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Review Article

A history of data management at ICES (1902–2025)

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Abstract

Data are essential for assessing the state of seas and oceans as well as for providing feedback on the effects of conservation and management measures. The management of marine data (including its submission, collation, storage, publication, and preservation) has been a key interest of the International Council for the Exploration of the Sea (ICES), since its foundation. This paper tells the story of ICES data management throughout the period 1902–2025—this includes changes and development in some key topics such as data collection platforms and techniques; data groups and data governance within ICES; metadata and data standards; data storage and distribution; and data rescue. The changes in data management are analysed through the lens of the five V's: volume, variety, velocity, veracity, and value. It shows that the volume and variety have increased significantly, and some aspects of the velocity have increased. Checks of data veracity have become more automated, transparent, and documented over time. ICES data have always been of value to its users but the number of secondary uses of the data have also increased. It also demonstrates that ICES data more clearly reflects the FAIR (Findable, Accessible, Interoperable, and Reusable) principles over time. It discusses how ICES is approaching the ongoing challenges and opportunities of the 21st century in the spirit of international cooperation and collaboration.

Keywords data management, FAIR, data governance, data rescue

Introduction

This paper tells the story of data management at the International Council for the Exploration of the Sea (ICES) throughout its life-time—this includes changes and development in some key topics such as data collection platforms and techniques; data groups and data governance within ICES; metadata and data standards; data storage and distribution; and data rescue.

A research data life cycle (RDLC) defines the different phases that research data goes through and the associated data management requirements. There isn't a single definition of the RDLC although the different versions have much in common. (Beja et al. 2022) present a 5-stage RDLC consisting of (i) acquisition; (ii) curation; (iii) publishing; (iv) processing; and (v) use/reuse. Data acquisition is the collection of data—as well as physical measurements and/or collection of specimens and data it also incorporates the design and analysis of a data collection programme. The data curation stage centres around maintaining, preserving, and adding value to research data, including the addition and maintenance of metadata. The basic aim of metadata is to answer the questions: Who?, What?, Where?, When?, Why?, and How? Data publishing has been a strength of ICES since its foundation as it recognised the importance of making data publicly available. Data must often be transformed, collated, and analysed—this happens during the processing stage. Typically data are collected for a specific initial purpose but it can also have value as evidence in many other studies, some of which won't have been foreseen when the data were initially collected. Making data available in international repositories means that it is more likely to be reused in the future.

Since ICES is an intergovernmental marine science organisation and does not directly collect data itself the focus of this paper is on the steps of managing data after it has been collected. However ICES does have an important role with respect to coordinating data collection. Examples include the ICES Interna-

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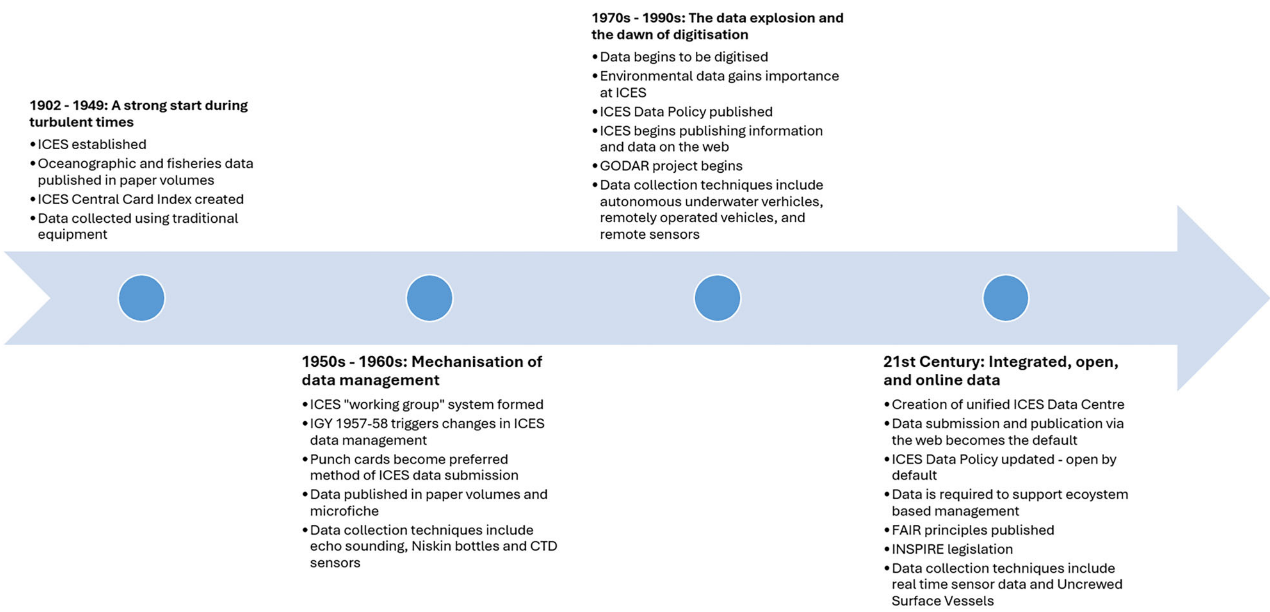

Figure 1. Timeline of data management at ICES (IGY = International Geophysical year, CTD = Conductivity Temperature Depth, GODAR = Global Ocean Data Archaeology and Rescue, FAIR = Findable, Accessible, Interoperable, and Reusable, INSPIRE = An EU Directive to establishing an infrastructure for spatial information in Europe).

tional Bottom Trawl Survey Working Group (IBTSWG) who coordinate fishery-independent bottom trawl surveys in the ICES Area (Northeast Atlantic and North Sea); and the ICES Working Group on Commercial Catches (WGCATCH) who document national fishery sampling schemes, and establish best practices and guidelines on sampling and estimation procedures using fishery data. As well as a coordination role ICES also has a networking role in terms of bringing people together to discuss the latest developments. This can be done via different fora including sessions at the Annual Science Conference, or workshops (e.g. the ICES Workshop on Technical Development to Support Fisheries Data Collection, WKSEATEC, ICES 2017). The current ICES Science Plan (ICES 2022d) identifies a number of priority tasks directly related to data collection. These include developing and coordinating monitoring programmes; developing and coordinating mapping of habitats; evaluating and optimising survey design and data handling; analysing and testing techniques and sensors; developing environmental monitoring; identifying opportunities for stakeholders to participate in citizen science; and developing data collection approaches for social and economic data.

Whilst this paper does not aim to present a comprehensive history of ICES, some historical context is necessary to understand the motivation for many of the changes in data management that have occurred throughout its lifetime. For a fuller consideration of the history of ICES there are a number of excellent volumes available including '*The sea knows no boundaries—a century of marine science under ICES* ' (Rozwadowski 2002), '*Seventy years agrowing'* (Went 1972), '*The evolution of ICES'* (Griffith et al. 2003), the papers from the '*100 Years of Science under ICES'* symposium (ICES 2002), and the Jens Smed archive (Smed 2016). The science of the sea is generally now known as oceanography but ICES tended to use the term 'hydrography' throughout most of the 20th century—in this paper, we will use 'oceanography' unless directly quoting names or text.

A history of data management at ICES

In this paper, we divide the history of data management at ICES into four distinct periods—see Fig. 1.

1902–49: a strong start during turbulent times

The constitutive conference of the ICES met in Copenhagen on 22 July 1902. Eight countries sent representatives to the inaugural meeting: Denmark, Finland, Germany, Great Britain, the Netherlands, Norway, Russia, and Sweden (ICES 1903). ICES was intended to encourage collaboration across national boundaries in order to produce science that would mitigate shared problems and allow maximum use of natural resources. World War I challenged the existence of ICES, but it survived and celebrated its twenty-fifth jubilee in 1927. Later in the century, the Second World War again suspended progress but the maturity that ICES had gained in the 1920s allowed it to navigate the period more effectively than the First World War (Rozwadowski 2002).

The original research interests of ICES were in both the physical conditions of the sea and the biological organisms that lived within it (particularly those that were used for human consumption). It was stated that even if the ICES work programmes for these subjects might be drawn up separately for practical reasons they should not be considered independently of each other since their interactions were of importance to solving problems (ICES 1903). The core of the original ICES oceanography programme consisted of a series of quarterly cruises designed to make observations in every season, year after year—this programme began one month after the ICES constitutional meeting of 1902. Although not all of the member countries had a dedicated research vessel at

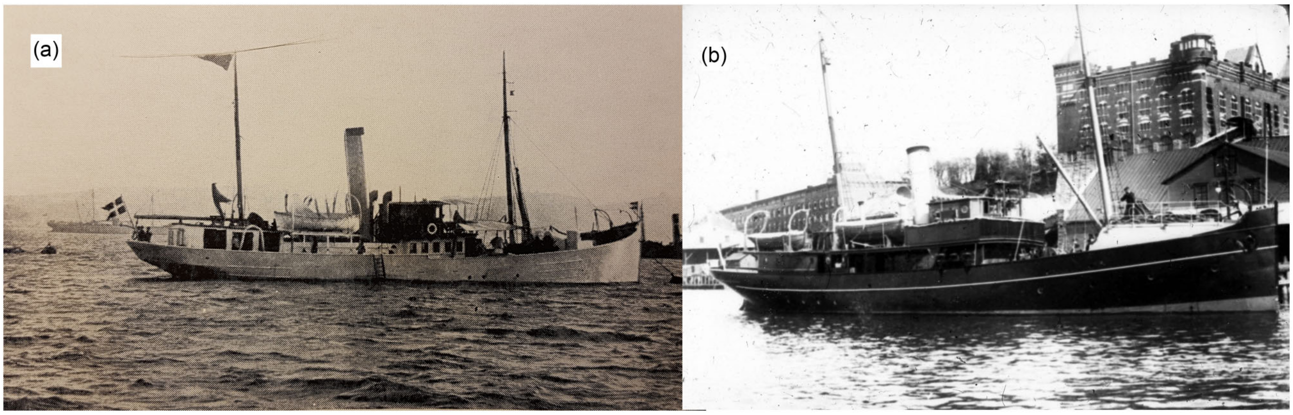

Figure 2. Examples of research ships used in early cruises coordinated by ICES. (a) The Danish Research trawler Thor (1903–27). Thor was a steam trawler, built in Newcastle upon Tyne 1899 and used for oceanographic research in the Atlantic and Mediterranean Oceans in the years 1903–27. https://en.wikipedia.org/wiki/Thor_(1898). (b) The Swedish Research vessel R/V Skagerrak (1903–35) built in Gothenburg and used in research by the Swedish Hydrographical-Biological Commission. Photo with permission from Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Crown Copyright.

this point, most sent out a ship to begin making temperature and salinity measurements. Seven specially designed research vessels (see Fig. 2 for the Danish and Swedish research vessels), and ten other ships were used during the first year of surveys (ICES 1903, Rozwadowski 2002). See also Box 1: 'A tale of four Scotias' for an example of how research vessels at one laboratory have changed over the last 100 years. Researchers would collect samples using nets, buckets, and other traditional equipment to gather biological, chemical, and physical data from the ocean. Data collection often included visual observations of marine fauna and weather conditions—this was typically recorded manually in logbooks or on paper forms.

Box 1 A tale of four *Scotias*

The development of research vessels during the lifetime of ICES can be illustrated by the tale of the four *Scotias* (Hawkins 1998). The Marine Laboratory, Aberdeen, currently has a research vessel named *Scotia.* She is the fourth research vessel to be given this name—see Fig. 3

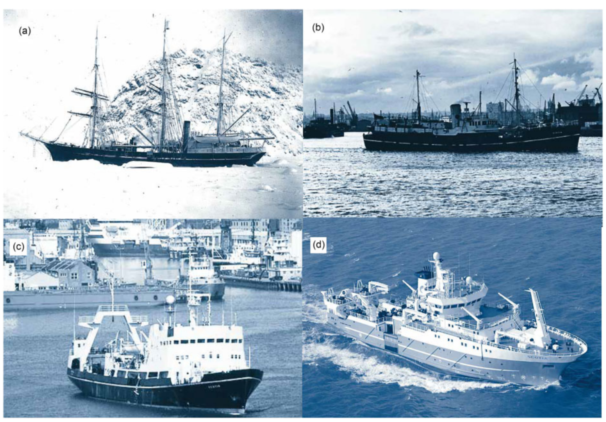

Figure 3. The four Scotias. (a) First Scotia, 1902–05. (b) Second Scotia, 1948–71. (c) Third Scotia, 1971–98. Fourth Scotia, 1988-. Photos used under crown copyright from the Marine Directorate, Scottish Government.

. Spanning over a century, these vessels have had a distinguished history of exploration and scientific achievement. The three Scotias operated by the Marine Laboratory have collected much data over their lifetimes. Close links have always been maintained with ICES and much of the data collected by these vessels has been provided to ICES in a timely manner.

The first Scotia, 1902–05, was a wooden sailing ship which took part in the Scottish National Antarctic Expedition of 1902–04, to the Southern Ocean. The second Scotia, 1948–71, was a 150-foot ex-Admiralty Shakespearean class trawler, a coal burner (later converted to oil), powered by a steam engine. She was acquired as a 'hydrographic -plankton research vessel'. Data were recorded manually. The third Scotia (1971–98) was a purpose-built 224 feet diesel-electric trawler, with the use of a hydraulic crane—latterly her position was determined by the global positioning system (GPS). Data collection began to be digitised. The fourth Scotia (1988-) is a multi-purpose, 70 metre, diesel electric vessel combining the essential features of a modern oceanographic research ship with those of a top-line pelagic and demersal trawler.

Data is essential for assessing the state of seas and oceans and the publication and distribution of data was an essential function of ICES from its foundation. ICES published data in the *Bulletin Hydrographique* annually from 1902 to 1956 (Fig. 4)—this included data from stations in the North Sea, Baltic Sea, and the Northeast Atlantic, including waters around Greenland. The reports of the Atlantic Slope Committee, published during the 1920s and 1930s, also contain fisheries and oceanographic data for the continental shelf and deep water areas to the south and west of the UK, Ireland, France, Spain, and Portugal (Dooley 1992). ICES also published fishery catch statistics in annual volumes of the *Bulletin Statistique des Pêches Maritimes* (renamed ICES Fisheries Statistics in 1988; the series has since been discontinued) (Lassen et al. 2012). The first volume of the *Bulletin Statis-*

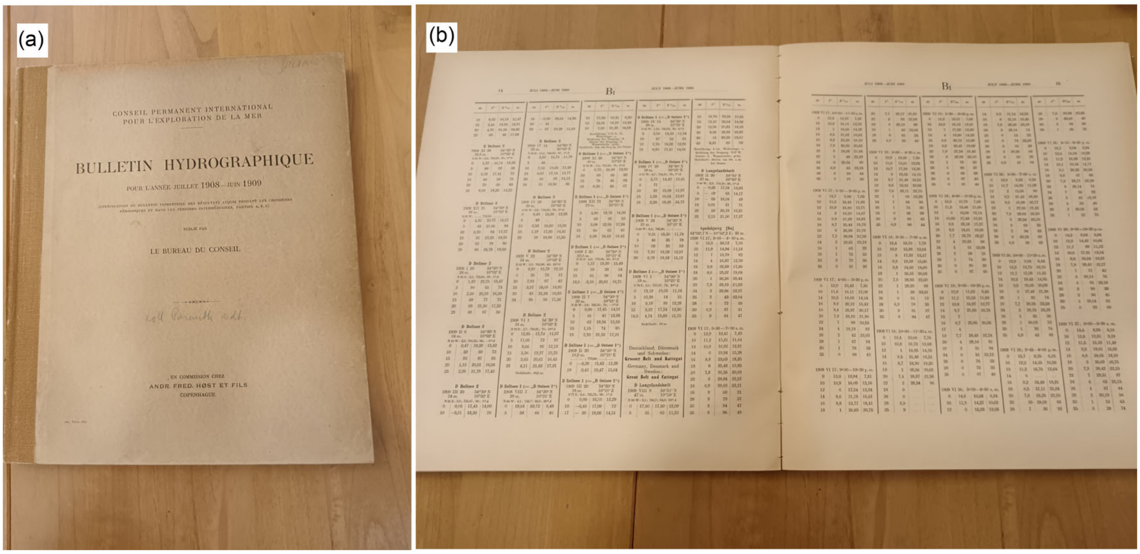

Figure 4. Oceanographic data published by ICES in the Bulletin Hydrographique, 1908–09, (a) title page and (b) examples of data. Photos by David Currie.

tique presented data for 1903 (ICES 1906). At the time of writing the volumes of *Bulletin Hydrographique* have not yet been digitised and are only available in physical format however much of the data from this source was later supplied to ICES on punch cards due to a data exchange arrangement with the US National Oceanographic Data Center (US NODC) (ICES 1966b). The reports of the Atlantic Slope Committee are in the process of being digitised and made publicly available. The data from the *Bulletin Statistique des Pêches Maritimes* has been digitised and published (ICES 2024b, 2024c).

