data from various ocean observing efforts and/or focus on collecting measurements in international waters will also be queried for annual or more likely multi-year data sets representing status and change of ocean acidification variables in the open ocean.

As mentioned the data collection process will take place in close collaboration with the IOC Project Office for IODE Oostende, Belgium and relevant data providers/national archives, the GOA-ON data portal, and entities such as the marine chemistry part of the European Marine Observation and Data Network (EMODnet).

The GOA-ON data portal features open access data, in addition to a global monitoring asset inventory. The portal is designed to offer two levels of access: 1) visualization and 2) download capabilities. Combining different open-access data sets may provide incentives to create new observing systems in under-sampled areas and to increase the application of open access data policies worldwide, according to the IOC Criteria and Guidelines for the Transfer of Marine Technology[5].The detailed SDG 14.3.1metadata and data forms (part of the final methodology to ensure inter-comparability between measurements) will be included on the GOA-ON website. The information requested will include a detailed habitat description, which will be required to assess the natural and anthropogenic causes of variability within the data sets.

Collection process:
(I) Counterparts:
The official counterparts are the IOC focal points. They, as well as National Oceanographic Data Centres (NODCs), will initially be contacted by IOC to request relevant data from the appropriate national oceanographic data centres and/or relevant scientists, agencies or programmes. An annual data submission request will be sent out directly to the member states asking for the respective data and metadata. It is envisaged that an online submission interface, to be developed in collaboration with existing ocean carbon data centres and biogeochemical data platforms will facilitate the submission process in the future.
(II) Validation and consultation process:
The counterparts are invited to provide references (metadata) for the information provided. The quality control mechanisms are described in more detail later in this document (see Quality Control).

Data Availability

[5] Intergovernmental Oceanographic Commission. *IOC Criteria and Guidelines on the Transfer of Marine Technology (CGTMT)/ Critères et principes directeurs de la COI concernant le Transfert de Techniques Marines (CPTTM)*. Paris, UNESCO, 2005. 68pp. (IOC Information document, 1203)

Description:
IODE and IOC HQ conducted an online survey among NODCs and ADUs in February 2018 requesting information about the national and institutional 14.3.1 related data sets. A total of 30 data centres replied positively that they host and serve biogeochemical data sets; 21 data centres serve all 4 parameters (DIC, TA, pH, pCO_2). However, only 14 centres also provide the corresponding metadata.
The list of 21 data centres that host all 4 parameters are:
Europe: RBINS (Belgium), BODC (UK), VLIZ (Belgium), Marine Institute (Ireland), Bjerknes Climate Data Centre / RI ICOS Ocean Thematic Centre (Norway)
North America: University of South Florida (USA), DFO (Canada), NCEI/OCADS (USA), WHOI (USA), NCEI (USA), NCEI (USA), Scripps (USA)
South America: Univeridad Simon Bolivar (Venezuela), Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) (Argentina)
Africa: KMFRI (Kenya)
Pacific: National Institute of Water & Atmospheric Research (New Zealand)
Asia: JODC (Japan), JMA (Japan), MIRC (Japan), MHI/RAS (Russian Federation), RSE Kazhydromet (Kazakhstan)

Time series:
The first assessment in 2018 will include first-level quality controlled data, since and including 2010, if available (all of the years or a subset).

Calendar

Data collection:
National data sets should be reported annually (at the least). The next data collection will start in February 2019.

Data release:
The first requests for data were sent to NODCs in August 2018, and the data received are currently undergoing secondary quality control. The next data points will become available in the second quarter of 2019.

Data providers

The general IOC data collection process is described in Document IOC-XXIX/2Annex 14.
The novelty of assessing ocean acidification at the global level, as for this indicator 14.3.1, requires the IOC secretariat to collect the data via a range of different pathways. This will include direct requests to National Statistical Offices (NSOs), annual requests to the IOC national focal points, and NODCs and associated data agencies in the member states, as well as international data centres and data providers which have made data available to the GOA-ON data portal.

Data compilers

The Intergovernmental Oceanographic Commission (IOC) of UNESCO is the custodian agency for this Indicator. In collaboration with the International Oceanographic Data and Information Exchange (IODE) of

IOC, the data will be collected and stored in a transparent and traceable manner, allowing the ocean acidification data to be shared.

References

URL:

IOC-UNESCO	http://www.ioc-unesco.org/
IODE	https://www.iode.org/
GOA-ON	http://goa-on.org/
GOA-ON data portal	http://portal.goa-on.org/
Document IOC/EC-LI/2 Annex 6 -14.3.1 Methodology	http://ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=21938
Document IOC-XXIX/2Annex 14	http://www.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=19589

References:

- Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) (2007) *Guide to best practices for ocean CO_2 measurements*. PICES Special Publication 3, 191 pp.
- Newton J. A., Feeley, R. A., Jewett, E. B., Williamson, P. and Mathis, J. (2015) Global Ocean Acidification Observing Network: Requirements and Governance Plan (2nd edition)
- Riebesell U., Fabry V. J., Hansson L. & Gattuso J.-P. (Eds.) (2011) Guide to best practices for ocean acidification research and data reporting. Luxembourg, Publications Office of the European Union, 258pp. (EUR 24872 EN).

Related indicators as of February 2020

14.a Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries