

## Dissolved oxygen

### Key message

Dissolved oxygen concentrations are above levels required to maintain healthy marine ecosystems in all Scottish Marine Regions (SMRs) except the Clyde. As part of the Water Framework Directive (WFD) one water body in the Clyde SMR (Inner Clyde Estuary) was classified as being below good status for dissolved oxygen. Robust trend analysis is not possible.

### Background

Eutrophication in the marine environment is the excessive growth of phytoplankton in response to enrichment by nutrients (nitrogen (N) and phosphorus (P)) resulting in an undesirable disturbance in the marine ecosystem. The consequences are often wide ranging, with overall impacts on the diversity and abundance of flora and fauna resulting from the depletion of oxygen in the water column, increases in water turbidity and behavioural changes in larger fauna.

Nitrogen and phosphorus can enter the sea from a number of natural and anthropogenic sources: direct discharges (e.g. sewage, aquaculture etc.), inputs from rivers, land runoff and atmospheric deposition.

The decomposition of excessive phytoplankton growth has the potential to lower the levels of dissolved oxygen (DO) in the water column. Above  $6 \text{ mg l}^{-1}$ , DO concentrations are able to support healthy marine ecosystems, whereas when DO concentrations fall below  $2 \text{ mg l}^{-1}$  hypoxic conditions are created that have detrimental effects on marine life. In between these two thresholds there may be some sub-lethal and lethal impacts on sensitive species such as salmonids.

Dissolved oxygen levels can also be affected by changes in salinity and temperature. Increasing water temperatures, as a



Dissolved Oxygen bottles.

consequence of greenhouse gas emissions, may result in degassing and lower dissolved oxygen concentrations.

This indicator assesses the levels of DO within each of the Scottish Marine Regions (SMRs) and Offshore Marine Regions (OMRs) as an indirect indicator of nutrient enrichment. It is assessed in two different ways. Firstly, results from Water Framework Directive (WFD) water body classification are presented for transitional and coastal water bodies within SMRs. Secondly, seabed DO data collected offshore were assessed against OSPAR and the Marine Strategy Framework Directive (MSFD) assessment thresholds.



Figure 1: Water samplers used for taking samples in the Clyde estuary

Waterbody	SMR	Status
Inner Clyde Estuary	Clyde	Moderate
Loch Striven	Clyde	Good
Loch Long (South)	Clyde	Good
Loch Long (North)	Clyde	Good
Upper Forth Estuary	Forth and Tay	Good

Table 1: Waterbodies with WFD classification lower than High Status for DO

data which are below the assessment level but above what is considered to be hypoxic.

There are also a number of cases where the lowest values within the range of data used to undertake the assessment fall below the assessment threshold e.g. Forth & Tay, and West Highlands. Looking at the annual data (not shown), these appear to be related to sampling within a specific year (West Highlands, Outer Hebrides) or year to year fluctuations around the threshold level (Forth & Tay).

There are however a number of data gaps in all SMRs, with no SMR having a full complement of data for both water types across the three decades.

## Results

In the latest WFD classification (2017) 499 of the 504 transitional and coastal water bodies classified were at a High status for DO. Of the remaining five waterbodies, four were classified as Good and one was Moderate (Inner Clyde Estuary). Waterbodies below High status are detailed in Table 1. The predominant cause of DO pressures in the Inner Clyde Estuary is from the decomposition of excess organic material released from municipal wastewater and diffuse pollution sources by microorganisms that use DO.

This classification demonstrates an improving picture since WFD classification started in 2007 when three waterbodies were classified as Poor.

Seabed data assessed against OSPAR and MSFD thresholds presents a similar result. Figure 2 presents the DO data by decade for each SMR and OMR. All regions are above the assessment level of  $6 \text{ mg l}^{-1}$  in the decades where data were available, with the exception of the Clyde Coastal

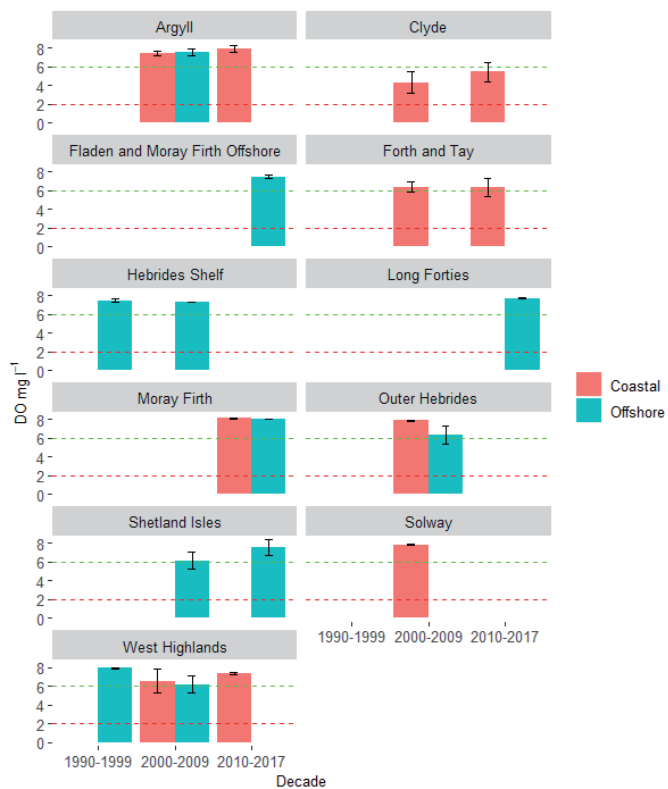


Figure 2: Average concentrations of DO ( $\text{mg l}^{-1}$ , as average values in the lowest quartile of the data) near the seabed in each SMR and OMR, 1990-2017.

The green line shows the threshold value ( $6 \text{ mg l}^{-1}$ ) used in assessments of status and red line shows the value ( $2 \text{ mg l}^{-1}$ ) below which detrimental ecosystem impacts are likely. Black error bars demonstrate standard deviation. Note: Only SMRs and OMRs that meet the threshold for data availability are shown in the plot (minimum of 5 data points per year).

### Trend assessment

There were insufficient data in each region to be able to undertake robust trend assessment for near bed DO. For WFD water bodies there has been an increase in the number of waterbodies classified as High status from 476 in 2007 to 499 in 2018. However, only a small fraction of these waterbodies are sampled for DO as detailed in the assessment methods.

## Knowledge gaps

The relationship between biological and physical processes near the seafloor is poorly understood. Robust assessments of oxygen deficiency require improved availability of near-bed data on DO concentrations together with salinity, depth and temperature measurements.

Data on seabed DO are only collected consistently within a subset of the regions. At the SMR and OMR scale, this presents a number of data gaps as shown in the results. In addition, WFD classification is based on monitoring in representative locations meaning DO is not routinely monitored in all water bodies. It is hoped that autonomous monitoring methodologies such as those outlined in the AlterECO case study will provide more data in the future to improve our understanding seabed DO.























## Conclusion

DO concentrations near the seabed have consistently met assessment levels in most SMRs and OMRs where monitored. The exception to these are coastal waters in the Clyde region which fall below the assessment level but above concentrations deemed to be hypoxic.



















WFD assessments also show similar results, with only one waterbody (Inner Clyde Estuary) exhibiting DO concentrations below the minimum Good WFD threshold. Pressures within the Clyde are well understood and efforts are underway to reduce nutrient loading.

## Status and trend assessment

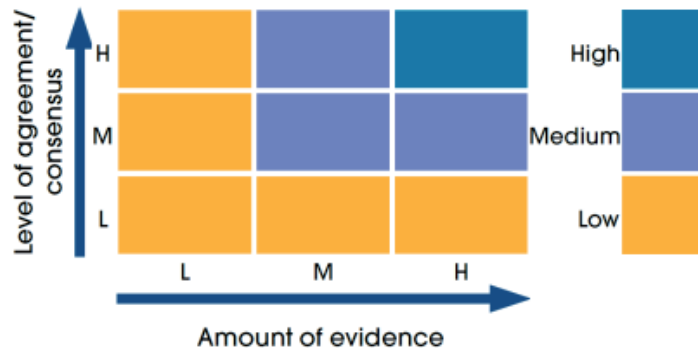
The status and trend assessment is for eutrophication and includes, nutrient inputs, winter nutrient concentrations, chlorophyll concentrations and dissolved oxygen concentrations.

Region assessed	Status with confidence	Trend with confidence	Comments
Argyle			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
Clyde			The status green box with blue circle is due to a localised issue within the inner Clyde estuary where the dissolved oxygen is failing. Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
Forth and Tay			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.  There is a localised issue with the trend assessment due to increasing chlorophyll concentrations, but trend not reflected in other eutrophication parameters.
Moray Firth			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
North Coast			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
North East			The status green box with blue circle is due to a localised issue within the Ythan Estuary which is categorised as being eutrophic. The rest of the SMR is not impacted and not considered to be Eutrophic. Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
Orkney Islands			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.  There is a localised issue of increasing nutrient inputs in the region associated with increasing aquaculture. This increasing input is not impacting nutrients across the SMR with no statistically significant trend in winter DIN observed.
Outer Hebrides			There is a localised issue of increasing nutrient inputs in the region associated with increasing aquaculture. This increasing input is not impacting nutrients across the SMR with no statistically significant trend in winter DIN observed.  Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
Shetland Isles			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
Solway			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.
Western Islands			Status and trends have been given a confidence of 2 stars because there is limited dissolved oxygen data available in the region and this has been acknowledged as a knowledge gap in the current assessment of overall Eutrophication status.

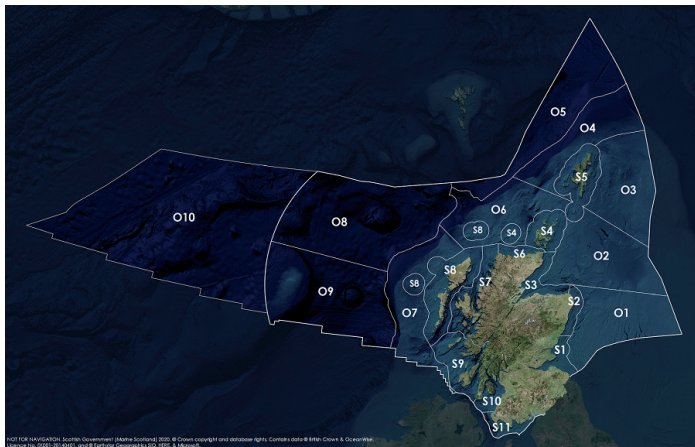
## Status and trend assessment legend

Status assessment (for Clean and safe, Healthy and biologically diverse assessments)		Trend assessment (for Clean and safe, Healthy and biologically diverse and Productive assessments)	
	Many concerns		No / little change
	Some concerns		Increasing
	Few or no concerns		Decreasing
	Few or no concerns, but some local concerns		No trend discernible
	Few or no concerns, but many local concerns		All trends
	Some concerns, but many local concerns	<b>Confidence assessment</b>	
	Lack of evidence / robust assessment criteria		
	Lack of regional evidence / robust assessment criteria, but no or few concerns for some local areas		Low
	Lack of regional evidence / robust assessment criteria, but some concerns for some local areas		Medium
	Lack of regional evidence / robust assessment criteria, but many concerns for some local areas		High

## Overall confidence

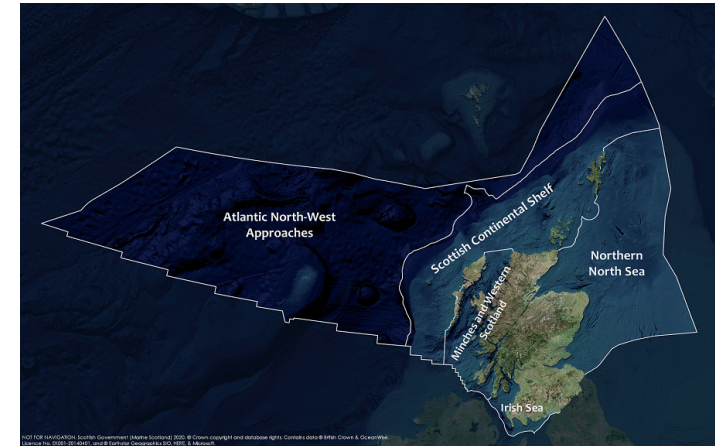


## Assessment regions

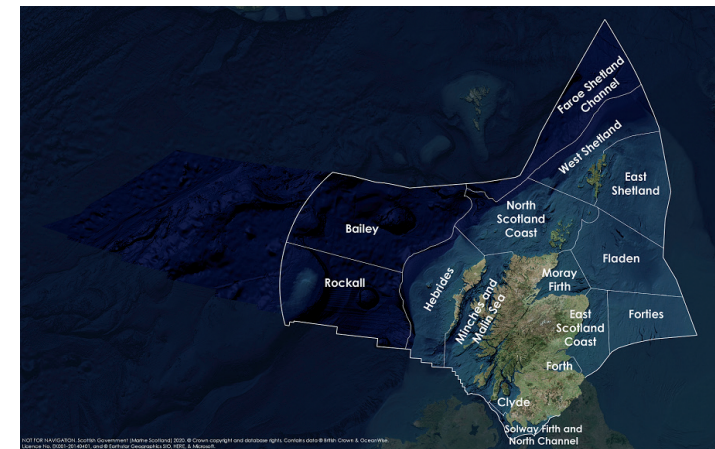


The Scottish Marine Regions (SMRs; S1 - S11) and the Scottish Offshore Marine Regions (OMRs, O1 - O10)

Key: S1, Forth and Tay; S2, North East; S3, Moray Firth; S4 Orkney Islands; S5, Shetland Isles; S6, North Coast; S7, West Highlands; S8, Outer Hebrides; S9, Argyll; S10, Clyde; S11, Solway; O1, Long Forties, O2, Fladen and Moray Firth Offshore; O3, East Shetland Shelf; O4, North and West Shetland Shelf; O5, Faroe-Shetland Channel; O6, North Scotland Shelf; O7, Hebrides Shelf; O8, Bailey; O9, Rockall; O10, Hatton.



Biogeographic, Charting Progress 2 (CP2) Regions. These have been used as the assessment areas for hazardous substances.



Scottish Sea Areas as used in Scotland's Marine Atlas 2011. These are sub divisions of the biogeographic, or Charting Progress 2 (CP2), Regions.