As the amount of oceanographic data sent to ICES by its member countries accumulated it became clear that it would be useful to have an index of it arranged geographically. In the mid-1930s ICES agreed to an initiative of its then Administrative Secretary, Cdr Nellemose, to create a Central Card Index of all surface and profile oceanographic data that had been published in *Bulletin Hydrographique*. Data from other ICES publications, such as the Atlantic Slope Committee reports and some national data were also indexed. Two types of cards were used in the index: 'Surface cards', for surface observations only; and 'Station cards', for observations at a series of depths at stations. The cards were arranged by 1° squares. The index was continued up to 1956, and for the years 1932–56 the *Bulletin Hydrographique* was based on it. This index was stopped in 1956 along with the cessation of the publication of the *Bulletin Hydrographique* because there was too much material being produced each year for the Service Hydrographique to handle. At the end, there were almost 200 000 cards which were arranged by position, year, and month. It provided an analogue database of oceanographic data and formed the basis of a large number of scientific publications and products. (Smed 1948; '*The ICES Service Hydrographique, its Development as a Regional Data Center and its Relation to the World Data Centres*': ICES 1966a, Dooley 1992).

The collation, management, and publication of oceanographic data by the ICES '*Service Hydrographique*' was seen as a notable achievement. The data it managed represented the vast majority of the research data being collected in the North Atlantic, and it was producing pioneering scientific outputs. These years have been described as its '*halcyon days*' [Annex 5: (ICES 2001)] and it was considered the premier oceanographic data centre in the world (Rozwadowski 2002).

1950-60s: mechanisation of data management

This period saw significant and long-lasting changes both in the overall activities of ICES and in its approach to managing data. In particular, an increase in the volume of data being submitted triggered improvements in data handling.

During the 1930s, ICES had been actively discussing the problem of overfishing. This work came to a head in the International Convention for the Regulation of the Meshes of Fishing Nets and Size Limits for Fish in 1937—however, this convention was not fully ratified due to the outbreak of World War II. In 1946, it was replaced by the more comprehensive International Fisheries Convention. In 1953, the 'Permanent Commission' was formed—this was the administrative body empowered to execute the measures in the Convention. (The 1946 Convention and its Permanent Commission were replaced by the North–East Atlantic Fisheries Convention and its Commission, NEAFC, in 1963.) The Permanent Commission was not itself a scientific organisation but was instead reliant upon ICES for scientific advice—this set into motion a series of events which significantly impacted ICES. In particular, the issuing of scientific advice would become more and more important to ICES during the following decades (Griffith 2002). One of these key changes was the concept of the 'working group', which is still a feature of ICES activities. A 'working group' was a group of experts formed to solve specific problems. Unlike ICES committees, which had an open-ended existence, working groups were disbanded once they were no longer needed. The working group is still an important feature of ICES—currently working groups operate over several years and either have annual or multi-annual terms of reference (ICES 2021). The expansion of ICES' advisory functions and the creation of its working group system also led to impacts in data management. For example, in 1955, the duty of the ICES Liaison Committee was described as the collection of information and statistics for the use of the Permanent Commission. ICES also worked to speed up reporting of national catch and effort statistics. A problem was observed where scientists could be reluctant to share their data with a working group before they had published their own scientific papers based on it. However, the rising importance of ICES advice led to the chairs of working groups being given the authority to insist that data were provided in a timely manner (p183, Rozwadowski 2002).

Improvements in the coverage of fisheries in international statistics took place after 1945, with the Food and Agriculture Organization (FAO—an agency of the United Nations) taking the lead in this development. The development was institutionalized through the establishment of the Coordinating Working Party on Atlantic Fishery Statistics (CWP) in 1960 (FAO 1995, 2026). Since 1950, it has been assumed that all countries that were fishing in the Northeast Atlantic have reported to ICES or to FAO, and that these data covered the entire fishery in FAO Major Fishing Area 27 for species of major importance.

Large-scale expeditions with their commensurate increase in data volumes prompted a need to change the data handling process at ICES, particularly the International Geophysical Year 1957–8 Polar Front Survey. Advances in data collection techniques had continued to be made and the development of sonar technology in the mid-20th century allowed for more accurate mapping of the seafloor and identification of fish schools. Echo sounding also provided critical information about water depth and substrate type. The introduction of Niskin bottles for collecting water samples at various depths, along with reversing thermometers improved the ability to gather physical and chemical oceanographic data. The introduction of sensors with Conductivity-Temperature-Depth (CTD) instruments, increased the resolution in the water column significantly improving further the physical and chemical oceanographic data.

To support these larger volumes of data, a new technology for processing and storing the data was required: the punch card (which encodes data using the presence or absences of holes in the card). In 1957 the Sub-Committee for Mechanizing the Index of Hydrographic Data held by the Council was constituted. Its first objective was to ensure that oceanographic data received by ICES was either in punch card format, or could be easily transferred to punch cards. Before introducing ICES punch cards a survey of the formats in use at other organisations was made—it was decided to make the ICES format compatible, as far as possible, with that of the US Navy Hydrographic Office. The lCES system was adopted by the Council in 1958 and was later published as a manual (see Fig. 5). The manual was widely distributed to marine institutions all over the world, and they were urged to use the lCES system, as a common format would greatly facilitate exchange of data. Although submitters could still deliver their data using formats other than punch cards, they were then charged a fee to cover the cost of ICES having to create punch cards from their data. (‘*The ICES Service Hydrographique, its Development as a Regional Data Center and its Relation to the World Data Centres*’: ICES 1966a, Levitus 2012). Punch cards sped up data submission since there was no need for manual transcription—data publications could also be directly prepared from them. International data sharing was facilitated by sending copies of the cards to other data centres. (Although punch cards were introduced for oceanographic data, fisheries statistics and biological data continued to be submitted on paper.)

