Foras na Mara
Marine Institute

BASELINE STUDY OF ESSENTIAL OCEAN VARIABLE MONITORING IN IRISH WATERS; CURRENT MEASUREMENT PROGRAMMES & DATA QUALITY

CLIMATE SERVICES MATRIX TEAM
MARINE INSTITUTE
Rinville, Oranmore, Co. Galway

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'to undertake, to coordinate, to promote and to assist in marine research and development and to provide services related to marine research and development, that in the opinion of the Marine Institute will promote economic development and create employment and protect the environment'

Marine Institute Act 1991

Our Vision

A thriving maritime economy in harmony with the ecosystem and supported by the delivery of excellence in our services.

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Baseline study of Essential Ocean Variable monitoring in Irish waters; current measurement programmes & data quality

August 2021

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Glossary

Acronym	Description
ADCP	Acoustic Doppler Current Profiler
AMETS	Atlantic Marine Energy Test Site
AMOC	Atlantic Meridional Ocean Current
ARMS	Automatic River Monitoring Station
AWQMS	Ambient Water Quality Monitoring System
CFC	Chloroflorocarbons
CO2	Carbon Dioxide
COMPASS	Collaborative Oceanography and Monitoring for Protected Areas and Species
CPR	Continuous Plankton Recorder
CTD	Conductivity, Temperature, Depth
DAFM	Department of Agriculture, Food & Marine
DECC	Department of Environment, Climate & Communications
DHLGH	Department of Housing, Local Government & Heritage
DIC	Dissolved Inorganic Carbon
ECV	Essential Climate Variable
EMFF	European Maritime and Fisheries Fund
ENSO	El Nino Southern Oscillation
EOV	Essential Ocean Variable
EPA	Environmental Protection Agency
ERIC	European Research Infrastructure Consortium
GCOS	Global Climate Observing System
GLEON	Global Lake Ecological Observatory Network
GLOSS	Global Sea Level Observing System
GLTC	Global Lake Temperature Collaboration
GSI	Geological Survey of Ireland
HABs	Harmful Algal Blooms
HEIs	Higher Education Institutes
HF Radar	High Frequency Radar
HFM	High Frequency Monitoring
IAMS	Irish Anglerfish and Megrim Survey
ICES	International Council for the Exploration of the Seas
IMDBON	Irish Marine Data Buoy Observation Network
IOC	Intergovernmental Oceanographic Commission
MI	Marine Institute
MSFD	Marine Strategy Framework Directive
N2O	Nitrous Oxide
NETLAKE	Networking Lake Observatories in Europe
NPWS	National Parks & Wildlife Service
O2	Oxygen
OA	Ocean Acidification
OCRS	Ocean Colour Remote Sensing
OPW	Office of Public Works

Acronym	Description
OSS	Ocean Surface Stress
pCO2	Partial Pressure of CO2
pH	Power of Hydrogen
QMF	Quality Management Framework
SEAI	Sustainable Energy Authority of Ireland
SOCAT	Surface Ocean CO2 Atlas
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SWAN	Simulating Waves Nearshore
TA	Total Alkalinity
TTD	Transit Time Distribution
UN	United Nations
WESPAS	Western European Shelf Pelagic Acoustic Survey
WFD	Water Framework Directive
WFD in TCW	Water Framework Directive in Transitional & Coastal Waters

1 EXECUTIVE SUMMARY

This report provides an initial assessment of Ireland's current measurement programmes and capacity for Essential Ocean Variables (EOV) data collection. These are typically programmes that involve physical sampling of the marine environment, using a combination of ship-based measurements, fixed platforms e.g. tide and wave gauges, offshore buoys, autonomous platforms e.g. underwater gliders, and conventional collection of physical samples that are analysed on board ships or in shore-based laboratories. Systematic measurement of essential ocean variables underpins the delivery of services to government and the public in terms of real-time decision support, assessments of ocean health e.g. Marine Strategy Framework Directive (MSFD), Oslo & Paris Conventions (OSPAR), International Council on the Exploration of the Sea (ICES) and long-term observations to inform policy on marine climate change and provide climate information to guide related adaptation measures required under climate change sectoral adaptation plans e.g. seafood sector, transport, biodiversity, and built heritage.

The figure below shows the Essential Ocean Variables (EOV), a subset of which are Essential Climate Variables (ECV), with colour coding denoting the level of maturity. Physical variables are clearly at a much higher maturity level than biogeochemical or more particularly biological variables although considerable efforts are currently underway to address this. Detailed descriptions of the ocean ECVs definitions can be found on the Global Climate Observing System (GCOS) website – ECV Ocean Matrix. GCOS was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users.

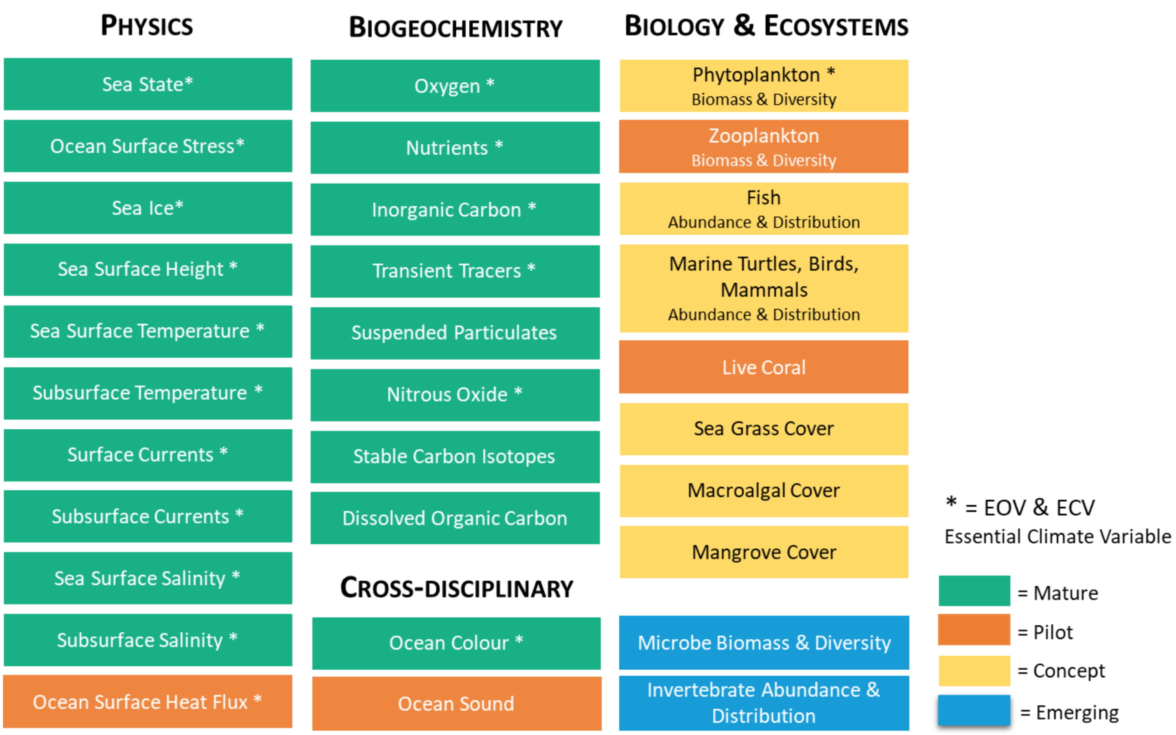

Figure 1: Global Ocean Observing System: Essential Ocean Variables – July 2021

This report highlights key messages and 10 recommendations associated with each Essential Ocean Variable to help guide future actions in terms of Ireland's continued collection of ocean data that underpins the evidence base for climate policy and action.

Recommendation 1

Ireland should provide sustained operational funding for the Marine Institute sea level monitoring programme and establish a National Sea Level Measurement Advisory Group.

Recommendation 2

Designate and fund Mace Head as a sentinel climate monitoring station for the ocean. Mace Head already has this status for atmospheric essential climate variables.

Recommendation 3

Commission a desk study to investigate what international data sets can be used to fill the gaps in the spatial coverage of physical and chemical EOVs e.g. salinity, temperature, oxygen in Irish waters.

Recommendation 4

Systematic collection and processing of fixed-point and vessel-mounted ADCP measurements should be implemented and investigate ways to ensure that the Galway Bay HF radar are made available to the public domain. Government support is required to ensure ocean models are developed near key population centres e.g. Dublin and Cork, to fill observational gaps e.g. important information on sea safety and pollution, and funding is required to support existing and future infrastructure.

Recommendation 5

Government funding is needed to sustain the Argo Ireland programme to measure temperature, salinity and oxygen in deep waters through float purchases (minimum 3 floats per annum) and membership in the Euro-Argo ERIC. There is a requirement to increase the coverage of oxygen measurements in Irish waters through survey activities to monitor the impact of changes on marine ecosystems.

Recommendation 6

Financial and technical support for pCO_2 measurements on the RV *Celtic Explorer* should continue. A pCO_2 system should be procured and installed on the new national research vessel, RV *Tom Crean*. Sampling for dissolved inorganic carbon and total alkalinity should continue to generate a time series appropriate to monitor changes in carbon chemistry, including ocean acidification in Irish waters. This requires building competence and capacity to routinely undertake climate-quality measurements and that will support international reporting obligations.

Recommendation 7

Extend phytoplankton sampling offshore (even opportunistically or using third parties) to gain insights into phytoplankton distributions and abundance including HABs. New technologies, e.g., Artificial Intelligence combined with *in-situ* flow cytometry instruments should be considered and implemented as an urgent requirement for both autonomous and high throughput sampling.

Recommendation 8

Conduct a review of historic zooplankton data collection in Ireland and devise a future monitoring strategy for this EOV. Zooplankton information can inform policy makers about marine food webs and the impacts of Ocean Acidification. There is currently no Irish monitoring programme. Set up a long-term sustainable zooplankton monitoring programme with taxonomic experts and a financial commitment from Government.

Recommendation 9

Dedicated resources should be awarded to undertake a comprehensive analysis of the Marine Institute's fisheries data sets in a climate context to inform policy making in the Seafood sector.

Recommendation 10

Resources and funding should be awarded to undertake a more detailed analysis of the existing seabird and mammal data sets (critical trophic components of marine food webs) collected by DECC and DHLGH to discern trends and inform policy development.

2 Current Monitoring Status in Ireland

This report focuses primarily on Essential Ocean Variables (EOVs), many of which are systematically collected in Irish waters. The report provides a focus on the Irish ocean observing system and includes the ocean variables considered in the EPA Climate Report (Camaro-Garcia and Dwyer, *2021*). The main aim is to summarise the spatial and temporal resolution of EOV data sets collected, and identify which data collection activities are mature and sustainably funded. This initial baseline report focuses primarily on data collected by the Marine Institute with limited reference to data collection by other organisations at this point. It is hoped that future iterations of this report will include data sets collected in a climate context by other organisations including the Environmental Protection Agency (EPA), the Geological Survey of Ireland (GSI), the National Parks & Wildlife Service (NPWS) and other relevant data sets in Higher Education Institutes (HEIs).

2.1 Oceanic Observations

The EOVs are a subset of the wider Essential Climate Variables (ECVs) established through the Global Climate Observing System (GCOS). They are chosen to reflect the key oceanic processes of importance to ocean resource management, decision and policy support and climate change adaptation. The EOVs are sub-divided into those needed to monitor and understand physical, biogeochemical and biological and ecosystem processes. This report considers each of these domains and outlines the measurement programmes underway in each area.

2.1.1 Physics

This is defined as the study of the physical processes in the ocean, including ocean interactions with the atmosphere and the cryosphere, ocean circulation patterns, transport and storage of heat and momentum, and ocean physical influences on ecosystem functions that control the uptake of climatically-important gases.

Below are the 11 EOVs listed under the physical processes, all are relevant to Ireland except for Sea Ice.

1. Sea State
2. Ocean Surface Stress
3. Sea Level
4. Sea Surface Temperature
5. Subsurface Temperature
6. Surface Currents
7. Sea Surface Currents
8. Sea Surface Salinity
9. Subsurface Salinity
10. Ocean Surface Heat Flux
11. Sea Ice

Full details of time series length, sampling frequency, policy supported by the networks and degree of maturity are provided in Table 1 (Appendix 1). The full list of EOVs measured by these networks are provided in Table 2 (Appendix 1).

2.1.1.1 Sea State

"Sea State relates to waves (height, wavelength, and period) and swell, typically in terms of height, wavelength, period, and directional wave energy flux. Waves generated by ocean surface stress evolve from wind waves to swell through nonlinear dynamical processes. Wave characteristics are modified by bathymetry when the depth of the water is comparable to the wavelength, and by surface currents. Sea state is most well-known for its impacts on marine safety, marine transport and damage to structures. It is also a substantial modifier of air-sea exchanges of momentum, moisture and CO_2. Waves also impact beach erosion, storm-related water damage (wave set-up contributes to storm surge), surface albedo, and transport of larva and contaminants such as oil. Waves can also modify the growth or decay of sea ice." *Source: GCOS Sea State ECV factsheet and GOOS Panel Physics EOV Sea State specification sheet*

Through a combination of providing services to weather forecasting and ocean energy development, Ireland has established a network of sites where sea state is systematically measured. These include the Irish Marine Data Buoy Observation Network (IMDBON; formerly known as the Irish National Weather Buoy Network) situated around the Irish coast, and the Galway Bay and Atlantic Marine Energy Test Sites (AMETS) in Belmullet, Co. Mayo. In the case of the data buoy network, wave measurements, at some platforms, began in 2001. Wave measurements in Galway Bay and at AMETS extend back to 2006.

Both the Irish Marine Data Buoy Observation Network and the Galway and AMETS test sites are sustainably funded under long-term agreements with DAFM and SEAI respectively. The data from both networks is quality assured and included in the Marine Institute's Quality Management Framework (QMF). Figure 2 shows the key wave monitoring stations in Irish waters.

Key Message

Wave measurements are essential for weather forecasting and safety at sea

The Irish Marine Data Buoy Observation Network (IMDBON) and the Galway and AMETS test sites with support from DAFM (previously the Department of Transport) and SEAI provide essential wave measurements for Ireland.

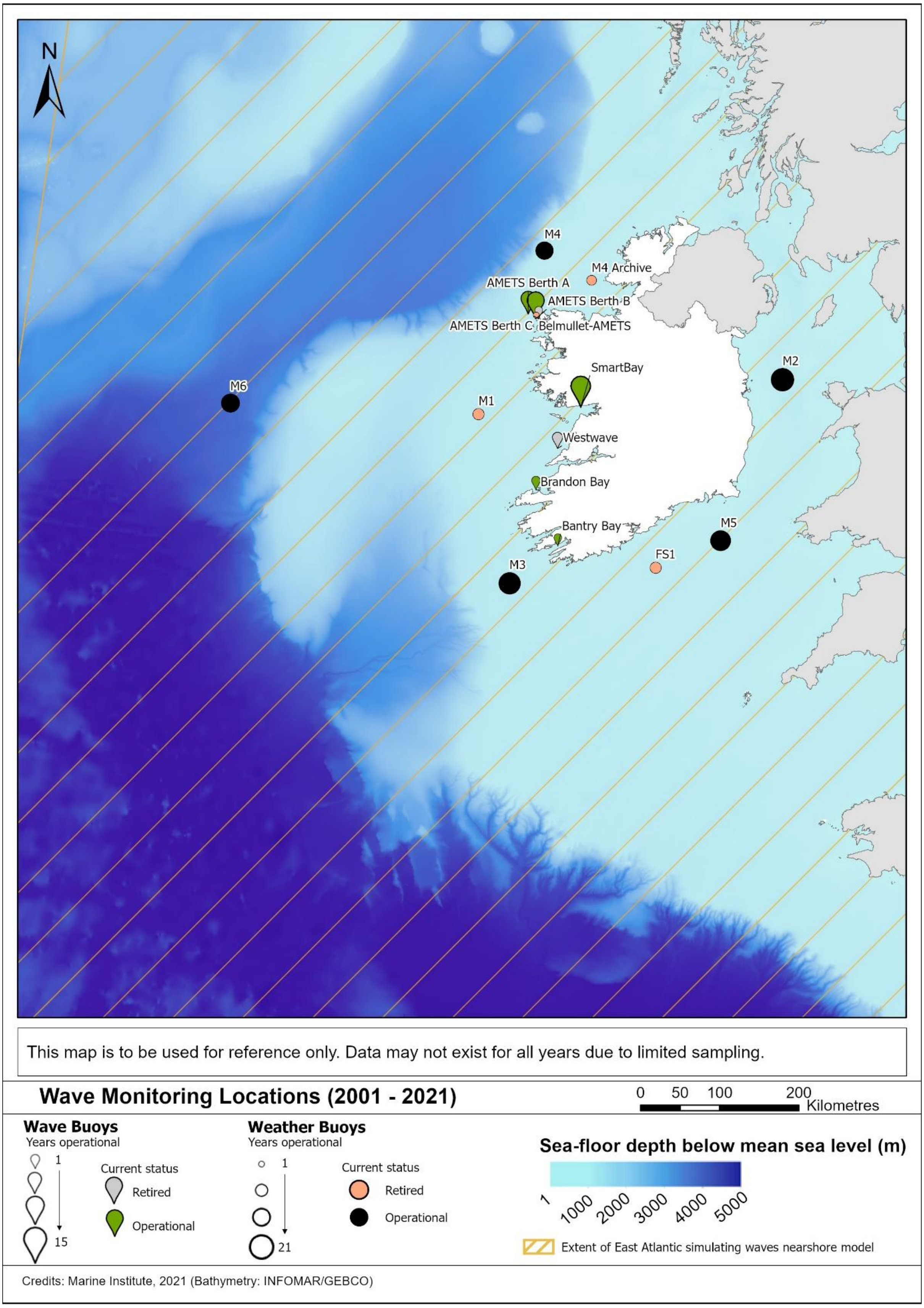

Figure 2 Locations of wave monitoring sites in Irish waters. Note that some sites are no-longer operational (retired). Droplet size at each location indicates the number of years the measurement site is operational. The SWAN wave model domain is shown as a hashed area on the map (see legend for more details).