From 1957, ICES published oceanographic data in a series called ICES Oceanographic Data Lists (IODL), but this publication survived only six years because of the diminishing interest of the scientific community in using printed data lists. In 1967, the Intergovernmental Oceanographic Commission (IOC) introduced the first edition of a cruise inventory called ‘Report on Scientific Cruises and Oceanographic Programmes’ (ROSCOP), which has subsequently passed through multiple revisions and is now called the Cruise Summary Report (CSR). ICES took on the task of coordinating the return of completed forms from its member countries, and published edited versions of them in the successor to the IODL series—the ICES Oceanographic Data Lists and Inventories (IODLI). These were published in manuscript until 1975, and then in microfiche form until 1983. The handling of these forms was further streamlined in 1984 by their digitisation (Dooley 1992).

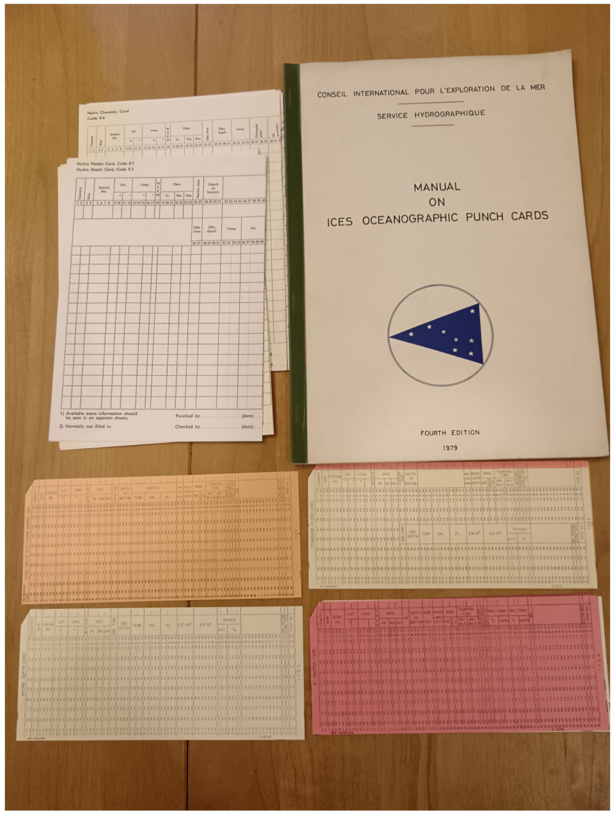

Figure 5. ICES Manual on punch cards containing oceanographic data from 1979, including example cards. Photo by David Currie.

During this period, the World Data Center (WDC) system was formed under the auspices of International Council for Scientific Unions (ICSU, now International Science Council (ISC)) to archive and distribute data collected from the International Geophysical Year, IGY (Korsmo 2010), and ICES provided a model for how these new World Data Centers would handle oceanographic data (p4, Rozwadowski 2002). During the 1960s countries also began establishing formal National Oceanographic Data Centers (NODCs) to archive ocean data and provide services (Levitus 2012). These were formed under the Intergovernmental Oceanographic Commission's International Oceanographic Data and Information Exchange (IODE) programme, which was established in 1961.

In 1967, worries were expressed about the proliferation of new types of data management technology, and the organisations involved. In particular, the ICES Sub-Committee on Automated Data

Processing noted their concerns that the increase in marine data generated by automated collection systems was leading to problems in processing, storing, and finding that data. Complications were also occurring due to the number of new oceanographic institutes and the emergence of the NODCs. These facts meant that costs were rising and that technical problems were becoming more difficult to solve (ICES 1967). The group recommended that it be reconstituted as the Working Group on the Development of Marine Data Systems with the following terms of reference: '*To act as the advisory body to the Committee as to how it can best use modern computer technology as a tool in the scientific interpretation of the oceanographic data collected by the member countries of ICES both on a unilateral and multilateral basis*'.

Another change occurred at the Service Hydrographique in 1968. Up until this point, ICES had taken responsibility for quality control of the oceanographic data. The high level of quality control applied had increased the esteem that its data were held in, alongside ICES' experience managing and publishing data (Rozwadowski 2002). After 1968, the responsibility for data quality was left to national institutes and ICES instead concentrated on analysing the data and publishing it.

1970–90s: the data explosion and the dawn of digitisation

During this period the variety of data that ICES was managing increased as 'environmental data' increased in prominence. (In the ICES context 'environmental data' initially referred to data about physical and chemical pollutants in the marine environment—more types of data, such as fish diseases, would also be classified as 'environmental' in later years.) The importance of ICES' advisory activities also continued to increase as more regional commissions requested advice from ICES, including the International Baltic Sea Fishery Commission (IBSFC) and the North Atlantic Salmon Conservation Organization (NASCO). The Commission of the European Communities (now called the European Commission) also began requesting fisheries advice from ICES in the 1980s (Griffith 2002). The volume of data was also still increasing and being seen as a challenge. Significant technical changes occurred as ICES progressed from punch cards, to data being digitised and stored on computers, and then being published on the World Wide Web.

In 1970, the Working Group on the Development of Marine Data Systems changed its name to the Working Group on Marine Data Management. Its terms of reference were also updated (ICES 1970). This new working group was long-lived and existed until 2007. Some notable achievements during this time include:

- Consideration of new formats including the ICES 'blueprint' to provide more flexibility. They also collaborated with IOC-IODE on this topic.
- Collaboration with the World Data Service for Oceanography (formerly World Data Centre for Oceanography), USA, on the Global Ocean Data Archaeology and Rescue (GODAR) project.
- A review of data provision (temperature, salinity and nutrients) to the Service Hydrographique by member countries was undertaken (Rickards 1993).
- A further collaboration with IODE was the revision of the IOC ROSCOP form for reporting data collected on research cruises. The result was the Cruise Summary Report (CSR), introduced in 1990. For many years, ROSCOP/CSR forms have been an integral part of the ICES data tracking system and CSRs are still in widespread use by NODCs and other data centres today.
- The development of guidelines for handling different data types, many of which are still in use and regularly reviewed. The current guidelines are available from the ICES website. (https://www.ices.dk/data/guidelines-and-policy/Pages/ICES-data-type-guidelines.aspx) and from the IOC Ocean Best Practices System repository (https://www.oceanbestpractices.org/).

ICES' commitment to environmental science had begun in 1966 under the auspices of its new Fisheries Improvement Committee (FIC). The Hydrography Committee continued to cover physical and chemical aspects of pollution, while FIC concentrated on pollution affecting fish and shellfish. In the 1970s, marine pollution became a growing concern and in 1971 ICES created the Advisory Committee on Marine Pollution. These events marked the beginning of a new category of data at ICES—there were now three main data streams within ICES: fisheries, oceanographic, and environmental data.

During the 1970s, the Service Hydrographique was struggling to cope with the increasingly large volumes of data. The creation of the NODCs had also reduced its relevance. ICES twice considered whether to close the Service Hydrographique—although it did survive, it did so with a reduced scope. By the early 1980s, the Service Hydrographique had effectively stopped being a data centre (Rozwadowski 2002, Annex 5: ICES 2001).

In 1971, the ICES Statistics Committee discussed the problems encountered in compiling and tabulating data—they agreed that the way forward was to adopt automatic data processing facilities (ICES 1971). The statistical data submissions used standardised forms; however, the format of the submissions used by stock assessment working groups varied, which meant they were not suitable for automatic processing (ICES 1972a, 1972b). Data from the International Young Fish Survey was being submitted on paper before some elements were entered on to computer (this was done by the Ijmuiden laboratory, Netherlands, who managed the database before it was later transferred to ICES) (ICES 1982b). Efforts were made to investigate whether statistical data could be transcribed to punch cards before being processed on a computer (ICES 1972b), but later technical developments such as submitting data on magnetic tape superseded this (ICES 1978).

By 1980, the amount of marine data being collected and processed was again causing problems—a joint session of the ICES Hydrography and Statistics Committees was convened to 'Consider Data Handling Problems'. This discussed various approaches to cope with the data 'explosion' in marine science in member countries by means of intelligent data gathering, automated data handling and interdisciplinary data structuring (ICES 1980). During the early 1980s, data started to become digitised and this allowed for greater storage volumes and processing capacity. In 1984, ICES had an ND-100 mini-computer (the 'NORD' computer) located in their building, and also used UNIVAC computers based in the University of Copenhagen, and IBM computers based in the Danish Technical University (ICES 1984). The NORD computer was mainly used to process data required by the assessment working groups and for data entry. The UNIVAC mainframes at the University of Copenhagen were extensively used by ICES for magnetic tape data exchange and for holding large volumes of data, such as the fish-

Figure 6. Examples of floppy discs containing ICES data. Photo by David Currie.

eries statistics (STATLANT) and IYFS projects (ICES 1982b, 1986). During the 1980s and 1990s tapes, floppy disks, and CD-ROMS were used to store and distribute data. In particular, CD-ROMs became a practical way to distribute large volumes of data (see Figs 6 and 7 for some examples).

The three main data streams within ICES (fisheries, oceanographic, and environmental data) were still treated separately. Communication between the different disciplines was minimal, which led to inefficiencies and duplication of effort. It was highlighted that there was no oceanographic database available—these data were still being stored using the now out-dated punch card format. Insufficient disk space was noted as being a problem, along with the need to convert data from tape to disk, and the magnetic tapes were split between two different locations. Environmental data were being submitted on paper, tape, and floppy disk—data were stored as ASCII files, which were accessed using an inventory master record (ICES 1990).

In the late 1980s, it was identified that substantial amounts of data existed only in manuscript, analogue, or obsolete digital formats and were in danger of being lost. The 'Global Oceanographic Data Archaeology and Rescue' (GODAR) project was established by the 14th Session of the IODE Committee (1992) and the project began in 1993 (Levitus 2012, IODE 2019). The goal of GODAR was to increase the volume of historical oceanographic data available to researchers by locating ocean profile and plankton data sets not yet in digital form, digitising the data, and ensuring their submission to national data centres and the World Data Center system (now the World Data System). The project also aimed to rescue historical oceanographic data that existed in manuscript or electronic media form that were at risk of loss due to media decay or neglect. In the project, 'historical' data were defined as pre-1992. ICES took a lead role in the project for the ICES region—they encouraged member states to participate in the project, provided a focus for member state's activities, and the Working Group on Marine Data Management regularly reported on the project's progress. It was observed that for the ICES member countries around 50% of the data rescued by the project activities had been acquired via ICES (ICES 1997). Data recovered through the GODAR project were submitted to National Oceanographic Data Centres and included in outputs such as the World Ocean Database releases (NCEI 2023, Mishonov et al. 2024). Detailed results for the increase of data provided during GODAR were given by the US NODC (now part of the National Centres for Environmental Information) (Levitus 2012).

The 1980s and 1990s saw a resurgence in the importance of the Service Hydrographique and it became a major provider of data to the World Data Center system. This was partly because the ICES Secretariat had invested in modern computing systems, and partly because the need for regional compilation of data was recognised. In 1988, Carlberg and Føyn (Carlberg and Føyn 1988) highlighted an issue regarding the inadequate submission of data (especially nutrient data) to ICES. They then described a number of initiatives that could be used to increase submissions, including

- ICES should increase their efforts in informing institutes about ICES activities in order to stimulate a wider participation.
- Contact scientists and assist them in submitting their data.
- Remind data originators that they may have an obligation to provide their results, including their data.
- Correctly attribute references to the originating institute.
- Ensure that submitted data are not made available for commercial purposes or other non-authorised uses.