2.1.1.2 Ocean Surface Stress

"Ocean Surface Stress is the two-dimensional vector drag at the bottom of the atmosphere and the dynamical forcing at the top of the ocean. OSS influences the air-sea exchange of energy, water (evaporation) and gases. Ocean surface stress vector components (u and v) is important for determining the large scale momentum forcing of the ocean, and consequent ocean circulation including ocean upwelling regions. Accurate knowledge of stress magnitudes is also essential for reliable computations of air-sea heat fluxes (e.g. sensible and latent heat fluxes) as well as air-sea gas exchanges and mass fluxes (e.g. CO_2 and fresh water). Stress is also coupled with surface waves, and is hence essential for marine safety." *Source: GCOS Surface Stress ECV factsheet and NOAA*

There are no systematic measurement programmes for ocean surface stress in Irish waters. Some details are provided in Camaro Garcia and Dwyer (2021).

Key Message

Surface stress drives coastal currents, storm surge, and surface waves

There are very limited ocean surface stress measurements recorded in Irish waters.

2.1.1.3 Sea Level

"Sea Level is one of the primary indicators of global climate change. Change in the global mean sea level provides a measure of the net change in ocean mass due to melting of glaciers and ice sheets, and net change in ocean volume due to thermal expansion. Sea level observations characterize inter-seasonal variability such as ENSO. On the regional scales, changes in sea level can be far larger than the globally averaged value due to changes in temperature, salinity and circulation. Along many continental margins vertical land displacement associated with crustal adjustments to past and current land ice melt also cause regional variations in apparent sea level independent of the ocean. Coastal sea level change is a major driver of societal impacts." *Source: GCOS Sea Level ECV factsheet*

The Marine Institute, the Office of Public Works (OPW), Local Authorities and Port Companies make systematic relative sea level measurements around the Irish coast. The "*EPA Gauging Station Register*" is the national inventory of lake, river and tide gauges/recorders. For the marine environment, the longest continuous records for Ireland are from Dublin Port with tide gauge records extending to 1923 and digitised records available from 1938. Another long term Irish tide gauge monitoring station is located at Malin Head, Co. Donegal, the most northerly point of Ireland in operation since 1958. Not all tide gauge measurements can be used for climate change sea level trend monitoring. The high precision standards of the Global Sea Level Observing System (GLOSS) are the benchmark in this respect. It is the intention of the Marine Institute to have pre-operational GLOSS compliant tide gauges at Union Hall, Co. Cork and Howth, Co. Dublin in 2021.

Information in the figures and tables of this report focus on the tide gauge coastal stations operated by the Marine Institute. A more comprehensive overview of sea level monitoring in Ireland is provided by Cámaro García and Dwyer (*2021*). Figure 3 shows the key sea surface height stations in Irish waters, maintained by the Marine Institute.

Key Message

Rising sea level impacts coastal communities

The Marine Institute tide gauge network requires sustainable long term funding. This is important since two GLOSS stations are due to be commissioned later this year to ensure Ireland produces high quality climate data.

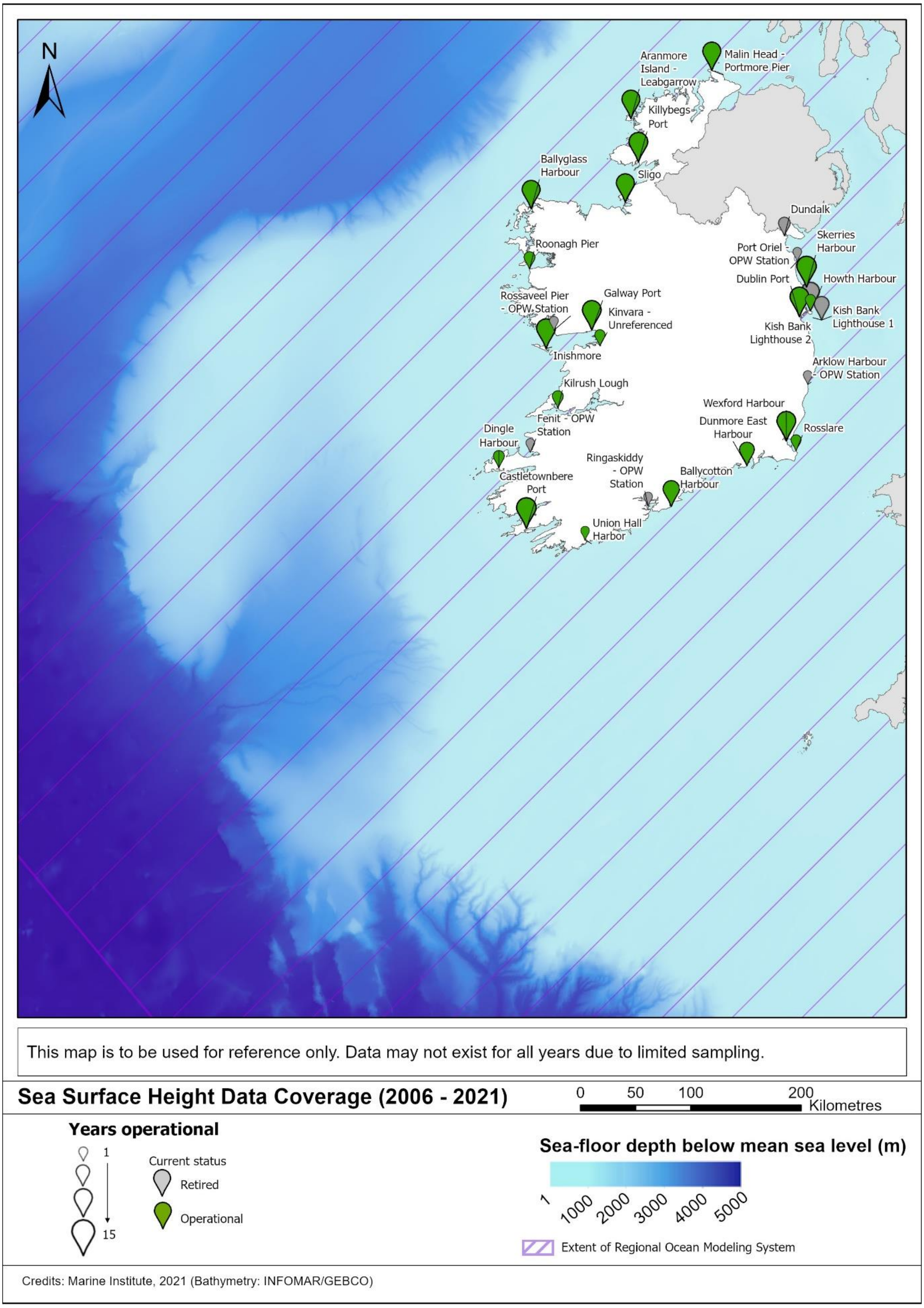

Figure 3 Locations of Marine Institute sea surface height monitoring sites in Irish waters. Note that some sites are no-longer operational (retired). Droplet size at each location indicates the number of years the measurement site is operational. The ROMS hydrodynamic model domain is shown as a hashed area on the map (see legend for more details).

2.1.1.4 Sea Surface Temperature

"Sea Surface temperature (SST) is a vital component of the climate system as it exerts a major influence on the exchanges of energy, momentum and gases between the ocean and atmosphere. SST largely controls the atmospheric response to the ocean at both weather and climate time scales. The spatial patterns of SST reveal the structure of the underlying ocean dynamics, such as, ocean fronts, eddies, coastal upwelling and exchanges between the coastal shelf and open ocean. Surface temperature observations are an important input to data assimilation ocean models that are being used to provide gridded global estimates of ocean circulation at varying spatial and temporal scales. Surface temperature observations are required to further our understanding of the ocean's role in the global energy budget, and to further quantify ocean changes in response to ongoing climate variability and change." *Source: GCOS Sea Surface Temperature ECV factsheet and GOOS SST specification sheet*

Sea surface temperature is one of the key variables identified as an indicator of changing conditions in our oceans. It is of critical importance in terms of ocean-atmosphere exchange and weather prediction and has impacts on many ecosystem processes in the ocean e.g. fish distribution and algal blooms. Increases in sea temperature also contribute to thermal expansion in the ocean and associated sea level rise. Ireland has a well-established network of sea surface temperature stations around the coast and offshore. Met Éireann have maintained a sea surface temperature monitoring station at Malin Head, Co. Donegal since 1959. The time series of sea surface observations at the Malin Head coastal station is inshore of coastal currents and influenced by run-off. The temperature record between 1959 and 2006 was constructed using manual measurements (i.e. water temperature measured using handheld thermometer) while the post-2007 period used an *in-situ* SBE 39 temperature sensor maintained by the Marine Institute. The National University of Ireland, Galway (NUIG) maintained a temperature monitoring station at Carna, Co. Galway from 1974-2003. In recent decades, the Irish Marine Data Buoy Observation Network (IMDBON) has collected SST data. These records extend back to 2001 in some cases. The Marine Institute also established a long-term SST monitoring site at Ballycotton, Co. Cork in 2008. The Marine Institute two national research vessels, RV *Celtic Voyager* and RV *Celtic Explorer* have collected sea surface temperature data underway i.e. along the vessel tracks, since the late 1990s. The quality of the underway SST measurements from the vessels is substantially improved when concurrent Conductivity, Temperature, Depth (CTD) measurements are available for cross calibration.

Figure 4 shows the key sea surface temperature stations in Irish waters maintained by Marine Institute.

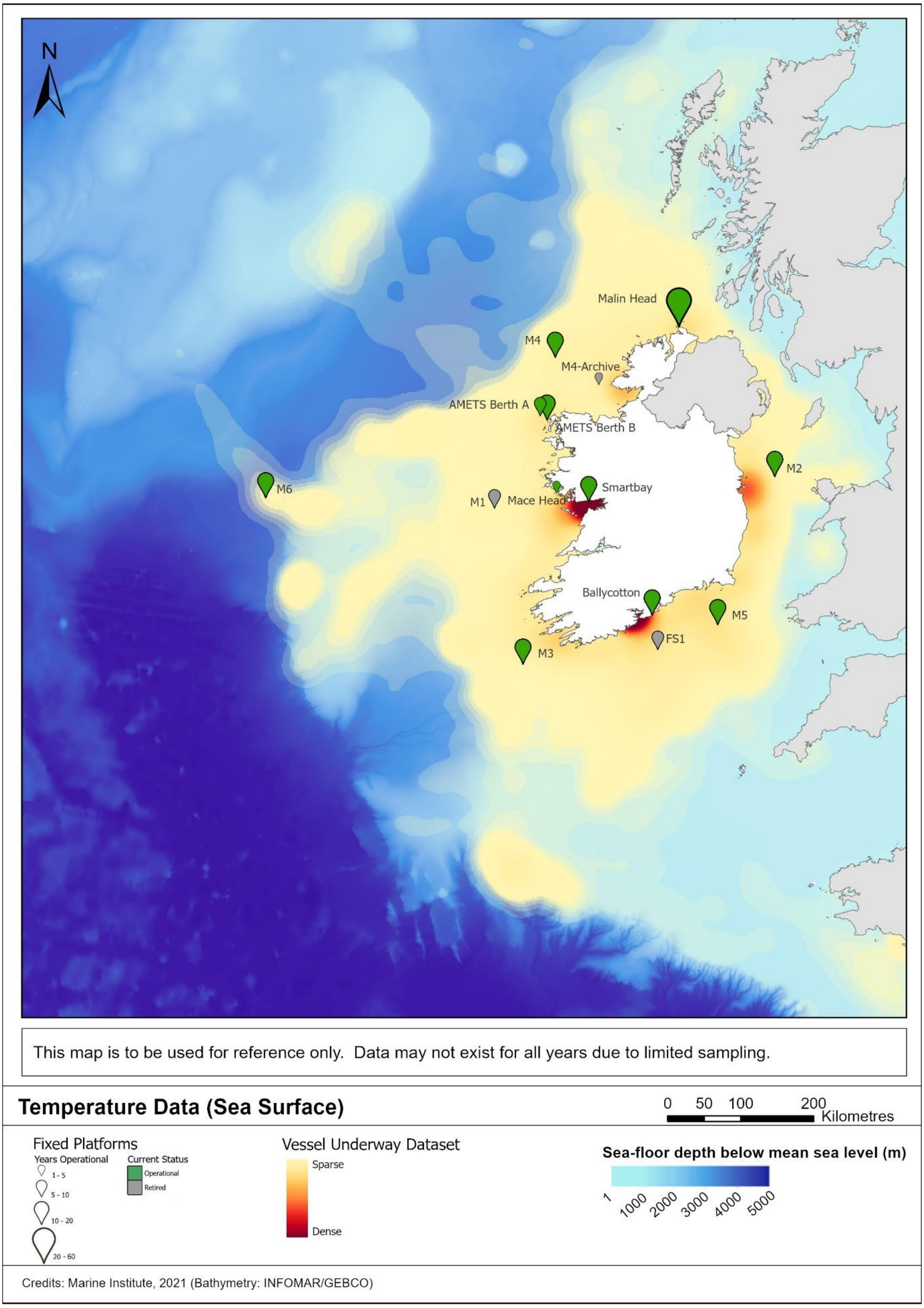

Figure 4 Heat map of sea surface temperature measurements in Irish waters conducted by Marine Institute. Note that some sites are no-longer operational (retired). Droplet size at each location indicates the number of years the measurement site is operational. (see legend for full details)

2.1.1.5 Subsurface Temperature

"Subsurface temperature is a fundamental variable that is required to monitor variability and change in the physical environment of the ocean, energy flows, climate patterns and sea level. Heat uptake by the global ocean accounts for more than 90% of the excess heat trapped in the Earth system in the past few decades. This ocean heat uptake helps to mitigate surface warming but, in turn, increases the global ocean volume through thermal expansion, and thus results in global-mean sea-level rise, accounting for about one third of the increase observed over the past few decades. Changes in subsurface temperature induce changes in mixed-layer depth, thermal/density stratification, mixing rates and currents. All of these physical changes can affect marine biology, not only directly but also indirectly through changes in marine biogeochemistry, such as nutrient and O_2 recycling, uptake of carbon emissions, ocean acidification and so on." *Source: GCOS Subsurface Temperature ECV factsheet and NOAA*

The primary method for collecting subsurface temperature data in Irish waters is through the Conductivity, Temperature, Depth (CTD) measurements made on national research vessel surveys (RV *Celtic Voyager* and RV *Celtic Explorer*). Approximately 500 CTD profiles are made each year from the two vessels combined. Several Marine Institute programmes collect CTD profile data and additional seawater bottle samples to provide robust calibration data and biogeochemical essential ocean variables at multiple depths in the water column (see section 2.1.2 for more details on biogeochemical measurements). These programmes include the Winter Environmental Monitoring Survey, the Water Framework Directive (WFD in TCW; transitional and coastal waters), the Marine Institute Ocean Climate Section Survey and the GO-SHIP TransAtlantic Section A02.

Ship-based CTD data collection is augmented by periodic deployments of moored temperature sensors or CTDs around the Irish coast. In recent years, a deep sea mooring near the M6 buoy location to the west of Ireland was equipped with CTD sensors located at discrete depths throughout the water column to monitor the key water masses in this region. The time series from this location is approximately 2 years in length.

Ireland also contributes to the International Argo programme via membership in the Euro-Argo ERIC. Argo floats generate CTD (and sometimes additional variable) water column profiles down to 1,000 m and the data is archived in an internationally database for open use. Ireland has recently begun to collect oceanographic data using autonomous gliders that collect CTD data in the upper 1,000 m of the water column.

Figure 5 shows the key subsurface temperature stations in Irish waters maintained by the Marine Institute.

Key Message

Changing temperatures impact sea level rise, ocean currents and marine ecosystems.

Temperature measurements are mature in shelf and coastal waters and there is a requirement to increase temperature measurements in the deep waters off Ireland to contribute to international efforts monitoring the Atlantic Meridional Ocean Current (AMOC), a critical part of the global climate system.

The national observing network for sea surface salinity relies on the Irish Marine Data Buoy Observation Network (IMDBON) and national research vessels salinity data.

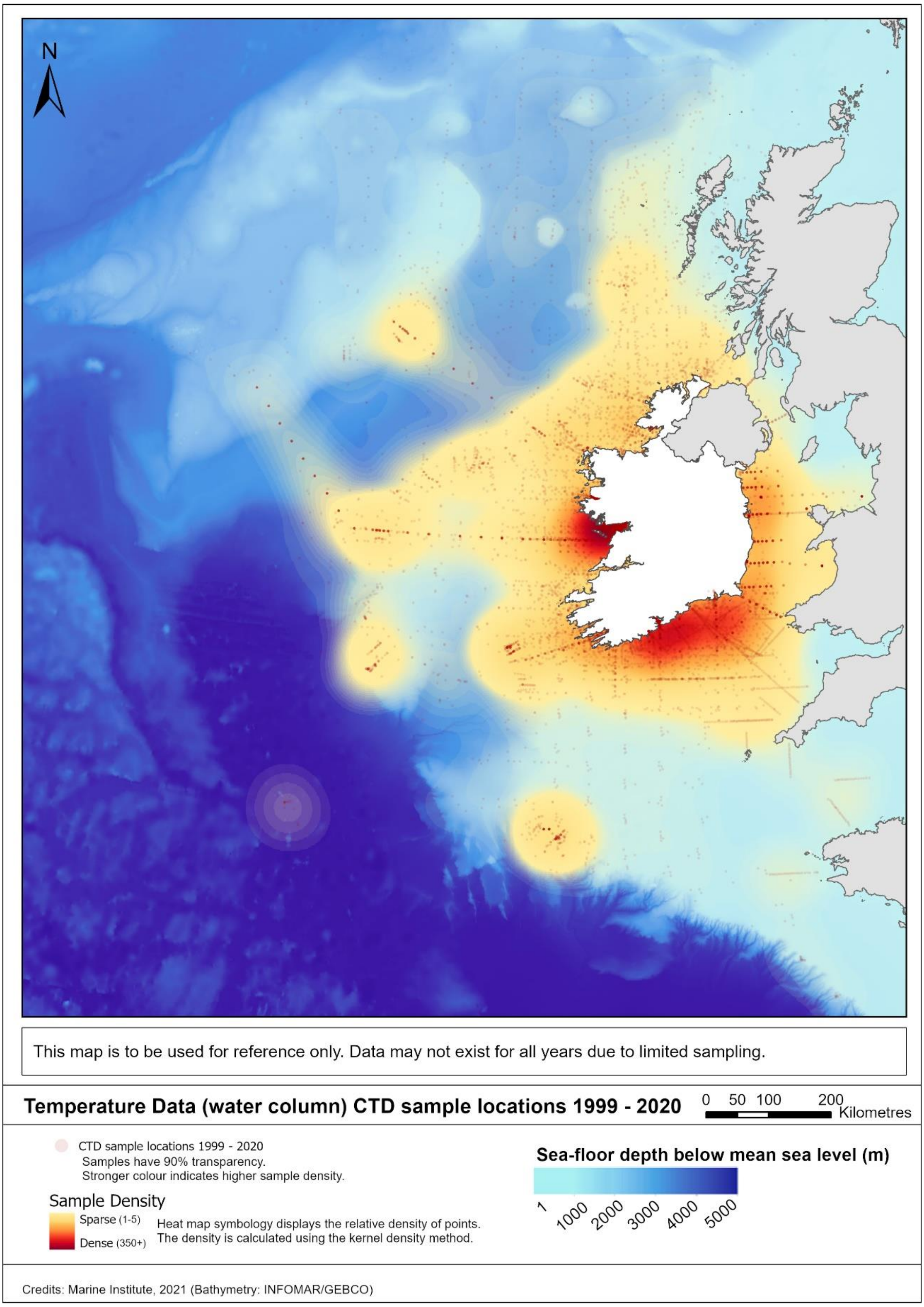

Figure 5 Locations of water column (subsurface) temperature monitoring sites in Irish waters. (see legend for more details).

2.1.1.6 Surface Currents

"The surface ocean general circulation is responsible for significant surface transport of heat, salt, passive tracers and ocean pollutants. On basin scales, surface currents and their variations are a major player in climate to weather fluctuations. The boundary currents on each side of the ocean basins transport significant amounts of heat, salt and passive tracers. Western Boundary Currents in particular transport heat and properties poleward, moderating climate. Convergences/divergences, spiralling eddies, and filaments all contribute to vertical motions and mass exchange. Surface currents impact the steepness of surface waves, and are thus important for generating accurate marine sea state forecasts." *Source: GCOS surface Currents ECV factsheet*

Surface current measurements are very scarce in Irish waters. Acoustic Doppler Current Profilers (ADCPs) are deployed typically on an ad-hoc basis for specific process studies and tend to be very localised and of relatively short duration. Some fixed-point ADCP deployments enable the elucidation of surface currents, but there can be significant errors in calculating currents for the surface layer as the instruments are typically deployed on the seabed looking upward.

A coastal high-frequency (HF) radar measuring surface ocean currents was maintained by NUI, Galway in Galway Bay for several years. These data are not available in the public domain to our knowledge.

2.1.1.7 Subsurface Currents

"Observations of subsurface ocean velocity contribute to estimates of ocean transports of mass, heat, freshwater, and other properties on local, to regional and basin to global scales. They are essential in resolving the wind and buoyancy driven ocean circulation, and the complex vertical velocity structure, for example, in the major ocean boundary currents, tides, equatorial currents, wave propagations, ocean eddies. Vertical velocity profile information can be used to estimate the order of ocean mixing using fine-scale parameterizations of turbulent dissipation by internal wave breaking. Velocity estimates can be combined in data assimilation models to provide gridded global estimates of ocean circulation at varying temporal and spatial scales." *Source: GCOS Subsurface Currents ECV factsheet*

Subsurface currents are measured systematically at the Galway Bay Observatory and at the Mace Head observation site in Carna, Co. Galway. The technology employed in both cases is an ADCP. The measurement record in Galway Bay is approximately 5 years in length while water column currents have been measured at Mace Head for approximately 3 years.

Both national research vessels operate vessel-mounted ADCPs. These have been used successfully in particular on the Ocean Climate Section Surveys along the ships track. These data sets require specialised post-processing to separate tidal velocities and ships speed to produce estimates of residual currents. A sample of some of the ship-mounted ADCP transects undertaken by the RV *Celtic Explorer* are included on figure 6 below.

Figure 6 shows the subsurface current measurement sites in Irish waters maintained by the Marine Institute.

Key Message

Ocean currents transport heat, salt, plankton, larvae and pollutants around our coast

Current measurements inform policy makers about the transport pathways of biological populations and hazards such as oil and provide information about the status of the Atlantic Meridional Ocean Circulation (AMOC), an important oceanographic feature that can help to monitor climate change.

Current measurements in Irish waters are sparse.

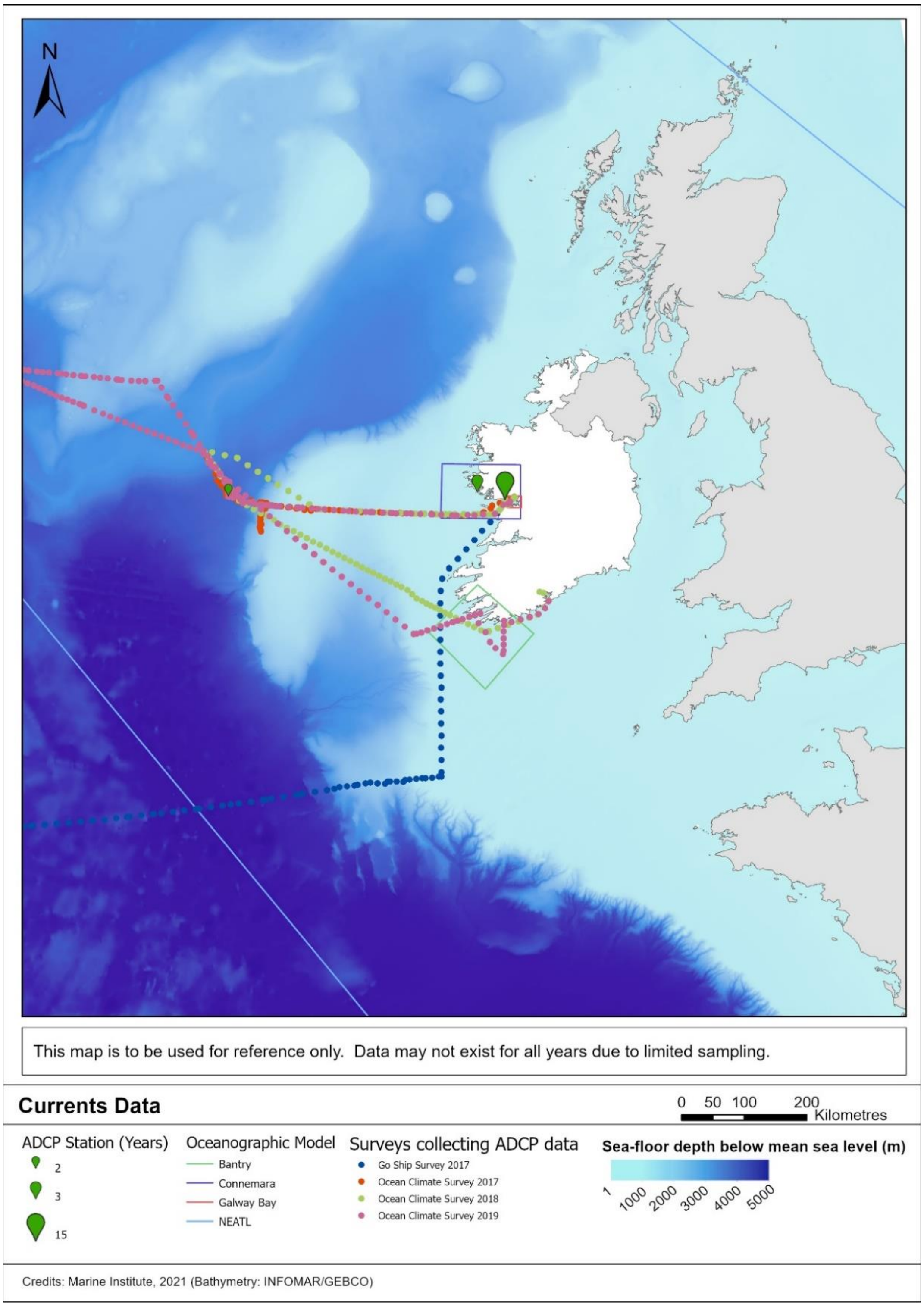

Figure 6 Subsurface current measurement sites in Irish waters including fixed point stations (droplets) and vessel-mounted ADCP transects. Geographic extents of ocean models producing surface and subsurface currents are shown as boxes (see legend for details).

2.1.1.8 Sea Surface Salinity

"Sea surface salinity observations contribute to monitoring the global water cycle (evaporation, precipitation and glacier and river runoff). On large scales, surface salinity can be used to infer long-term changes of the global hydrological cycle. Surface salinity, together with surface temperature, is indicative of the surface expression of ocean frontal features and eddies." *Source: GCOS Sea Surface Salinity ECV factsheet*

Sea surface salinity (SSS) is an important indicator of changing conditions in our oceans. It impacts on many key processes in the ocean e.g. ocean acidification, fish distribution, and frontal location. Changes in surface salinity influence the location of oceanic fronts and density gradients in the coastal seas in particular. Ireland has a well-established network of sea surface temperature stations around the coast and offshore. The Irish Marine Data Buoy Observation Network (IMDBON) routinely collects SSS data. These records extend back to 2001 in some cases. The Marine Institute also measures surface salinity at the Galway Bay Observatory and at the AMETS berth B offshore Belmullet, Co. Mayo. The Marine Institute also utilises the two national research vessels to collect sea surface salinity data underway i.e. along the vessel tracks, since the late 1990s. The quality of the underway SSS measurements from the vessels is substantially improved when concurrent Conductivity, Temperature, Depth (CTD) profiles, including bottle samples are available for cross calibration.

Figure 7 shows the key sea surface salinity stations in Irish waters maintained by the Marine Institute.

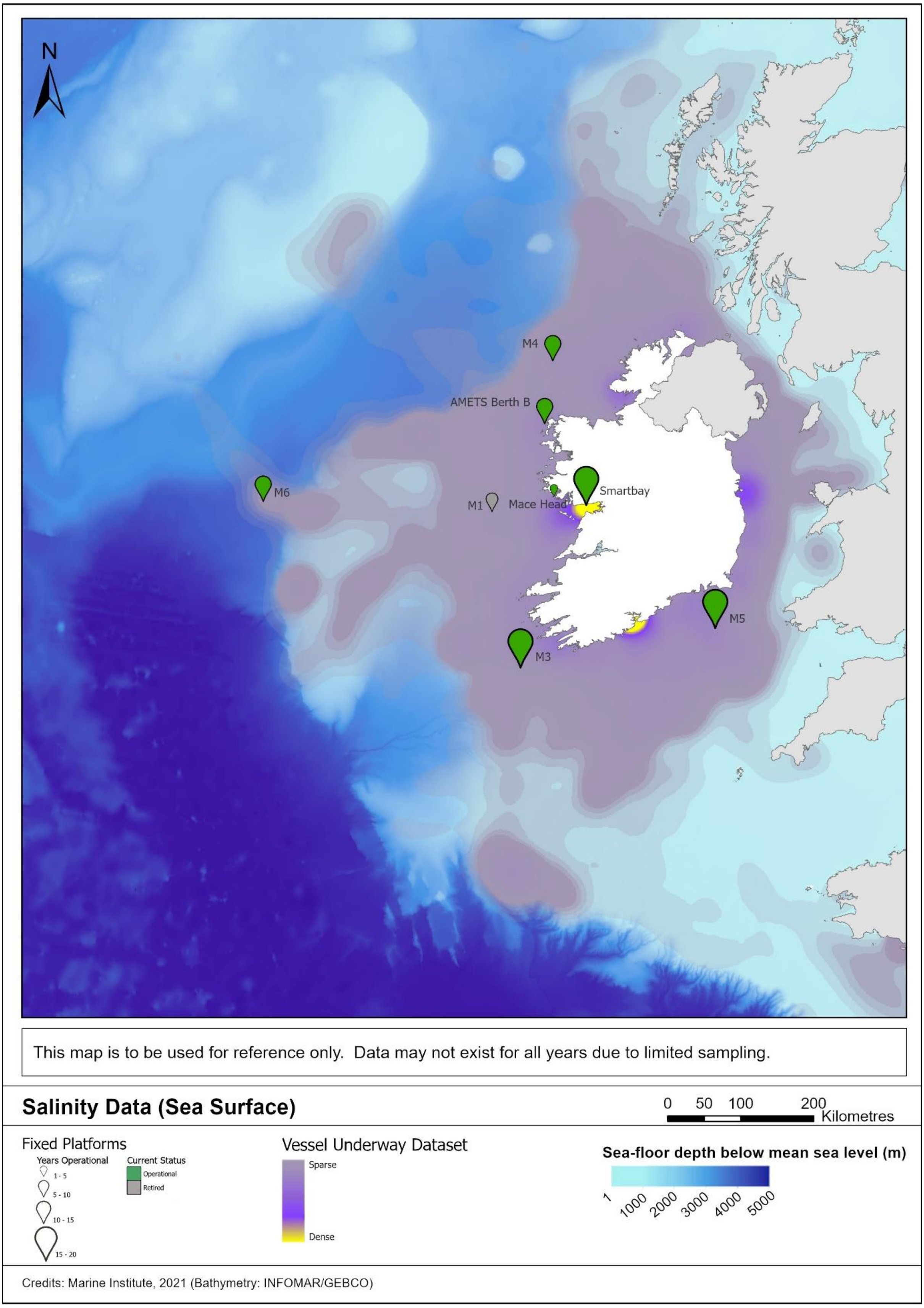

Figure 7 Heat map of surface salinity measurements in Irish waters conducted by Marine Institute. Note that some sites are no-longer operational (retired). Droplet size at each location indicates the number of years the measurement site is operational. (see legend for full details)

2.1.1.9 Subsurface Salinity

"The global subsurface salinity observing system is vital for closure of the global hydrological cycle, estimates of oceanic evaporation and precipitation, and halosteric component of sea level change. Subsurface salinity are required to calculate i*n-situ* density and ocean freshwater transports, respectively, and coincident subsurface observations of salinity, temperature and pressure provide an estimate of the ocean geostrophic velocity. In addition, subsurface salinity is used to derive large-scale gridded climate products including ocean velocity, mixed-layer depth, density stratification, sea level and indirect subsurface ocean mixing used in many weather and climate applications." *Source: GCOS Suburface Salinity ECV factsheet*

The primary method for collecting subsurface salinity data in Irish waters is with CTD measurements taken on board the national research vessels. Approximately 500 CTD water column profiles are collected each year from the two vessels combined. Several Marine Institute programmes collect CTD profile data and additional bottle samples to provide robust calibration data and biogeochemical essential ocean variables at multiple depths in the water column (see section 2.1.2 for more details on biogeochemical measurements). These programmes include the Winter Environmental Monitoring Survey, the Water Framework Directive (TCW), the Ocean Climate Section Survey and the GO-SHIP TransAtlantic Section A02.

Ship-based CTD data collection is augmented by periodic deployments of moored CTDs around the Irish coast. In recent years a deep sea mooring near the M6 buoy location equipped with CTD sensors throughout the water column monitors the key water masses in this region. The time series from this location is approximately 2 years in length.

Argo Ireland floats and autonomous gliders also generate CTD (and sometimes additional variable) water column profiles providing open access data.

Figure 8 shows the key subsurface salinity stations in Irish waters maintained by the Marine Institute.

Key Message

Changes in salinity impact marine ecosystems

Salinity is used to identify important oceanic features and provides information related to the global water cycle.

Salinity measurements are mature in shelf and coastal waters and there is a requirement to increase temperature measurements in the deep waters off Ireland to contribute to international efforts monitoring the Atlantic Meridional Ocean Current (AMOC), an important part of the global climate system. The national observing network for sea surface salinity relies on the Irish Marine Data Buoy Observation Network (IMDBON) and national research vessels salinity data.

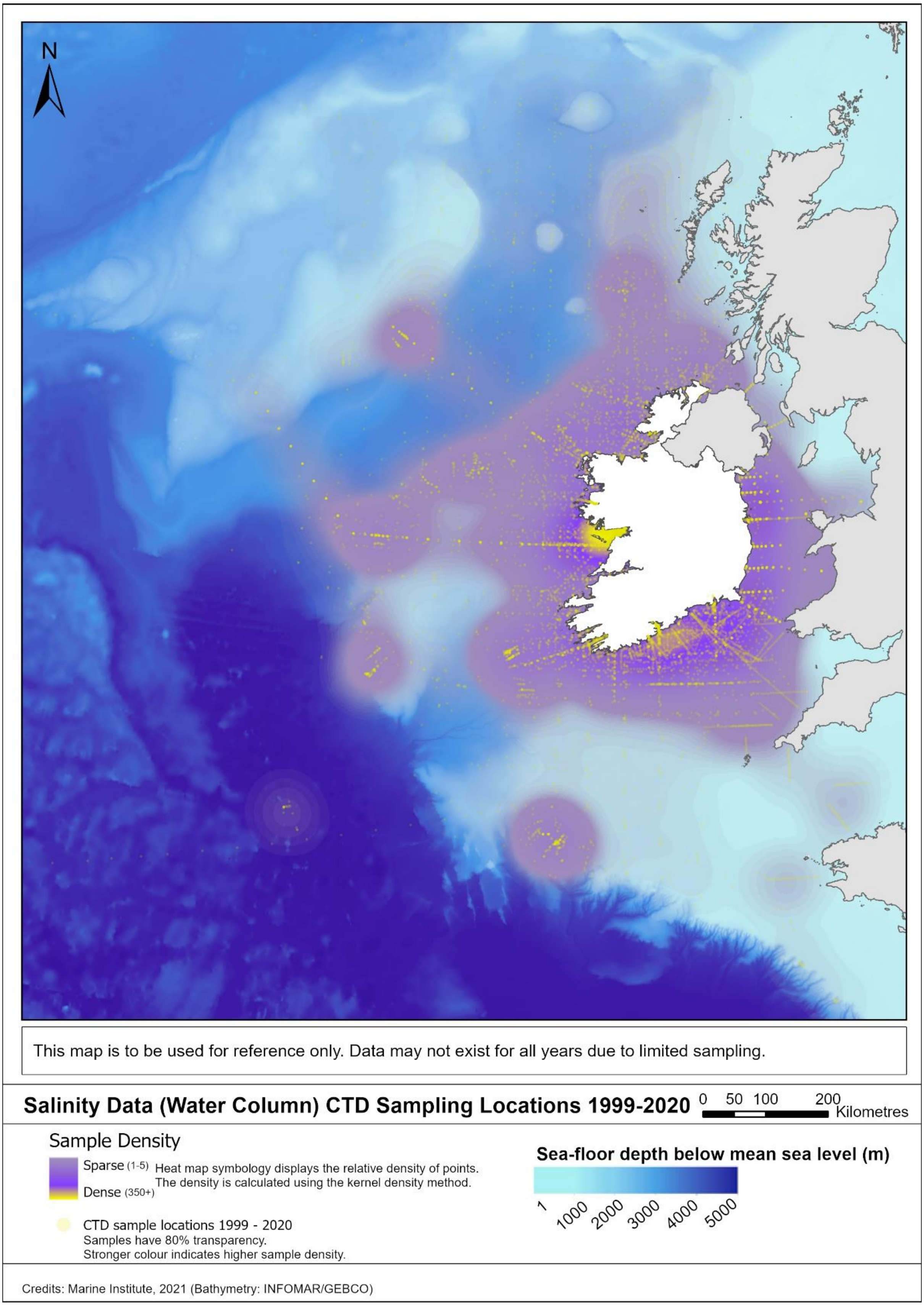

Figure 8 Locations of water column (subsurface) salinity monitoring sites in Irish waters. (see legend for more details).

2.1.1.10 Ocean Surface Heat Flux

"Surface heat flux is exchange of heat, per unit area, crossing the surface between the ocean and the atmosphere. It consists of the turbulent and the radiative components. These fluxes are major contributors to the energy and moisture budgets, and are largely responsible for thermodynamic coupling the ocean and atmosphere at global and regional scales, and variability of these fluxes is in part related to large-scale variability in weather and climate patterns." *Source: GCOS Ocean Surface Heat Flux ECV factsheet*

There are no systematic measurement programmes for ocean surface heat flux in Irish waters. Some details are provided in Camaro Garcia and Dwyer (2021).

2.1.2 Biogeochemistry

This wide ranging interdisciplinary science focuses on chemical and biological processes interacting with ocean physics and geology. Biogeochemistry ocean observing activities are commonly focused on environmental threats e.g. human induced pollution (pelagic and sediment), habitat degradation, ocean acidification, deoxygenation in pelagic and benthic environments, over exploitation of fisheries, biodiversity decline etc. Studies span from the land-sea interface (estuarine and coastal water environments) to the open ocean. This wide ranging field, covers multiple marine habitat types e.g. mudflats, sandflats, rocky shores, pelagic and sedimentary habitats, deep sea hydrothermal vents, reefs etc.

Below are the 6 EOVs listed under the biogeochemical processes, all are relevant to Ireland.

1. Oxygen
2. Nutrients
3. Inorganic Carbon
4. Transient Tracers
5. Nitrous Oxide
6. Ocean Colour

Full details of time series length, sampling frequency, policy supported by the networks and degree of maturity are provided in Table 1 (Appendix 1). The full list of Essential Ocean Variables measured by these networks are provided in Table 2 (Appendix 1).

2.1.2.1 Oxygen

"Oxygen (O_2) is essential for nearly all multicellular life. Subsurface oxygen concentrations reflect a balance between supply through circulation and ventilation and consumption by respiratory processes. Changes in either of these processes is susceptible to lead to changes in O_2 distribution. A global ocean O_2 observing network will act as a sensitive early warning system for trends that climate change is causing. Ocean deoxygenation (decline in O_2 concentration) is under way in part because of ocean warming and increased stratification, but also because of increased nutrient loads in the coastal ocean. Deoxygenation has been largely under the radar to most people including policy advisers and decision makers. Yet it is deoxygenation that will have profound implications not just for ecosystems but also for communities and economies that depend on a healthy ocean." *Source: GCOS Oxygen ECV factsheet*

Oxygen is a key water quality measurement in coastal and inshore waters as dissolved oxygen deficency is a key indicator of eutrophication due to excess nutrient inputs. Global ocean deoxygenation is also a consequence of climate change. The collection of oxygen data in Irish waters is usually connected with monitoring on dedicated oceanographic surveys on the two national research vessels. Sampling began in 2004.

Dissolved oxygen is routinely measured using electrode or optode sensors but the reference method for calibration of sensors remains a chemical analysis (Winkler titration). Approximately 500 CTD profiles are made each year from the two vessels combined. Several Marine Institute programmes collect CTD profile data and additional bottle samples to provide robust calibration data and biogeochemical essential ocean variables at multiple depths in the water column. Oxygen profiles are collected on a subset of these CTD casts. Bottle water samples for Winkler titration are also collected at multiple depths on the Ocean Climate Survey (e.g. 320 samples collected/analysed on 2021 Ocean Climate Section Survey). The surveys where oxygen profiles are collected include the annual Winter Environmental Monitoring Survey, the annual Ocean Climate Section Survey and the GO-SHIP TransAtlantic Section A02. Oxygen data are also collected at the Galway Bay Observatory, Mace Head Observatory and at the Marine Institute stations in Newport, Co. Mayo.

Ireland also contributes to the International Argo programme via Euro-Argo ERIC. A small number of Argo floats deployed from Ireland include dissolved oxygen sensors. It is also feasible to collect oxygen data using autonomous gliders in the upper 1,000m of the water column.

Figure 9 shows the key oxygen stations in Irish waters maintained by the Marine Institute. The EPA and the Marine Institute routinely sample for oxygen in coastal and estuarine waters for the Water Framework Directive using multiparameter sondes.

Key Message

Deoxygenation negatively impact marine ecosystems

Oxygen provides information on the status of ocean health.

Oxygen measurements are mature in coastal waters with limited measurements in Irish shelf seas and deep waters.

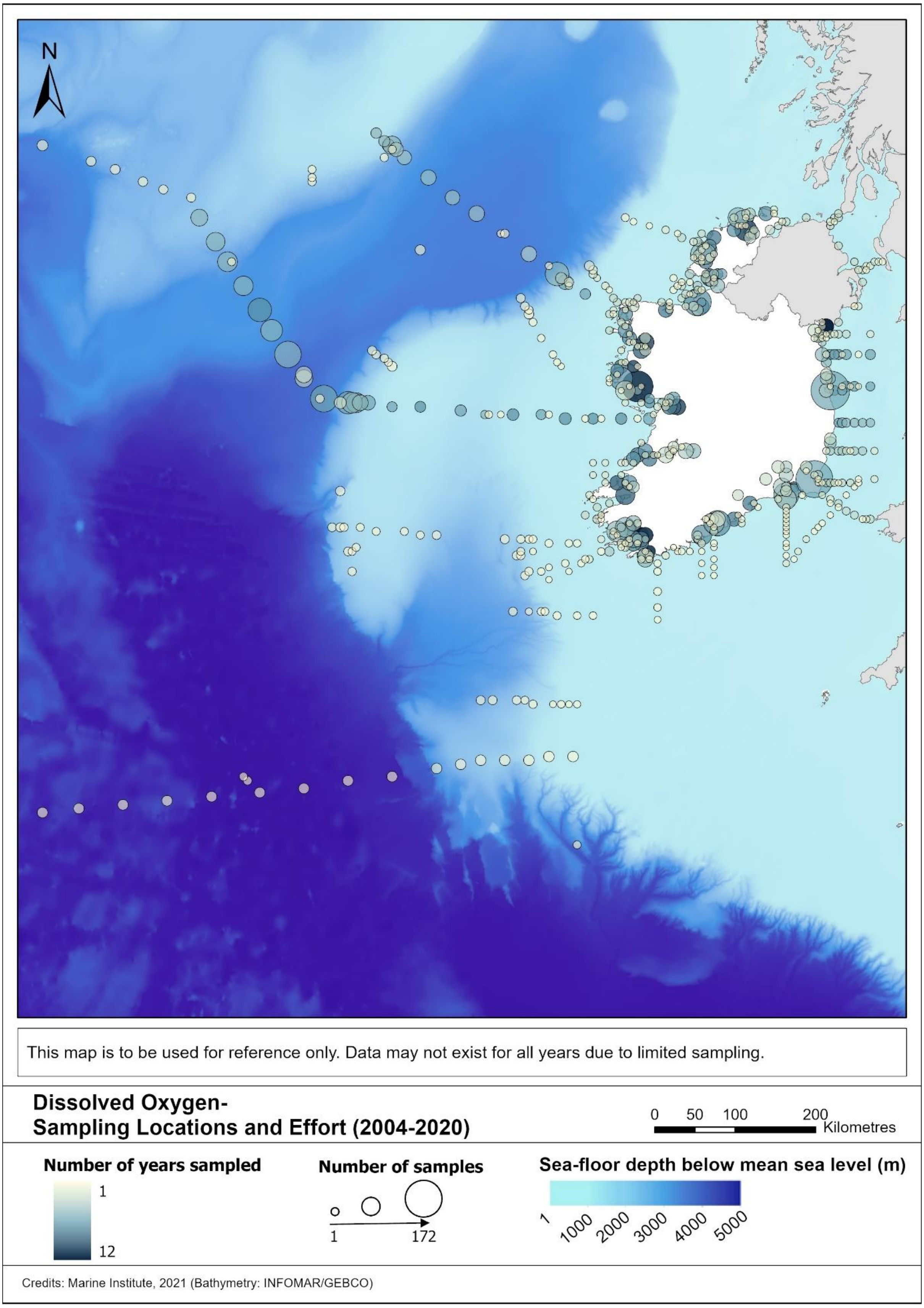

Figure 9. Heat map of dissolved oxygen measurements in Irish waters conducted by Marine Institute.

2.1.2.2 Nutrients

"Nutrients are essential for ocean life. Nutrient data provide important biogeochemical information, and provide essential links between physical climate variability and ecosystem variability. They can provide additional information on ocean mixing and climate related phenomena such as changes in primary and export production (nutrient transports regulate new production which is correlated with export production), eutrophication and shifts in phytoplankton community composition. Therefore it is necessary to develop accurate observations of trends in dissolved nutrients in both upper- and deep-ocean waters." *Source* *GCOS Nutrients ECV factsheet*

Dissolved inorganic nutrients are essential to primary productivity and the concentrations are a limiting factor controlling plant growth. Excess nutrients can cause eutrophication. The collection of dissolved inorganic nutrient data (total oxidised nitrogen, nitrite, phsosphate and silicate) in Irish waters is generally carried out on two dedicated chemical oceanographic cruises on the national research vessels. Sampling began in 1991, initially in the Irish Sea, but subsequently extending to all coastal and shelf waters around Ireland, in support of international commitments that Ireland has regarding eutrophication and water quality monitoring (e.g. OSPAR Coordinated Environmental Monitoring Programme and European Water Framework and Marine Strategy Directives). These data are combined with inshore nutrients data collected by the EPA for this purpose.

Discrete water samples are collected at various depths using the bottle rosette on the CTD/rosette instrument package for subsequent on-board or on-shore laboratory measurement of nutrients. Additionally, underway surface samples are collected for analysis using the ship's pump on the RV *Celtic Voyager*. Figure 10 shows the geographic locations and sample density of nutrient samples collected in Irish waters since 1991. The surveys where nutrient samples are collected include the Winter Environmental Monitoring Survey which samples coastal and shelf waters, the Ocean Climate Section survey and the GO-SHIP TransAtlantic Section A02. Nutrient data are also collected at the Mace Head, Co. Galway in recent years as part of the Interreg COMPASS project.

The Marine Institute is accredited to ISO 17025 for the analysis of dissolved nutrients in estuarine and sea water. Nutrient data are submitted annually to the ICES data centre/OSPAR.

The EPA also routinely sample for nutrients typically in the coastal, estuarine and inland waters.

Key Message

Nutrients are essential for ocean life

Nutrients provides information on the status of ocean health.

Nutrient measurements are mature in coastal waters with limited measurements in Irish shelf seas and deep waters.

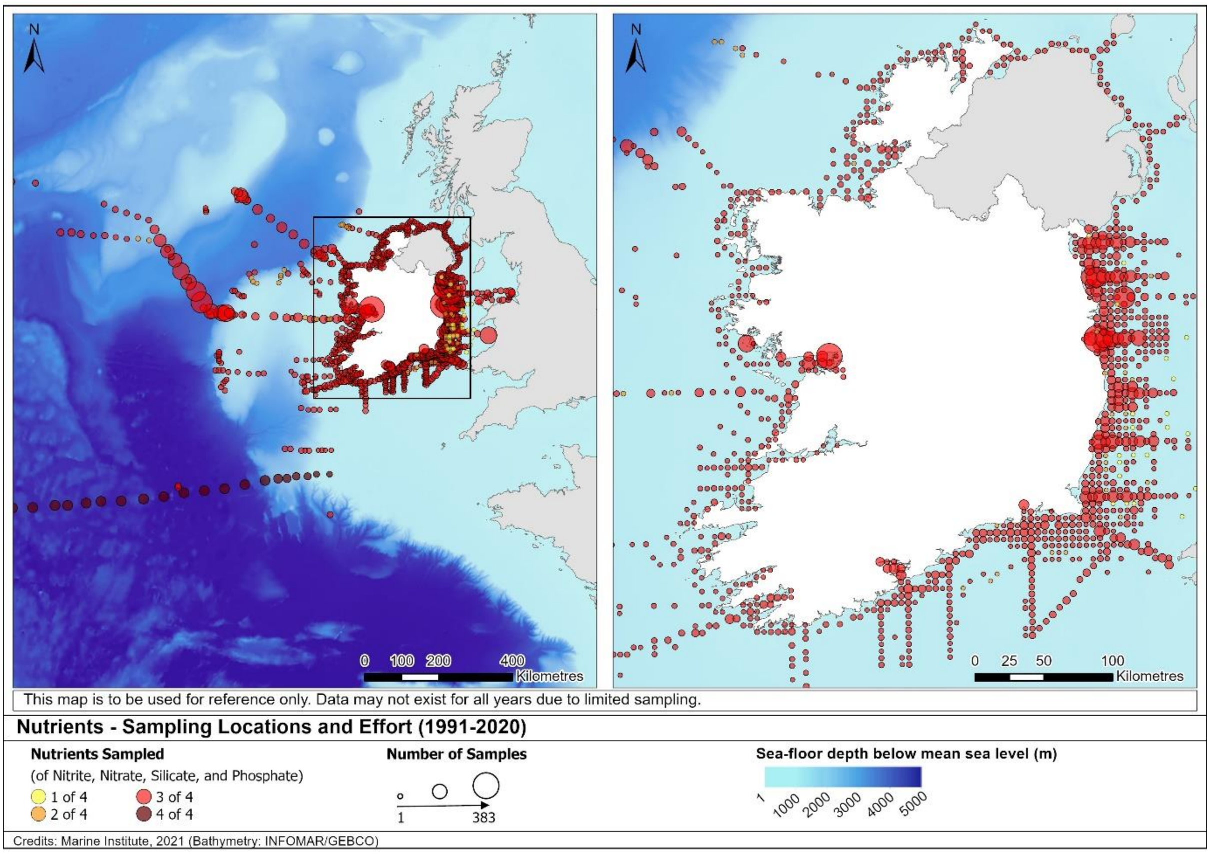

Figure 10 Heat map of nutrient measurements in Irish waters conducted by Marine Institute since 1991 (see legend for more details)

2.1.2.3 Inorganic Carbon

"The ocean is a major component of the global carbon cycle, absorbing enormous quantities of carbon in natural cycles driven by the ocean circulation, biogeochemistry and biology. Since seawater has a very high capacity for absorbing carbon, the ocean has an inhibitory effect on the atmospheric accumulation of carbon dioxide and related greenhouse effect. The net ocean carbon uptake depends significantly on chemical and biological activity, and therefore it varies due to changing oceanic conditions and ecosystem composition. The chemical pathways of the inorganic carbon in the ocean mean that this uptake causes a decline in ocean pH, also known as ocean acidification." *Source: GCOS Inorganic Carbon ECV factsheet*

Increasing ocean uptake of carbon dioxide (CO_2) from the atmosphere due to anthropogenic activities, such as fossil fuel use, causes changes in ocean chemistry, leading to a decrease in the pH of seawater. This process is referred to as ocean acidification. To measure ocean acidification, at least two of the carbonate system parameters (DIC, TA, pH and pCO_2) must be measured, with DIC and TA, generally the preferred combination for high accuracy climate measurements. The measurement of dissolved inorganic carbon (DIC), total alkalinity (TA) and partial pressure of CO_2 (pCO_2 - a measure of dissolved carbon dioxide), allows us to determine changes in pH and will also assist in detecting long term trends in the carbonate system.

Laboratory measurements of DIC and TA from bottle samples, collected at multiple depths using the CTD rosette, have been taken regularly on two annual surveys in Irish waters since 2008; the Winter Environmental Survey and the Ocean Climate Section Survey, and also on a number of other research surveys. The decadal GO-SHIP TransAtlantic Section A02 also collected DIC and TA data across the Atlantic, but with limited activity in Irish waters. Figure 12 shows the geographic locations and sample density of DIC samples collected in Irish waters since 2008. Dissolved inorganic carbon samples are also collected at the Mace Head, Co. Galway in recent years as part of the INTERREG COMPASS project, which also includes a semi-continuous pCO_2 sensor. The DIC/TA measurements provide good depth and temporal coverage, but the spatial coverage is currently limited. This data is the outcome of a series of collaborative one-off projects between NUI Galway and the Marine Institute with currently no long term programme to sustain these measurements.

A pCO_2 system was installed on the RV *Celtic Explorer* in 2017. The system collects underway measurements on a semi-continuous basis for most of the RV *Celtic Explorer* surveys and provides good spatial and temporal coverage of surface waters. Areas where the vessel works or transits frequently are evident as a darker colour in the pCO_2 heatmap (Fig. 11). The coverage of pCO_2 in the Irish Sea is sparse compared to other areas around the Irish coast as the RV *Celtic Explorer* works mainly to the north, west and south of Ireland.

pCO_2 data collected are quality controlled and submitted annually to the Surface Ocean CO_2 Atlas (SOCAT) where they are widely used. DIC/TA data are also reported to the ICES datacentre/OSPAR Commission and carbonate system data will form basis of reporting to IOC to fulfil requirements under UN Sustainable Development Goal 14.3.

Key Message

Ocean acidification negatively impacts marine life e.g. corals

Inorganic carbon provides information on ocean acidification

Carbon measurements are sparse in Irish waters and limited to short-duration research projects.