By the mid-1990s, the situation was seen to be very positive, with an estimated 30% of potentially available data being captured. Relations with the NODCs were also seen to be productive, both for data exchange, and exchange of Cruise Summary Reports (ROSCOP) (Annex 5: ICES 2001). In the period 1967–91, it was seen that nearly half of the data reported on ROSCOP forms had actually been supplied to ICES (Rickards 1993). Data submission was generally better from those countries geographically close to ICES and from projects where ICES was the specified data centre or project coordinator.

In 1994, ICES summarised its rules and procedures related to databases [CM 1994 Del-10 (ICES 1994)]. At that time, the ICES Secretariat maintained several oceanographic, environmental, and fisheries databases—see Table 1.

Some of the databases were for the sole use of ICES, some were for client organisations (e.g. OSPAR), and some had multiple users (e.g. the oceanographic database). It was pointed out that some of the previously unwritten 'agreements' and 'understandings' were not sufficiently clear for the Secretariat to act as custodians of the data. For example, the International Bottom Trawl Survey Working Group operated on a 'gentlemen's agreement' on access to the data. It was understood that full access to the International Bottom Trawl Survey (IBTS) database was only granted to the national laboratories involved in the survey, as well as to working groups within ICES. These users were not allowed to export detailed data from other participating laboratories without prior contact with the national contact persons. Another example was the procedures relating to requests for ICES oceanographic

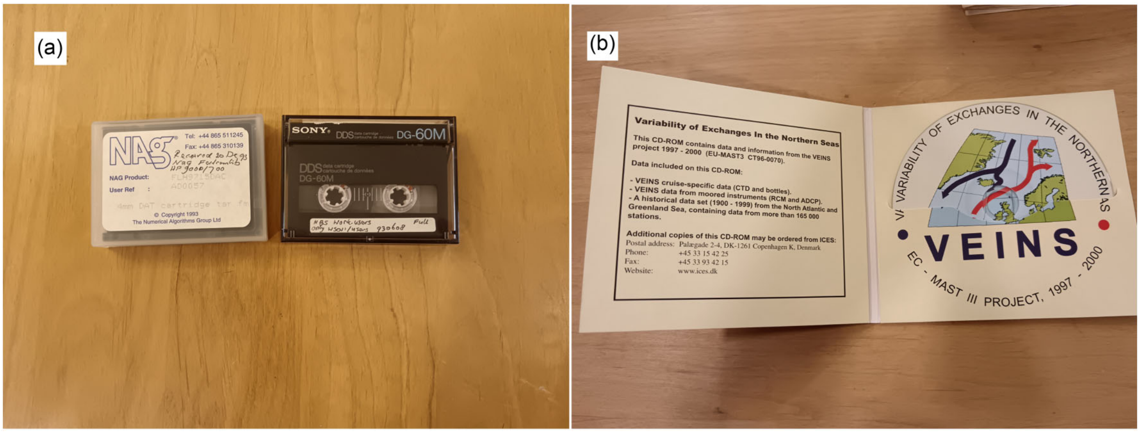

Figure 7. Examples of different media used to store and distribute data as the volume increased. (a) Data cartridges, (b) CD-ROM of data from the VEINS project 1997–2000. Photos by David Currie.

Table 1. ICES databases in 1994.

ICES database name (category at the time in brackets)	Description
The ROSCOP database (Oceanography)	Details of almost 25 000 research cruises conducted by ICES Member Countries since 1967.
The hydro-chemistry database (Oceanography)	The hydro-chemistry database was one of the largest oceanographic profile collections in the world, containing data from 1902 onwards (half of which included oxygen/nutrient/chlorophyll/pH data) along with temperature and salinity surface data values originating from the ICES ship route programme.
Environmental Data Bank (Environmental)	Computerized in 1983, the database contained data back to 1978 for contaminants. Data included contaminants in finfish and shellfish; contaminants in sea water; contaminants in sediments; data from measurements of the biological effects of contaminants; and fish disease prevalence data.
STATLANT 27 data (Fisheries)	Fisheries statistics data. The data consist of ‘STATLANT 27A’ data (annual landings of fish and shellfish by ICES Statistical Area) and “STATLANT 27B” data (monthly landings and fishing effort by ICES Statistical Area and vessel or gear category).
FISHSTAT AO data (Fisheries)	Aquaculture production statistics since 1982.
The IBTS (International Bottom Trawl Survey) database (Fisheries)	Data from the International Young Fish Survey from the year 1970 onwards. The data consisted of the haul-by-haul data. In 1990, it was decided to expand the database to include the results of quarterly bottom trawl surveys of the North Sea planned to take place from 1991 onwards.
The Fish Stock Assessment data base (IFAP) (Fisheries)	The data in the IFAP database consisted of catch in tonnes, catch in numbers at age, fishing effort and biological data and parameters by stock, and in some cases also by fleet.
The STCF database (Fisheries)	The database on the North Sea was set up by the Scientific and Technical Committee on Fisheries of the European Community (STCF). It contained disaggregated data for the years 1989 and 1991 including fleet specifications; catch and effort data; catch-at-age data; and price-at-age data.

data—these were similar, but not identical, to those procedures adopted in the IODE system. An important difference was that ICES reserved the right to ‘refuse or hinder a request’ if the data requester was also a potential data supplier who was refraining from supplying data to the ICES Secretariat. It was proposed that some general rules should be applied to data access:

- The reasons for which the applicant requires the data must be stipulated, and uses for other purposes later require prior approval.
- Suitable acknowledgement of ICES or the specific source of the data is expected.
- With regard to fees to be charged, all commercial enterprises and persons/bodies receiving consultancy fees for their work,

should pay the full cost incurred by the Secretariat. All non-governmental organisations should also be charged based on this same costing principle.