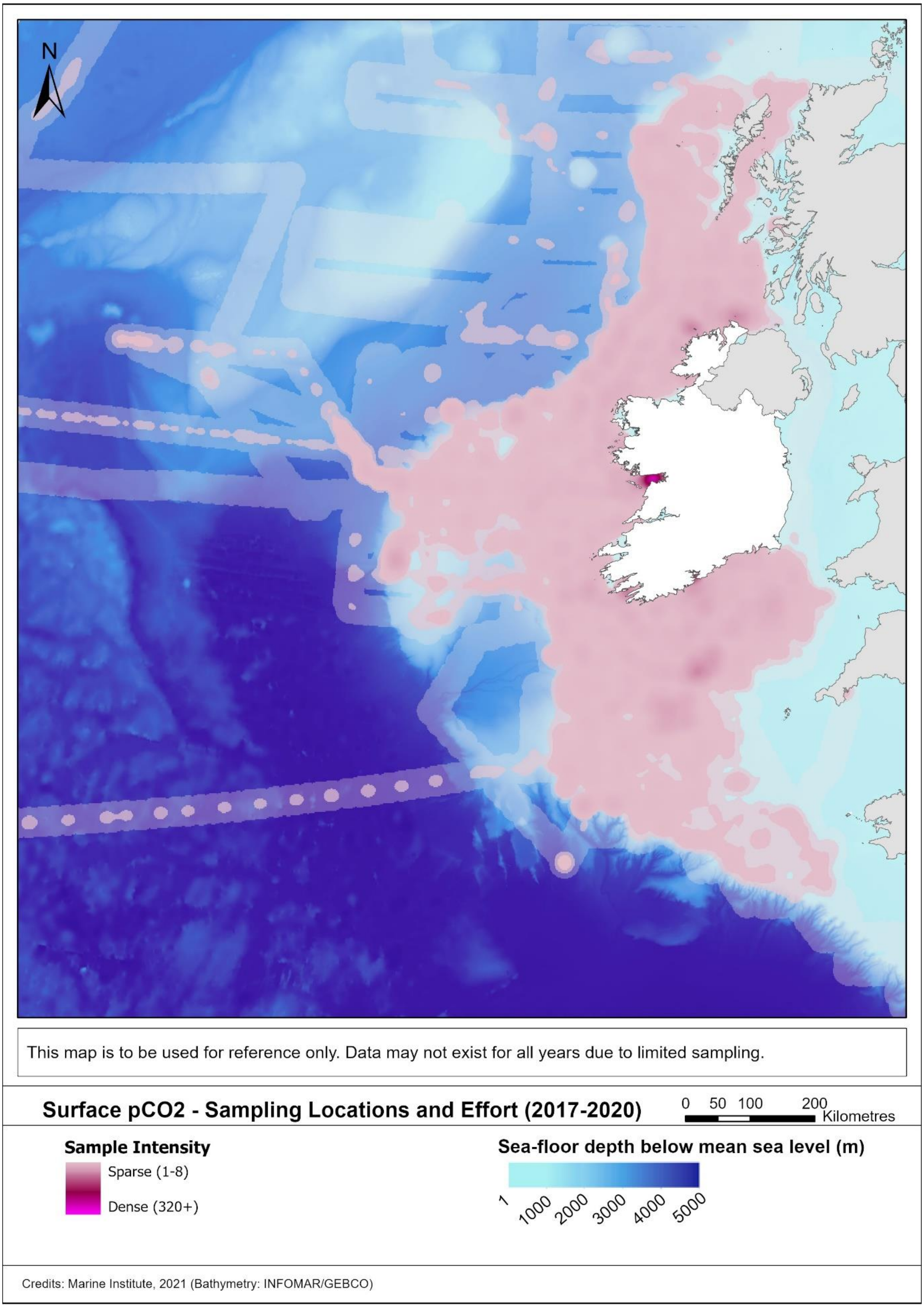

Figure 11 Heat map of pCO_2 measurements in Irish waters conducted by Marine Institute.

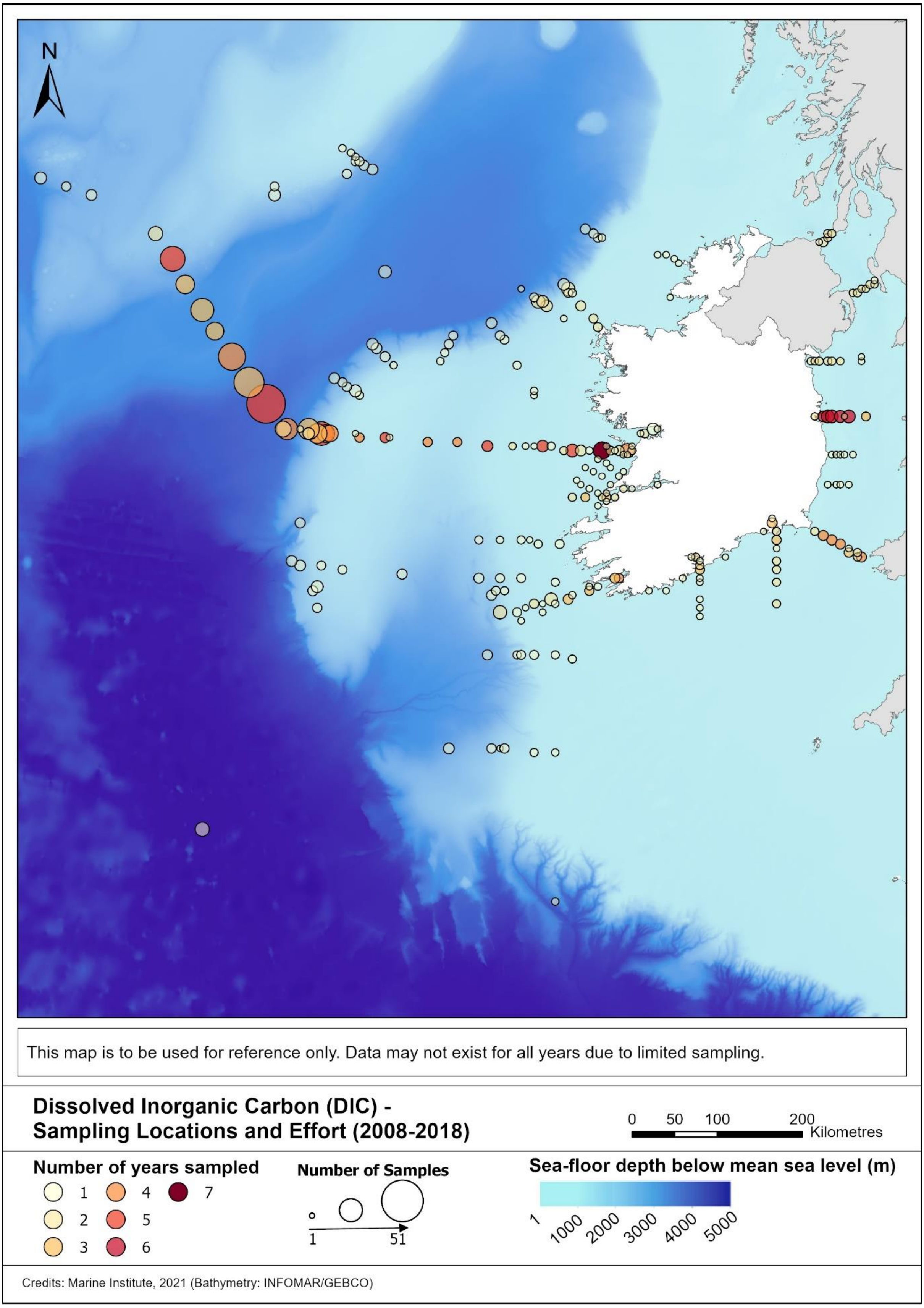

Figure 12 Heat map of dissolved inorganic carbon measurements in Irish waters conducted by Marine Institute.

2.1.2.4 Transient Tracers

"Transient tracers are man-made chemical compounds released to the atmosphere at known quantities that can be used in the ocean to quantify ventilation, transit time distribution and transport time-scales. Measurement of transient tracers in the subsurface ocean thus provides information on the time-scales since the ocean was ventilated, i.e. in contact with the atmosphere. A combination of these tracers provide the means to constrain the transit time distribution (TTD) of a water-mass that allows inference of concentrations or fates of other transient compounds, such as anthropogenic carbon or nitrous oxide." *Source:* *GCOS Inorganic Transient Tracers ECV factsheet*

Some limited detail on these Essential Ocean Variables is included in the EPA Climate State Report 2021 (Camaro Garcia and Dwyer, 2021). To date, the Marine Institute has in collaboration with the National University of Galway and GEOMAR (Helmholtz-Zentrum für Ozeanforschung Kiel) in Germany collected information on transient tracers (chlorofluorocarbons) on the 2017 GO-SHIP A02 TransAtlantic line and from the south Rockall Trough in 2019.

Key Message

Transient tracers study ocean currents

To date there is limited measurements of CFCs in Irish waters; restricted to the two surveys (the MI Annual Ocean Climate Survey in the South Rockall Trough and the Go-Ship A02 Trans-Atlantic Survey.

2.1.2.5 Nitrous Oxide

"Nitrous oxide (N_2O) is an important climate-relevant trace gas in the Earth's atmosphere. In the troposphere it acts as a strong greenhouse gas and in the stratosphere it acts as an ozone depleting substance because it is the precursor of ozone depleting nitric oxide radicals. The ocean - including its coastal areas such as continental shelves, estuaries and upwelling areas - contribute about 30 % to the atmospheric N_2O budget." *Source:* *GCOS Nitrous Oxide ECV factsheet*

Some limited detail on these Essential Ocean Variables is included in the EPA Climate State Report (Camaro Garcia and Dwyer, 2021).

2.1.2.6 Ocean Colour

"Ocean colour is the radiance emanating from the ocean normalised by the irradiance illuminating the ocean. Products derived from ocean colour remote sensing (OCRS) contain information on the ocean albedo and information on the constituents of the seawater, in particular, phytoplankton pigments such as chlorophyll-a. OCRS products are used to assess ocean ecosystem health and productivity, and the role of the oceans in the global carbon cycle, to manage living marine resources, and to quantify the impacts of climate variability and change." *Source:* *GCOS Ocean Colour ECV factsheet*

The Marine Institute is currently funding a Cullen PhD fellowship research project focused primarily on harmful phytoplankton. The project is working to set-up and collect in-air ocean colour measurements, useful to validate satellite data, using multispectral radiometers on-board the RV *Celtic Explorer*. Activities are presently at the preoperational stage and further work is required to build the system toward an operational programme. Ocean colour is also used in the Marine Institute weekly harmful algal bloom bulletin to identify potentially harmful high biomass phytoplankton blooms that present in surface waters.

Key Message

Ocean colour is used to assess ecosystem health and productivity

Ocean surface colour derived satellite data products have great potential to support Ireland reporting requirements for the MSFD and WFD since it is possible to capture information on large ocean surface areas on cloud free days. However, government investment is required to build and sustain national capacity in this area.

2.1.3 Biology & Ecosystems

The science that studies plants and animals and how they interact with chemical and physical processes in different habitats. Since it is not possible to measure everything, EOVs are used to observe and monitor changes in marine biodiversity, ecosystem function, and the services they provide.

"Marine coastal regions are amongst the most productive systems of the planet, yet they are undergoing rapid transformations in response to intensifying human activities and global change. Regime shifts, abrupt transitions between alternative states, are increasingly observed in a wide range of coastal systems, including coral reefs, macroalgal forests, seagrasses and mangroves. These non-linear responses to deteriorating environmental conditions often result in considerable loss of ecosystem functions and services." *Source:* *GCOS Marine Habitats factsheet*

Below are the 10 EOVs listed under the biology and ecosystem; all are relevant to Ireland except for Mangrove.

1. Phytoplankton, Biomass & Diversity
2. Zooplankton, Biomass & Diversity

3. Fish Abundance & Distribution
4. Marine Turtles, Birds, Mammal Abundance & Distribution
5. Hard coral cover and composition
6. Seagrass Cover & Composition
7. Macroalgal Cover & Composition
8. Mangrove Cover & Composition (not relevant in Irish waters)

Emerging EOVs not presented in this report:

9. Microbe Biomass & Diversity
10. Invertebrate Abundance & Diversity

Full details of time series length, sampling frequency, policy supported by the networks and degree of maturity are provided in Table 1 (Appendix 1). The full list of Essential Ocean Variables measured by these networks are provided in Table 2 (Appendix 1).

2.1.3.1 Phytoplankton, Biomass, Diversity & Distribution

"Plankton are at the base of the marine food web and generally not fished by humans. Changes in the plankton will have impacts on the rest of the marine ecosystem including on the carbon cycle, living marine resources used by humans and threatened marine species including apex predators. Climate variability significantly impacts plankton in the ocean, both the microflora (phytoplankton) and the microfauna (zooplankton), over both short and long timescales." *Source: GCOS plankton factsheet*

Phytoplankton species are monitored routinely in Irish waters, primarily under two main monitoring programmes conducted in accordance with the requirements as laid down in the relevant legislation

1. Water Framework Directive (WFD), 2000/60/EC, S.I. No. 722 of 2003) for the Irish Environmental Protection Agency (EPA) for monitoring of phytoplankton in coastal waters

2. National Phytoplankton Monitoring Programme in Classified Production areas (EC No. 854/2004 & EU 2017/625) for the monitoring of phytoplankton in inshore areas where aquaculture operations and activities are occuring.

The focus of the national monitoring programme is on detecting the distribution and abundance of harmful microalgae, particulary species which are toxin producing. These toxins can accumulate within the flesh of filter feeding bi-valve molluscs, and can often exceed regulatory levels, thereby making them unfit for human consumption, and resulting in the closure of the area prohibiting the placing on the market of contaminated shellfish which could give rise to human illness. The programme also focuses on species which, when environmental conditions are favourable, can dramatically increase in cell densitiy and form blooms which can lead to discoluration of the surface water, produce foam/scum on the surface, produce substances causing finfish mortalities, and on the collapse of the bloom, result in oxygen depletion of the water column leading to potential mortalities of finfish, shellfish and benthic invertebrates. These are often referred to Harmful Algal Bloom events (HABs).

The phytoplankton monitoring programme has been in place since 1990 and has over the years increased as the Irish aquaculture industry grew and expanded geographically. Sampling is carried out primarily in shallow coastal water sites, in or adjacent to shellfish production areas and at some fish farms. Samples are either surface or integrated water column depth samples, and upon sampling are preserved, and submitted to the Marine Institute Phytoplankton Laboratories in Galway and Bantry. Phytoplankton analysis is carried out by trained and specialised taxonomists using light inverted microscopy with occasionally scanning electron end epi-fluoresence microscopy as required for confirmatory species identification.

Since 2014, weekly phytoplankton sampling in active harvesting production areas has been mandatory and now results in up to 3,500 samples being submitted and analysed on an annual basis. Since 2021, all samples received for analysis receive a full species identification and enumeration of all phytoplankton species composition within the sample. Prior to 2021, approximately 60% of samples received, dependent on area, were analysed for full species identification, whereas the remainder were analysed for the identification and enumeration of harmful and toxin producing species only. Results of analysis are reported and published on a daily basis to stakeholders and industry.

In addition to the two progammes, some dedicated offshore samples are collected on research cruises, but spatial and geographic coverage is intermittent. Figure 13 shows the geographic locations where national monitoring programme phytoplankton sites were sampled and analysed between 2002 – 2021. In some coastal locations, more than 10,000 phytoplankton samples have been collected within the same production area/regions since the inception of this programme, e.g. Bantry Bay, southwest Ireland.

All results from the WFD programme are available through the EPA, whereas all phytoplankton results from the national monitoring programme for classified production areas are publicly available through the MI's HABs website https://webapps.marine.ie/habs

Key Message

Phytoplankton are an essential part of marine food webs

Phytoplankton information can provide an early warning of impending harmful algal blooms (HABs) that can negatively impact the aquaculture industry.

Phytoplankton measurements are mature in coastal waters with limited measurements in Irish shelf seas and deep waters.

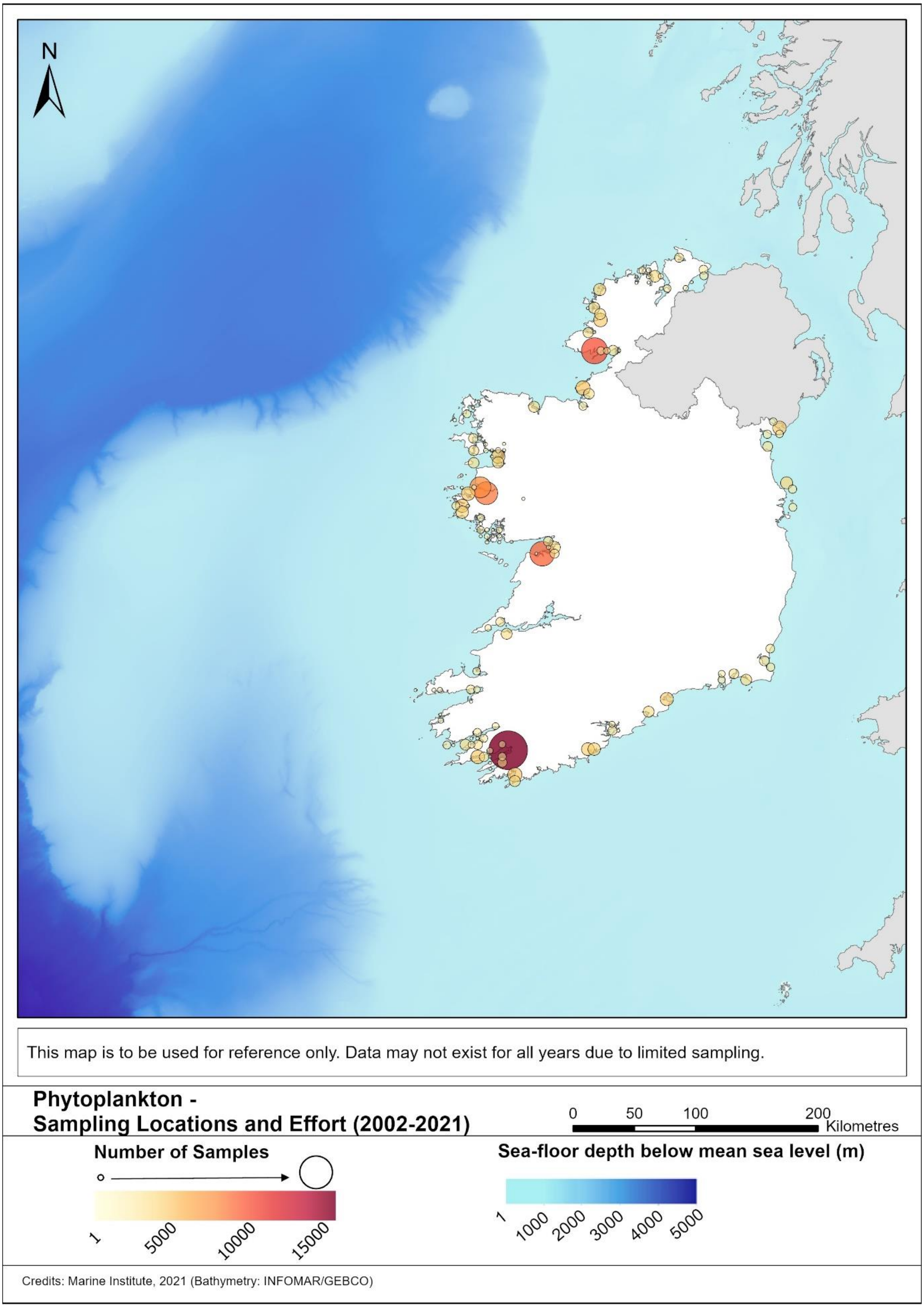

Figure 13 Geographic locations where national monitoring programme phytoplankton samples are collected.

2.1.3.2 Zooplankton, Biomass & Diversity

"Zooplankton is a broad category of the plankton that includes all animal or animal-like organisms whose dispersal in the ocean is dominated by physical processes such as ocean currents. The zooplankton includes protozoans and metazoans. Zooplankton are the food for many mammals, birds, fish, corals and other invertebrates including zooplankton. They are consumers of the phytoplankton and can also be carnivorous. They are an intermediary between primary productivity and higher trophic levels. They also play a key role in defining the chemistry of the ocean by recycling nutrients and carbon in near-surface waters of the ocean and by delivering these materials to deeper ocean waters through defecation and through daily and ontogenetic migration. Zooplankton biomass is an important and commonly used variable to evaluate fisheries potential and ecosystem health. The zooplankton can be extremely diverse. Zooplankton diversity refers to the number of zooplankton species, taxonomic composition, or community structure within a region. Zooplankton diversity influences ecosystem health and productivity through trophic links. In turn, zooplankton diversity is sensitive to environmental pressures such as climate change, including ocean acidification, warming and deoxygenation. The abundance and functional types of zooplankton, even their presence or absence, are accepted indicators of marine ecosystem responses to climate change. Ichthyoplankton surveys, focusing on larval fish species, can also be informative for zooplankton diversity" *Source: GOOS Panel Biology & Ecosystem Panel EOV Zooplankton specification sheet*

Inshore zooplankton information can inform policy makers about the impacts of Ocean Acidification (OA) on shellfish aquaculture, e.g. damage to bivalves shell integrity. Inshore and offshore zooplankton data can help generate fish recruitment indicators related to climate change stressors such as changes in temperature and salinity.

While zooplankton is a useful indicator of ecosystem health, this essential ocean variable is currently absent from any Irish monitoring programme with the exception of ad-hoc zooplankton samples collected for research projects on some pelagic fisheries surveys e.g. WESPAS since 2016. Recently the MI initiated a desk study to investigate the spatial and temporal extent of historical zooplankton records in the Irish waters and a pilot study is planned to investigate zooplankton population composition at an inshore site off the west coast at Mace Head. Historically, the UK ran a non-profit "ships of opportunity" ocean zooplankton observation programme, called the continuous plankton recorder (CPR), to measure biodiversity and abundance of zooplankton in surface waters along offshore shipping lines to the north (Malin Shelf) and south (Celtic Sea) of Ireland. The CPR observation programme is now in danger of collapse due to a lack of financial support with little or no monitoring taking place in recent years off the Irish coast. Ireland is supporting a pilot project to collect zooplankton data along a surface transect in the Celtic Sea.

An Irish long term sustainable zooplankton monitoring programme requires taxonomic experts and financial commitment from government for the collection, analyses, data interpretation and reporting on zooplankton.

Key Message

Zooplankton is a useful indicator of ecosystem health

Zooplankton information can inform policy makers about marine food webs and the impacts of Ocean Acidification which negatively impacts shellfish.

There is currently no Irish monitoring programme.

2.1.3.3 Fish Abundance & Distribution

"Fish and fisheries are key parts of ecosystems, economies and societies. Fish consume lower trophic level organisms, including plankton and other fish, and are consumed by marine mammals, seabirds, fish, invertebrates, and microorganisms. Many fish serve as grazers in different ecosystems (coral reefs, rocky bottoms), ensuring their ecological balance. Fisheries provide food for a large fraction of the world's population, meal and oil for aquaculture, and livelihoods for fishers. Fish and fisheries occupy important roles in societies, including traditional cultures. Fish and fisheries are affected by climate variability and are vulnerable to climate change. Food security affects fisheries and, in turn, both are affected by human population growth and climate. For these and other reasons, the abundance and spatial distribution of fish of different species need to be measured routinely, widely and in a standardized manner. Such information is useful to inform a variety of types of decisions, including those that involve fisheries management, conservation and sustainable use policies, and that affect economic investment and societal resilience in the face of climate change." *Source: GOOS Panel Biology & Ecosystem Panel EOV Fish specification sheet*

Fisheries data collection is a cornerstone of the Marine Institute's multi-annual work plan and provides the basis for advice to Government regarding the status of fish stocks in Irish waters. The Marine Institute utilises approximately 200 days on the national research vessels to collect data on the distribution, abundance and biology of fish stocks. These surveys have been conducted in a standardised way since 2008. A robust assessment framework is established through the International Council for the Exploration of the Seas (ICES) where Irish data are shared with international colleagues and advice is produced for annual EU fisheries negotiations.

Fisheries data collection is highly systematic and undertaken to agreed international standards. The main surveys each year are the Irish Ground Fish Survey, Western European Shelf Pelagic Acoustic Survey, Nephrops Underwater TV survey, Irish Anglerfish and Megrim Survey (IAMS), Blue Whiting Acoustic Survey, Celtic Sea Herring survey and inshore fisheries surveys. The Institute is also involved in the Irish Mackerel Egg Survey every three years.

An overview of the full array of fisheries surveys is provided in figure 14. More details of the individual surveys are provided in figures 15, 16 and 17.

In principle, the data coverage to estimate changes in fish distribution and abundance is comprehensive. However, the primary rationale for fisheries data collection is to support stock assessment and very few fisheries data sets have been analysed in a climate change context to date.

Key Message

Fisheries populations are vulnerable to climate change

Recent research has shown that the spatial distribution of fish stocks is heavily influenced by other essential ocean variables e.g. temperature, salinity.

While the collection of fish data in Irish waters is a mature activity, more analysis is required to inform policy makers on future food security, sustainable fisheries management and conservation.

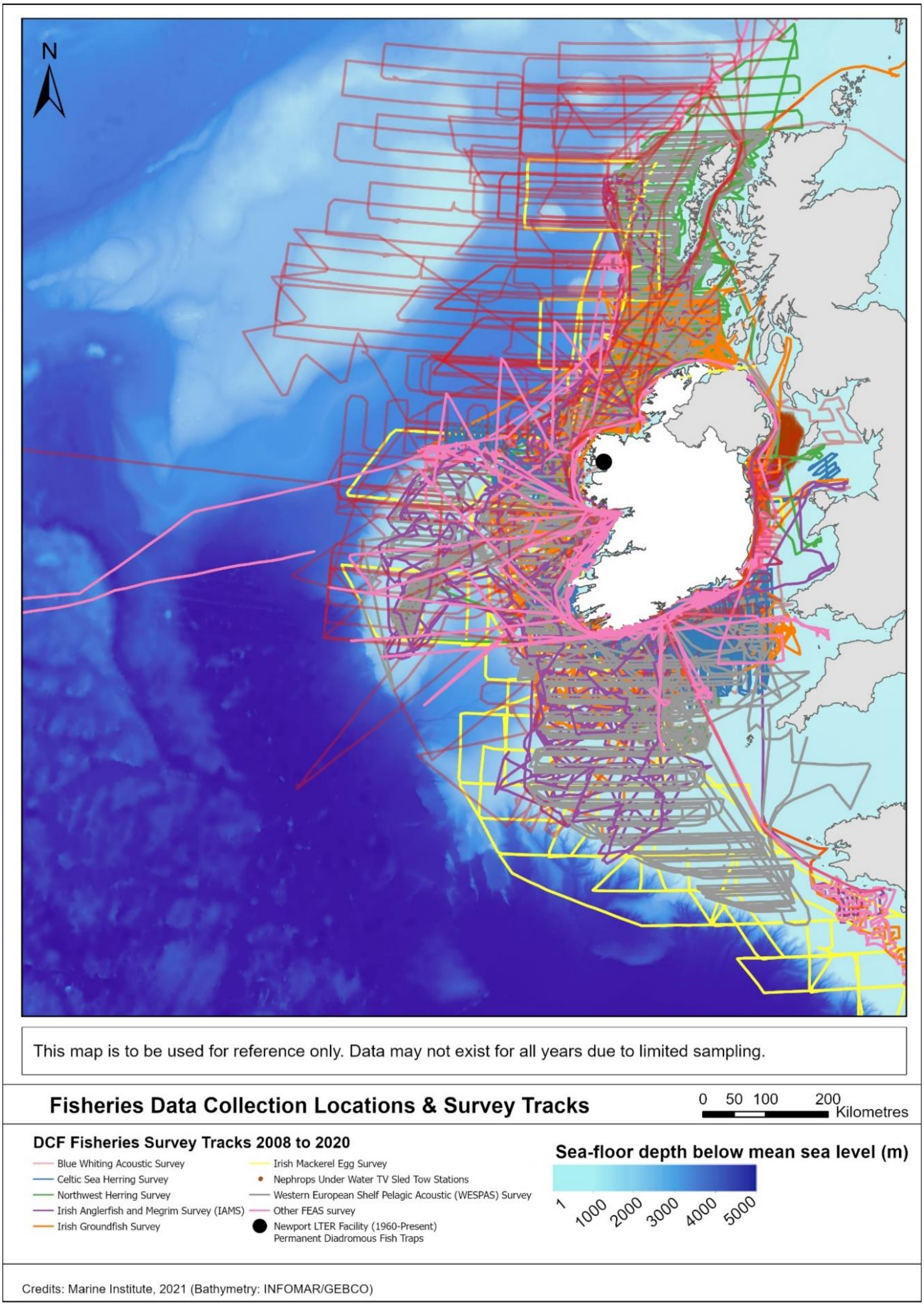

Figure 14 Fisheries survey tracks under the data collection framework since 2008. Eight major survey programmes for key stocks are included.

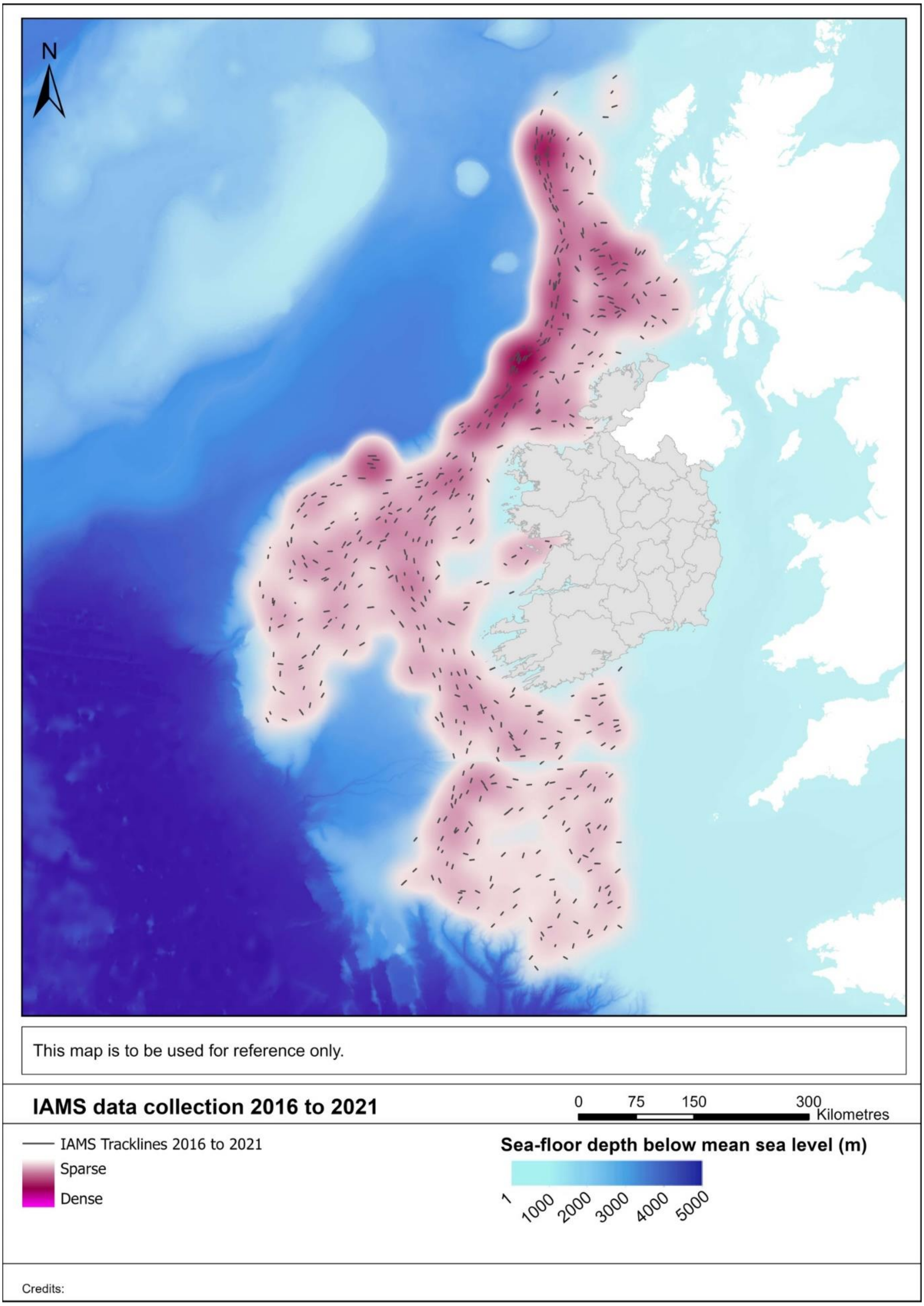

Figure 15 Indicative heat map from the Irish Anglerfish and Megrim surveys conducted since 2016 showing regions of sparse and dense data coverage.

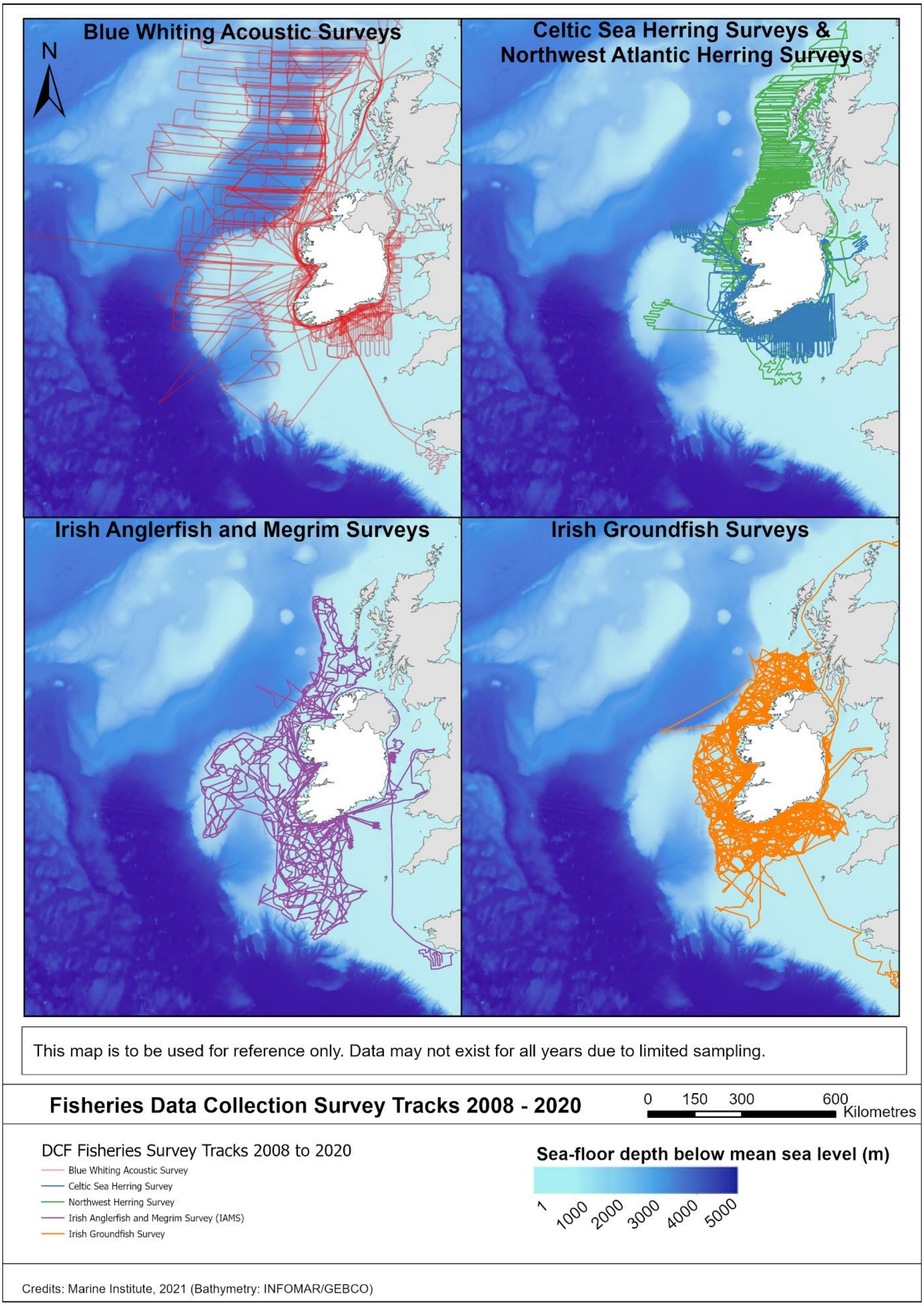

Figure 16 Survey tracks for various fisheries surveys undertaken since 2008 (see legend for specific details)

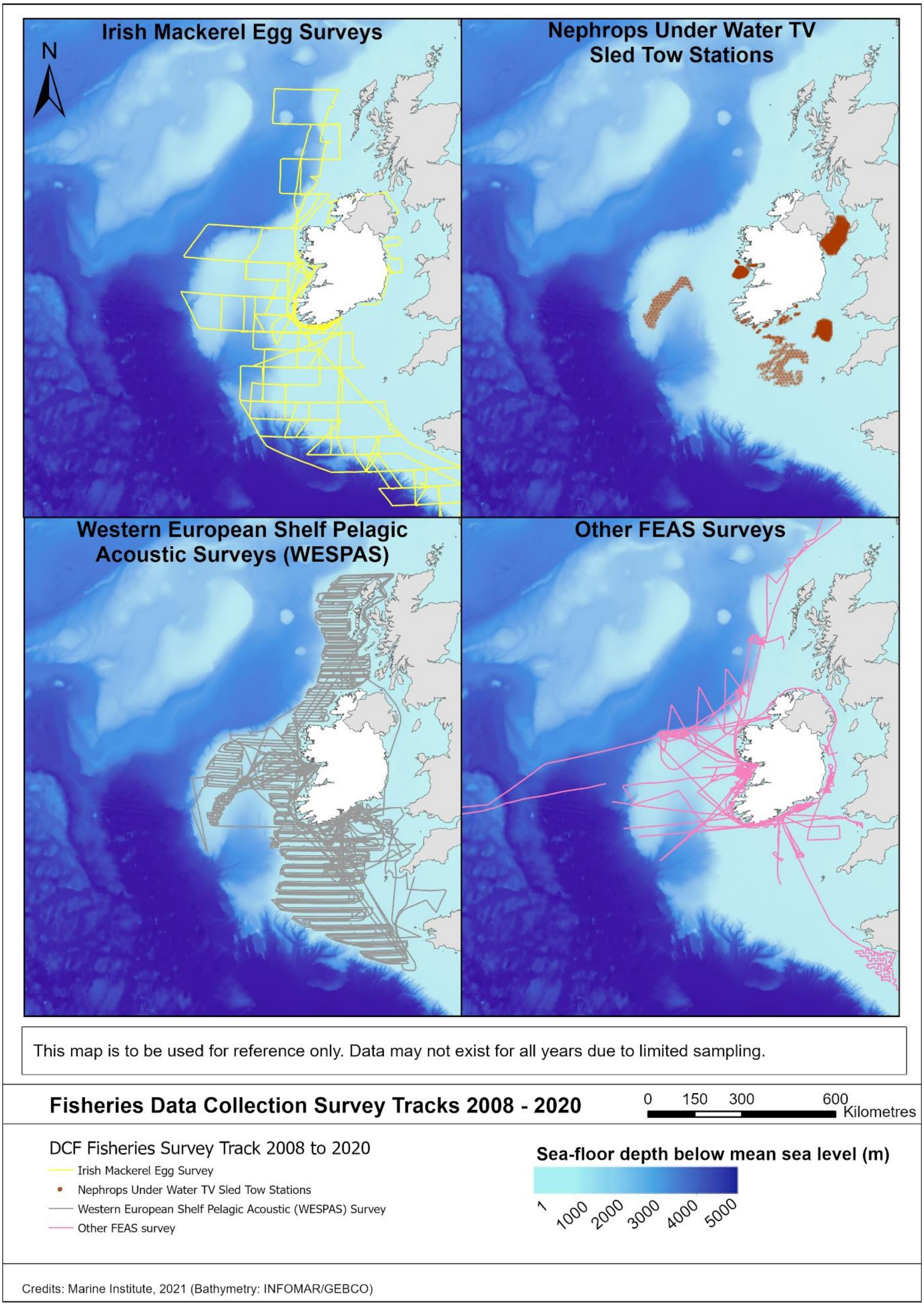

Figure 17 Survey tracks for various fisheries surveys undertaken since 2008 (see legend for specific details)

2.1.3.4 Marine Turtles, Birds, Mammals Abundance & Distribution

"As wide-ranging, relatively long-lived and large-bodied animals, marine turtle, bird, and mammal species play a crucial role in maintaining the health of their ecosystems. These charismatic megafaunas interact with and influence population dynamics and distribution of numerous prey species. To evaluate these interactions and their variability, an understanding of turtle, bird and mammal abundance and distribution is essential. Stock assessment analyses require accurate, up to-date information on abundance and distribution in order to inform appropriate management and/or conservation measures. This EOV will facilitate evaluation of the potential impacts of several pressures (e.g. Climate change, loss of resources (fisheries, habitats, diversity), pollution/eutrophication, ocean acidification, noise, coastal development, invasive species, solid wastes, mining) on upper trophic levels of marine food webs" *Source: GOOS Panel Biology & Ecosystem Panel EOV Marine Turtles, Birds, Mammals specification sheet*

A suite of field survey techniques and platforms have been used in Ireland to map and calculate the distribution and abundance of a wide range of larger vertebrates occurring in Irish waters. These include more than 40 species of marine mammals and birds and one commonly occurring species of sea turtle. At the forefront of the monitoring effort at sea in recent years has been the ObSERVE Programme, a joint scientific initiative established by the Department of the Environment, Climate and Communications (DECC) and the Department of Housing, Local Government and Heritage (DHLGH) in 2014. Now in its second phase (2020-2025), Phase 1 of the ObSERVE Programme saw field surveys begin in 2015 and it involved two large-scale multiannual projects: an Aerial Survey project and an Acoustic Survey project. Further details on these projects and the wider programme can be found at www.gov.ie/observe.

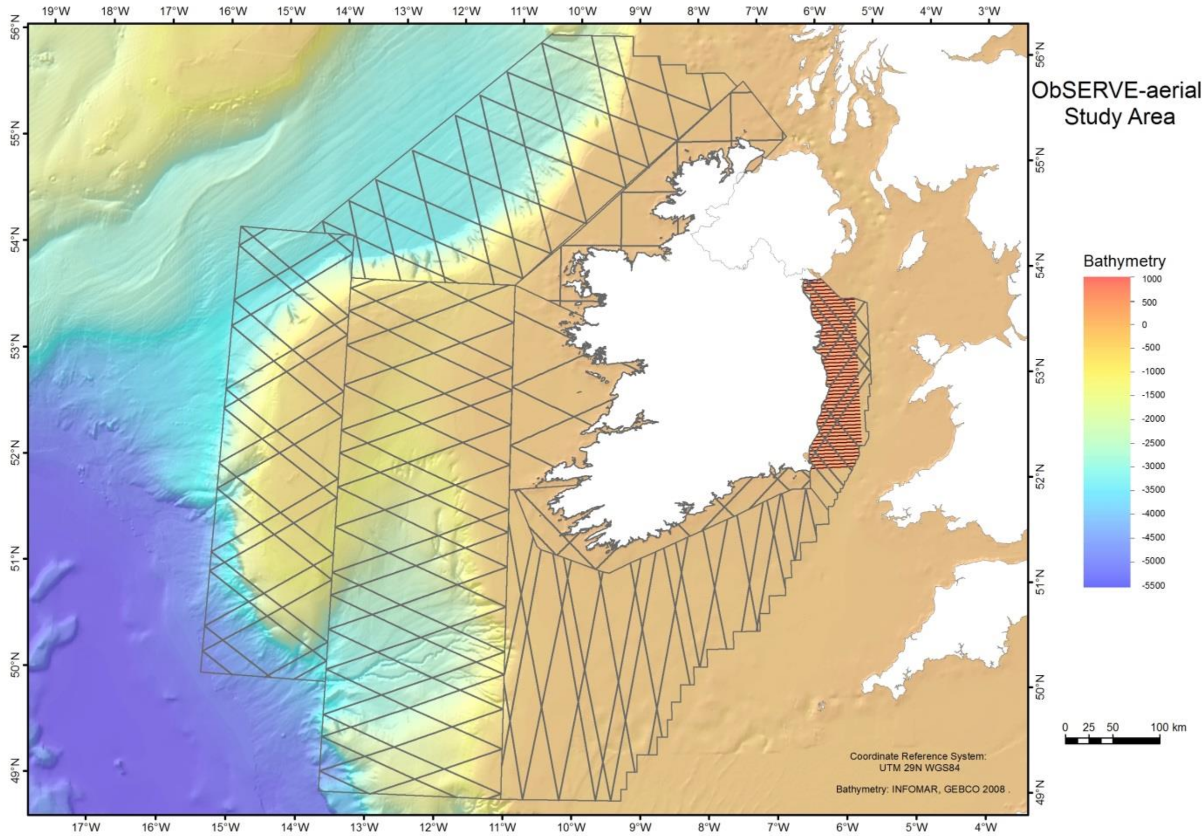

Figure 18 Transects flown by the ObSERVE Programme (Phase 1) aerial survey project, 2015-2017, where cetacean and seabird abundance observations were systematically made. The map shows combined aerial survey lines for coverage in summer and winter 2015-2017 (grey zig-zag lines) and aerial survey lines targeting seabirds in the Irish Sea in summer/autumn/winter 2016 (red parallel lines). Figure reproduced from Rogan et al. 2018.

2.1.3.5 Hard Coral, Cover & Composition

"Hard corals are the principal architects of coral reefs, supporting the high biodiversity and productivity of shallow, tropical coral reef systems. Coral reefs are among the most biodiverse and highly valued ecosystems worldwide for their ecosystem goods and services. They are also one of the most threatened ecosystems of the world. Many people that depend on coral reefs live in low-income tropical countries. Healthy reefs are a foundation for their livelihood and food security; some products derived from coral reefs have global markets, including ornamental fish, cement, and tourism and recreation. Climate change, ocean acidification, fisheries, pollution, and coastal development are all significant threats to coral reefs. Hard corals are particularly vulnerable because they are slow-growing and susceptible to stress, particularly when there are synergies between natural and anthropogenic stresses. The health and areal extent of the hard coral community within a reef are direct indicators of the ability of a system to sustain the diversity of associated species, productivity, and valuable ecosystem services." *Source: GOOS Panel Biology & Ecosystem Panel EOV Hard Coral specification sheet*

A recently funded project under the European Maritime and Fisheries Fund (EMFF) supported the mapping and identification of cold coral reef habitats around the Irish coast. The SeaRover project synthesis report is available at: https://emff.marine.ie/marine-biodiversity/synthesis-and-development-advisory-products-searover-phase-3

2.1.3.6 Seagrass Cover

"Seagrasses are vascular plants that that can reproduce by flowering (sexually) and also spread asexually through rhizome extension. They can form dense, submerged meadows in coastal and estuarine waters. There are approximately 72 seagrass species that belong to four major groups. Seagrasses are often highly productive and provide essential habitat and nursery areas for many finfish, shellfish, charismatic megafauna, and species of concern, including sea turtles, dugongs and manatees. Seagrasses also help stabilize and protect coasts by binding underlying sediments. They contribute to good water quality by trapping sediment and absorbing nutrient runoff. Seagrasses are recognized as a "blue" carbon storage system, by fixing inorganic carbon via photosynthesis and storing and sequestering it in seagrass rhizomes and associated sediments. Although coastal vegetated habitats comprise only 0.2% of the world ocean they contribute >10% of all carbon buried annually in the sea. Vigorous photosynthesis by seagrasses can also reduce the acidity of surrounding water by removing dissolved carbon dioxide. Seagrasses are declining worldwide as a result of coastal development, nutrient loading that leads to poor light conditions on the sea floor, climate change, and cascading impacts of fishing. Loss of resources, including biological habitats such as seagrass meadows, is a major concern for governments worldwide and emerges as a major societal pressure motivating international conventions and bodies focused on ocean environment and resources. Regular monitoring of seagrass cover and ecosystem structure will be useful to modelling coastal and reef fishery production, the global carbon cycle, and tracking impacts of climate change and coastal eutrophication." *Source: GOOS Panel Biology & Ecosystem Panel EOV Seagrass specification sheet*

The Marine Institute commissioned a desk study on blue carbon (Cott *et al.* 2021) where seagrass cover was considered as a possible mitigation measure for the drawdown of CO_2 from the atmosphere. The Institute will now fund a larger multi-year study to develop this work in the 2021-26 period.

2.1.3.7 Macroalgal Canopy Cover & Composition

"Macroalgal forests (dominated by kelp and fucoid brown algae) are iconic on rocky reefs around the world's temperate coasts. These highly diverse ecosystems provide many important functions and services including high primary production, provision of nursery areas, human food resources, and protection from coastal erosion. Macroalgal forests are vulnerable to global threats such as ocean warming and to regional stressors resulting from intensifying human activities along the coast, including habitat degradation, pollution, eutrophication, and spread of invasive species. The compounded effects of global and regional stressors are eroding the resilience of these systems, making regime shifts and population collapses more likely. Regime shifts such as the replacement of macroalgal canopies by less productive, low-diversity assemblages of turf-forming algae and barren habitat are increasingly observed on many reefs around the world. Vulnerability begets sensitivity and macroalgal forests respond quickly to deteriorating environmental conditions, potentially allowing the early detection of impending regime shifts. Furthermore, their broad distribution from boreal to temperate regions allows for comparison of latitudinal trends and the tracking of geographic shifts in species ranges. Macroalgal forests provide a sensitive and well understood indicator of changing coastal marine environments, and are also models for understanding more complex interactions influencing marine communities, building on the detailed experimental knowledge and basic ecological understanding accumulated for these systems over decades." *Source: GOOS Panel Biology & Ecosystem Panel EOV Macroalgal specification sheet*

The Marine Institute commissioned desk study on blue carbon (Cott *et al.* 2021) also considers macroalgal cover as a possible mitigation measure for the drawdown of CO_2 from the atmosphere. The Institute funded larger multi-year study will develop this work in the 2021-2026 period.

3 Newport Catchment – Long Term Ecological Observatory

3.1 Background

The Burrishoole catchment, Newport, Co. Mayo, while similar to many of the coastal humic catchments found in the west of Ireland, is unique in terms of the long term monitoring effort that centres around its diadromous fish populations of Atlantic salmon (*Salmo salar* L.), Sea Trout (*Salmo trutta* L.) and European Eel (*Anguilla anguilla* L.) and its associated High Frequency Monitoring (AWQMS) of the aquatic environment and weather. Diadromous fish are species that move between freshwater and marine habitats for parts of their life cycle. Established in 1955, the programme of fisheries development and associated science laid the basis for what is now a long-term ecological observatory with datasets back to the late '50s and early '60s (de Eyto *et al*. 2020) for a description of the catchment, data collection and research activity).

The Burrishoole, situated in the Nephin Beg Mountains, drains into the north east corner of Clew Bay (Fig. 19). The weather is dominated by frequent depressions rolling in off the north Atlantic, with prevailing warm, wet, south-westerly winds. Long-term average annual rainfall in the upper part of the catchment often exceeds 2,000 mm per annum (making this one of the wettest areas in Ireland), and this decreases to 1,200 - 1,600 mm at the coastal end of the catchment. The gulf stream (North Atlantic current) ensures mild weather - snow is rare in winter, as are hot days in summer. This is the perfect climate for development of blanket bog over millennia, and the resulting humic peat soils of the Burrishoole catchment give the rivers and lakes their typical brown colour and dystrophic (humic) characteristics.

3.2 Diadromous Fish

Data collection on salmon, trout and eel commenced in 1958 with the opening of the first fish trap in Burrishoole. These traps have allowed a complete census of all migratory fish movements since 1970. Long term data of this kind are rare but play an important role in understanding and conserving fish stocks. Associated juvenile salmon trout and eel stock data are also collected by electrofishing and seine netting upstream of the traps in the rivers and main lakes in Burrishoole. These data include juvenile densities, smolt output, adult returns, silver eel migration and relevant biological and genetic data. Time series of freshwater and marine survival data are derived. Some key publications include (Poole *et al*. 2006, de Eyto *et al*. 2016a, Sandlund *et al*. 2017, Poole *et al*. 2018). Data are provided to national and international expert groups for stock assessment and advisory purposes.

3.3 Environmental monitoring

The lakes and rivers of Burrishoole are characteristic of surface waters draining blanket peats, being oligotrophic, acidic and relatively unproductive. Several EPA river water quality-monitoring sites in the catchment, with historic Q-values (1971–2016) typically recorded as 4, 4–5 and 5, equating with good or high ecological status. Occasional Q-values of 3 or 3–4 have been recorded in recent years, most likely the result of multiple stressors in the area, including climate, land use, forestry and peat degradation. Lough Feeagh is currently regarded as being of good ecological status (de Eyto *et al*. 2020). Temperature and water level recorders on Lough Feeagh were originally installed in 1960, and the Marine Institute continues this work, maintaining an extensive environmental HFM program in the catchment, including hosting two Met Eireann weather stations in Furnace, which is used to record climate and land use changes that may impact fish stocks (http://Burrishoole.marine.ie).

Through a series of EU funded projects commencing in 1993 through to 2005, the MI in conjunction with a series of partners, including UK Centre for Ecology and Hydrology and Lakeland Instrumentation Ltd installed a suite of high frequency (HF) monitoring stations, two on the lakes (AWQMS), 3 river stations (ARMS) and upgraded the water level and temperature stations on the Mill Race. These have been the basis for much of the environmental monitoring and research in the catchment and have laid the foundation for tracking climate and water quality changes into the future.

Data from the HFM stations have been used to investigate carbon cycling, whole lake ecosystem metabolism, deep chlorophyll maxima, water-to-air heat fluxes and lake physical processes. HFM pays dividends in studies of the response of aquatic ecosystems to episodic events, such as heat waves, excessive rainfall and drought, and determining how long it might take a lake or river to recover (de Eyto *et al*. 2016b, Jennings *et al*. 2012). Changes in freshwater have also been demonstrated clearly to be a reflection of what goes on in the wider oceans (Jennings *et al*. 2000).

3.4 Concluding Comment

Like freshwaters around the world, the rivers and lakes of Burrishoole, and their inhabitants, face many challenges, some within the control of the local community, and some not. Climate change is an omnipresent reality, the direct effects of which are already being felt. Water temperatures are warming, particularly in winter (Woolway *et al.* 2016, 2019), and stronger storms are more frequent (Andersson *et al*. 2020; Kelly *et al*. 2020). Indirect ecosystem impacts take longer to become apparent, and are perhaps more difficult to quantify, but nonetheless threaten the very nature of these upland peat catchments and their flora and fauna.

Key Message

Newport Catchment is an important long-term observatory for Ireland

Continued long term data collection and observation will inform the future management of catchments and how best to preserve and protect the unique ecosystems in them. Collaboration with international networks such as the GLTC (www.laketemperature.org), GLEON (www.gleon.org) and NETLAKE (www.dkit.ie/netlake) ensure that the valuable data collected in Burrishoole are used by a wider scientific community to address questions of global significance.

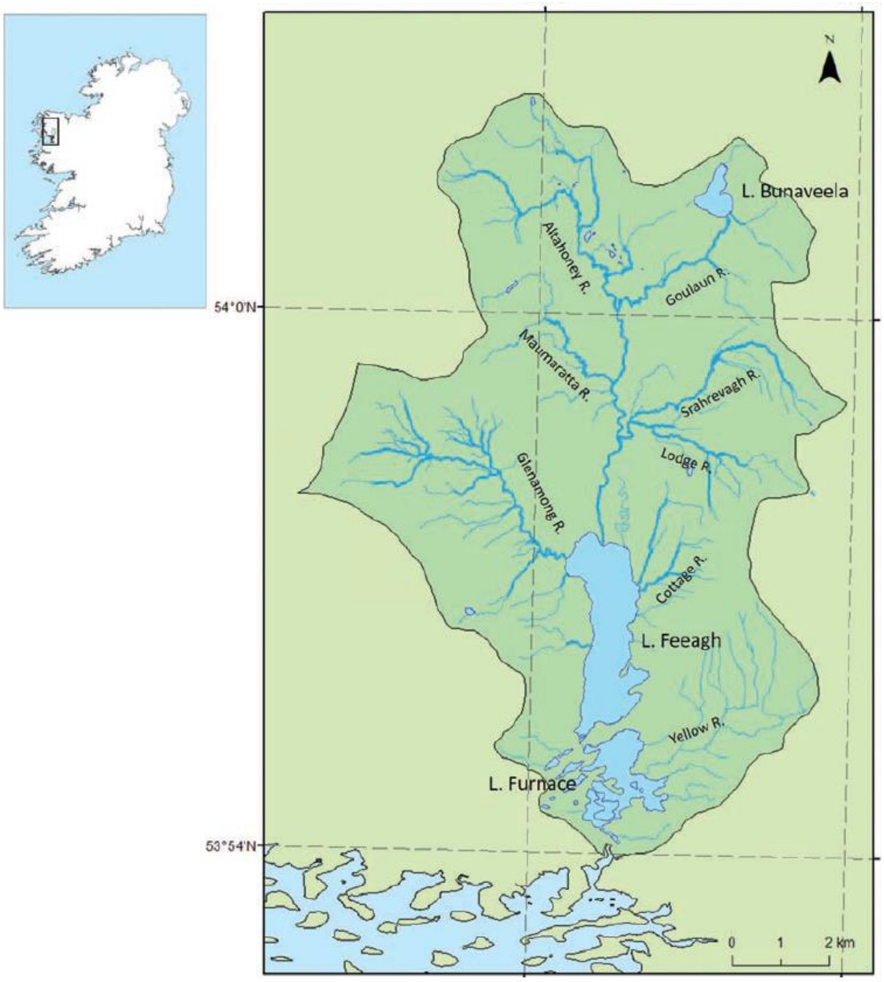

Figure 19 Map of the Burrishoole catchment.

4 CONCLUSION & RECOMMENDATIONS

This report has provided an initial examination of EOVs collected primarily by the Marine Institute. This has included an assessment of the spatial and temporal coverage of various data collection activities and the sustainability and maturity of the data collection programmes. It is anticipated that future assessments will be carried out to provide more detailed information about EOVs/ECVs in Irish waters.

Ireland has a long history of monitoring some essential ocean variables e.g. temperature, fish abundance and distribution, phytoplankton diversity. Other essential ocean variables have only begun to be monitored in recent times with significant reliance on ad-hoc research funding rather than a sustained long-term programme e.g. sea state, salinity, nutrients, oxygen, inorganic carbon, ocean colour and ocean sound. Ireland also monitors some essential ocean variables for the Marine Strategy Framework Directive and Water Framework Directives e.g. macroalgae, seagrass, seabirds and mammals, fish abundance and distribution, invertebrate distribution and abundance. There are several essential ocean variables that require further attention and resourcing e.g. sea level, zooplankton, carbon and transient tracers. For many EOVs there is a need to extend current monitoring programmes to areas further offshore and into deep waters.

As a result of this initial baseline assessment 10 high priority recommendations are listed below.

Recommendation 1

Ireland should provide sustained operational funding for the Marine Institute sea level monitoring programme and establish a National Sea Level Measurement Advisory Group.

Recommendation 2

Designate and fund Mace Head as a sentinel climate monitoring station for the ocean. Mace Head already has this status for atmospheric essential climate variables.

Recommendation 3

Commission a desk study to investigate what international data sets can be used to fill the gaps in the spatial coverage of physical and chemical EOVs e.g. salinity, temperature, oxygen in Irish waters.

Recommendation 4

Systematic collection and processing of fixed-point and vessel-mounted ADCP measurements should be implemented and investigate ways to ensure that the Galway Bay HF radar are made available to the public domain. Government support is required to ensure ocean models are developed near key population centres e.g. Dublin and Cork, to fill observational gaps e.g. important information on sea safety and pollution, and funding is required to support existing and future infrastructure.

Recommendation 5

Government funding is needed to sustain the Argo Ireland programme to measure temperature, salinity and oxygen in deep waters through float purchases (minimum 3 floats per annum) and membership in the Euro-Argo ERIC. There is a requirement to increase the coverage of oxygen measurements in Irish waters through survey activities to monitor the impact of changes on marine ecosystems.

Recommendation 6

Financial and technical support for pCO_2 measurements on the RV *Celtic Explorer* should continue. A pCO_2 system should be procured and installed on the new national research vessel, RV *Tom Crean*. Sampling for dissolved inorganic carbon and total alkalinity should continue to generate a time series appropriate to monitor changes in carbon chemistry, including ocean acidification in Irish waters. This requires building competence and capacity to routinely undertake climate-quality measurements and that will support international reporting obligations.

Recommendation 7

Extend phytoplankton sampling offshore (even opportunistically or using third parties) to gain insights into phytoplankton distributions and abundance including HABs. New technologies, e.g., Artificial Intelligence combined with *in-situ* flow cytometry instruments should be considered and implemented as an urgent requirement for both autonomous and high throughput sampling.

Recommendation 8

Conduct a review of historic zooplankton data collection in Ireland and devise a future monitoring strategy for this EOV. Zooplankton information can inform policy makers about marine food webs and the impacts of Ocean Acidification. There is currently no Irish monitoring programme. Set up a long-term sustainable zooplankton monitoring programme with taxonomic experts and a financial commitment from Government.

Recommendation 9

Dedicated resources should be awarded to undertake a comprehensive analysis of the Marine Institute's fisheries data sets in a climate context to inform policy making in the Seafood sector.

Recommendation 10

Resources and funding should be awarded to undertake a more detailed analysis of the existing seabird and mammal data sets (critical trophic components of marine food webs) collected by DECC and DHLGH to discern trends and inform policy development.

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6 Appendix 1 – Initial Assessment of EOVs and EOV Activities Measured in Ireland

Table 1 Overview of activities measuring EOVs with time series length, sampling frequency, policy supported and degree of maturity.

No.	Activity	Is the programme funded sustainably (Y/N)	Start and end years of the data set	Sampling frequency (hourly/daily/weekly/ monthly/annually)	National/International Policy / organisations the data supports (e.g. MSFD, OSPAR, WFD... Statutory Instruments, Directives etc.)	Maturity Level (concept / pilot / mature)
Fisheries						
1	Irish Ground Fish Survey	Y	2003- present	Annual	EMFF DCF & MSFD	Mature
2	Irish Mackerel Egg Survey	Y	1995 - present	Triennial	EMFF DCF & MSFD	Mature
3	Western European Shelf Pelagic Acoustic (WESPAS) Survey	Y	2012- present	Annual	EMFF DCF & MSFD	Mature
4	Nephrops Under Water TV Survey	Y	2003 - present	Annual	EMFF DCF & MSFD	Mature
5	Irish Anglerfish and Megrim Survey (IAMS) Survey	Y	2015-present	Annual	EMFF DCF & MSFD	Mature
6	Blue Whiting Acoustic Survey	Y	2004 - present	Annual	EMFF DCF & MSFD	Mature
7	Celtic Sea Herring Survey	Y	2003 - present	Annual	EMFF DCF & MSFD	Mature
8	Inshore Fisheries Survey	Y	2008-present	Annual	EMFF DCF & MSFD	Mature
Environment						
9	Mace Head	N	2018 - present	6 hourly	To be determined	Pilot
10	Marine Institute Research Vessel Underway data	Y	2017 - present	every 2.5 mins	Currently SOCAT	Mature
11	Phytoplankton National Monitoring Programme	Y	1980's - present	Weekly from 2014 onwards. Prior to 2014 weekly/monthly/ad-hoc dependent on site	(a) REGULATION (EU) 2019/627 (b) EU Reference Laboratory - Guidelines and Good Practice Document for Phytoplankton monitoring (c) FSAI Code of Practice for Biotoxin Monitoring	Mature
12	Water Framework Directive (TCW)	Y	2011 - present	monthly	WFD	Mature

		6 year programme plans (SLA)				
13	Winter Environmental Monitoring Survey	Y	1991 - present	annual (weather permitting)	WFD MSFD OSPAR UN SDG 14.3(IOC)	Mature
14	Ocean Climate Section Survey	Y	2006-present	Annual (weather permitting)	ICES WGOH, MSFD, OSPAR, UN SDG 14.3(IOC)	Mature
15	GO-SHIP TransAtlantic Section A02	Y	2017 - present	Decadal	GCOS / GOOS, OOPC, MSFD, Galway Statement - Atlantic Strategy	Mature
16	National tide gauge network	N	2004-present	Every 5 minutes	General purpose best endeavours tide monitoring feeds into flood schemes / floods directive	Mature
17	Wave Buoys (Bellmullet, Galway, Brandon Bay, Bantry Bay)	Y	2006 - present	~30 min	SEAI	Mature
18	Galway Bay Observatory CTD+Oxygen Data (Processed)	Y	2016 - present	5 seconds	EMSO, SEAI	Mature
19	Galway Bay Observatory CTD+Oxygen Data (Raw)	Y	2016 - present	5 seconds	EMSO, SEAI	Mature
20	Galway Bay Observatory PCO2	Y	2020-present	5 seconds	EMSO, SEAI	Pilot
21	Galway Bay Observatory ADCP	Y	2016 - present	~1 min	EMSO, SEAI	Mature
22	Galway Bay 1/4 Scale Marine Energy Test Site Waverider(Raw)	Y	2006- present	~30 min	EMSO, SEAI	Mature
23	EuroArgo	Y		10 days	International Argo programme, GOOS	Mature
24	Weather buoy at M2	Y	May 2001-present	Hourly	WMO, GOOS	Mature
25	Weather buoy at M3	Y	July 2002 - present	Hourly	WMO, GOOS	Mature
26	Weather buoy at M4	Y	April 2003 - present	Hourly	WMO, GOOS	Mature
27	Weather buoy at M5	Y	October 2004-present	Hourly	WMO, GOOS	Mature

28	Weather buoy at M6	Y	September 2006- present	Hourly	WMO, GOOS	Mature
29	South Rockall Trough Sub-surface Mooring Time-Series (October 2018 - current) - CTD Data (Raw)	N	2018-present	Hourly	EMSO pilot	Pilot
30	Irish National Seabed Survey (INSS) Seabed Mapping Surveys / INFOMAR	Y	1999 - present	Seasonally during survey period (80-100 days per year recently) - underway data, & daily to hourly SV or CTD water column profiles & continuous acoustic multibeam	UNCLOS, SOLAS, UNESCO, IMP, MSF, CFP, Habitats Directive, CBD, MSFD, WFD, OSPAR, ICES, EMODnet, Seabed 2030, EU 2030 Biodiversity Strategy, Programme for Government - Our Shared Future, Climate Action Plan 2019	Mature
31	Climate Sensor data (Malin)	Y	Malin: 1959 - present	Daily then went to every 30 minutes	ICES WGOH (Malin)	Mature
32	Climate Sensor data (Ballycotton)	Y	2008-present	Every 30 minutes		Mature
33	Marine Institute Research Vessel Underway data	Y	1994 - present	every 10 seconds	WFD, MSFD	Mature
34	Potential offshore aquaculture sites	N				
Ocean Modelled Variables						
35	E Atlantic Swan model	Y	2011 - present	Every 3 hours	SEAI, RNLI, Coastguard, Gardai, EPA, FSAI, SFPA, Irish Water, UCC, NUIG, UCD	Mature
36	NE Atlantic ROMS model	Y	2012 -present	Hourly (3-hourly prior to 2017)	SEAI, RNLI, Coastguard, Gardai, EPA, FSAI, SFPA, Irish Water, UCC, NUIG, UCD	Mature
37	Bantry Bay ROMS model	Y	2012 -present	Hourly (3-hourly prior to 2017)	SEAI, RNLI, Coastguard, Gardai, EPA, FSAI, SFPA, Irish Water, UCC, NUIG, UCD	Mature
38	Connemara ROMS Model	Y	2012-present	Hourly (3-hourly prior to 2017)	SEAI, RNLI, Coastguard, Gardai, EPA, FSAI, SFPA,	Mature

					Irish Water, UCC, NUIG, UCD	
39	Galway_Bay ROMS model	Y	2021-present	Hourly	SEAI, RNLI, Coastguard, Gardai, EPA, FSAI, SFPA, Irish Water, UCC, NUIG, UCD	Pilot
Newport Catchment						
40	Lough Furnace Automatic Water Quality Monitoring Station (AWQMS) profiles 2009-2014	N	2009-current	Sub-hourly	N/A	Mature
41	Water quality and meteorological data from the Lough Feeagh Automatic Water Quality Monitoring Station (AWQMS), 2004-2019	N	2004-current	Sub-hourly	N/A	Mature
42	Surface water temperatures of Lough Furnace, Co. Mayo	N	2009-current	Sub-hourly	N/A	Mature
43	Water Temperature Profiles Lough Bunaveela Co.Mayo Ireland 2009 - 2019	N	2009-current	Sub-hourly	N/A	Mature
44	Midnight surface water temperatures from the Mill Race, Furnace, Newport, Co. Mayo	N	1960-current	Sub-hourly	N/A	Mature
External Data Sets						
45	Measurement of Seawater Temperature at Carna, Co. Galway (1974-2003)	Discontinued				
46	Seabirds Observations					

Table 2 High level overview of EOVs measured by activities in Ireland

No.	Activity	Sea Surface Height	Temperature (surface)	Salinity (surface)	pCO_2	Temperature (water column)	Salinity (water column)	Fish Distribution &	Waves	Nutrients	Oxygen	Radiative Fluxes	Currents	Carbonate System	Plankton	Other Parameters
Fisheries																
1	Irish Ground Fish Survey		x	x	x	x	x	x								
2	Irish Mackerel Egg Survey		x	x	x	x	x	x								
3	Western European Shelf Pelagic Acoustic (WESPAS) Survey		x	x	x	x	x	x							x	
4	Nephrops Under Water TV Survey		x	x	x	x	x	x								
5	Irish Anglerfish and Megrim Survey (IAMS) Survey		x	x	x	x	x	x								
6	Blue Whiting Acoustic Survey		x	x	x	x	x	x								
7	Celtic Sea Herring Survey		x	x	x	x	x	x								
8	Inshore Fisheries Survey							x								
Environment																
9	Mace Head		x	x	x	x	x			x	x		x	x	x	
10	Marine Institute Research Vessel Underway Data				x						x					
11	Phytoplankton National Monitoring Programme														x	
12	Water Framework Directive (TCW)		x	x		x	x				x				x	pH
13	Winter Environmental Monitoring Survey		x	x		x	x			x	x			x		
14	Ocean Climate Section Survey		x	x	x	x	x			x	x		x	x		
15	GO-SHIP Trans-Atlantic Section A02		x	x	x	x	x			x	x		x	x		Transients tracers
16	Irish National Tide Gauge Network (INTGN)	x														
17	Wave Buoys (Bellmullet, Galway, Brandon Bay, Bantry Bay)		x						x				x			

18	Galway Bay Observatory CTD + Oxygen Data (Processed)					x	x				x					
19	Galway Bay Observatory CTD + Oxygen Data (Raw)					x	x				x					
20	Galway Bay Observatory PCO2				x											
21	Galway Bay Observatory ADCP								x				x			
22	Galway Bay 1/4 Scale Marine Energy Test Site Waverider (Raw)								x							
23	Argo Ireland					x	x									
24	IMDBON - Weather Buoy at M2		x	x					x							
25	IMDBON - Weather Buoy at M3		x	x					x							
26	IMDBON - Weather Buoy at M4		x	x					x							
27	IMDBON - Weather Buoy at M5		x	x					x							
28	IMDBON - Weather Buoy at M6		x	x		x	x		x							
29	South Rockall Trough Sub-surface Mooring Time-Series (October 2018 - current) - CTD Data (Raw)					x	x						x			
30	Irish National Seabed Survey (INSS) Seabed Mapping Surveys / INFOMAR	x	x	x		x	x									
31	Climate Sensor data (Malin)		x													
32	Climate Sensor data (Ballycotton)		x													
33	Marine Institute Research Vessel Underway data		x	x	x											
34	Potential offshore aquaculture sites		x	x		x	x		x				x			
Ocean Modelled Variables																
35	E Atlantic Swan model								x							
36	NE Atlantic ROMS model	x	x	x		x	x						x			
37	Bantry Bay ROMS model	x	x	x		x	x						x			
38	Connemara ROMS Model	x	x	x		x	x						x			
39	Galway Bay ROMS model	x	x	x		x	x						x			
Newport Catchment																
40	Lough Furnace Automatic Water Quality Monitoring Station (AWQMS) profiles 2009-2014		x	x		x	x				x					

41	Water quality and meteorological data from the Lough Feeagh Automatic Water Quality Monitoring Station (AWQMS), 2004-2019		x		x	x					x	x		x		
42	Surface water temperatures of Lough Furnace, Co. Mayo		x			x										
43	Water Temperature Profiles Lough Bunaveela Co.Mayo Ireland 2009 - 2019		x			x										
44	Midnight surface water temperatures from the Mill Race, Furnace, Newport, Co. Mayo		x													
External Data Sets																
45	Measurement of Seawater Temperature at Carna, Co. Galway (1974-2003)		x													
46	Seabirds Observations		x													