- Information should be supplied only to persons affiliated with identifiable corporate bodies, e.g. institutes, universities.

Following the initial proposal a data request form was implemented for access to fisheries databases [CM 1994 Follow up to Del: 10 (ICES 1994)]. On receipt of the completed request, a clear distinction was drawn between studies carried out under contract or for remuneration, and those carried out for scientific studies not associated with contracts. These proposals were accepted (ICES 1995).

Sampling instruments for collecting data had continued to improve during this period and the late 20th century also saw the emergence of autonomous vehicles both at surface and subsurface capable of conducting underwater surveys without requiring a human presence. These vehicles could be equipped with various sensors to collect data autonomously. The launch of Earth-observing satellites allowed for large-scale monitoring of marine environments. Remote sensing technologies enabled scientists to collect data on sea surface temperature, chlorophyll concentrations, and ocean currents from space. Remotely operated vehicles (ROVs) and manned submersibles became more common, enabling scientists to explore deeper marine environments collecting samples.

Following the invention of the World Wide Web in 1989, and with the prevalence of website development during the early 1990s, www.ices.dk was launched in 1996. In 1997, ICES data available on the web included ROSCOPs generated by EU MAST programmes; environmental data (via a direct link to the database); the ICES data policy, and data product guidelines [Section 9: (ICES 1997)].

21st century: integrated, open, and online data

This period saw significant changes in data management within ICES, including the creation of a unified ICES Data Centre, and, through a programme of agreed amendments of the ICES data policy, data were made openly available by default. The volume and variety of data being managed also continued to increase, and the use of the internet and World Wide Web for distributing and publishing data became the default method. Many different ICES databases and data portals were launched from 1999 onwards—see Table 2. In this table, the categorisation follows the current way of thinking about ICES data, rather than the coarser categories of fisheries/oceanographic/environmental data which were more commonly used in the 20th century. While some new categories can be easily mapped to the older categories (e.g. 'Fisheries Independent' data are a sub-set of 'Fisheries' data) not all of the new categories can be as easily mapped to the coarser schema (e.g. 'Biodiversity' data).

In the early 2000s, the situation was not looking favourable for the Service Hydrographique—in particular huge back-logs of data were building up. The Service Hydrographique was not alone in this problem, as NODCs were also seen to be experiencing similar problems. It was also highlighted that Cruise Summary Reports were not being completed which meant that it became impossible to track what data was being collected (Annex 5: ICES 2001).

With respect to commercial fisheries data, annual nominal catches of more than 200 species of fish and shellfish in the North-east Atlantic region were officially submitted by ICES member countries. Statistical data were (and still are) collected and coordinated in collaboration with the Statistical Office of the European Communities (Eurostat). Until fairly recently, the electronic database of catch statistics maintained by ICES and Eurostat only contained data from 1973 onwards. The digitisation of older data was of mutual interest to ICES and Eurostat, as was the validation of more recent data. Long time series of data are essential to analyse and predict the effects of global challenges. A joint project was initiated by ICES and Eurostat to digitise data from the ICES hard-copy archives for 1903–72, and validate data in the Eurostat/ICES database for 1973–2005. On completion of this project, the Eurostat/ICES catch database was updated and the results were published on the ICES website (ICES 2026a). It was noted that countries have changed data-collection and compilation methodology several times during the period but these changes are not fully documented in the literature—this makes it difficult to assess the consistency of the series. Furthermore, there are changes in coverage by countries and by areas. Nevertheless, the efforts of data rescue projects to recover, preserve, and share data increase the amount of scientific evidence available to everyone (Lassen et al. 2012).

In the 2001 Working Group on Marine Data Management (WGMDM) report (ICES 2001), it was highlighted that the ICES oceanographic data policy of the time was to a large extent based on the 1988 Carlberg and Føyn paper. Free and open exchange of data was encouraged but any restrictions specified by data submitters were respected. In 2004, the ICES Study Group on Management of Integrated Data (SGMID) noted that ICES had last reviewed the data policy in 1994, and that new policies had been added since that time but there was not always a clear justification for why access to certain data was restricted. Different arrangements were also in place for the different data streams (fisheries, oceanographic, and environmental) with little consistency between them. The group recommended that ICES should revisit its data policy in order to provide users with maximum accessibility and openness (ICES 2004). In 2005, the ICES Bureau Working Group for Data Development Project (BWGDDP) proposed a data policy (C.M. 2005/Del.04/05/03 (ICES 2005b), which contained an important statement: '*All data submitted to ICES are considered to be in the public domain unless otherwise explicitly specified and agreed*.' In 2005, the new data policy was subsequently adopted with minor changes (ICES 2006) and many of the points it contained have survived through to the current ICES Data Policy (ICES 2025g). Box 2 highlights the key points of the ICES Data Policy.

Box 2 ICES data policy

By maximizing the availability of data to the community at large, ICES promotes the use of these data, thereby ensuring that their maximum value can be realized and thus contribute to an increased understanding of the marine environment.

The latest version of the ICES Data policy was revised and approved by ICES Council in April 2025, this replaced all previous versions.

Key points about this policy

Table 2. Launch years of ICES databases and data portals.

Launch year	ICES databases/data portals (category in brackets)
1999	OCEAN (Ocean Hydro Chemistry)
2003	DATSU—Data Screening Utility (ICES Data Portals)
	RECO—Reference Codes (ICES Data Portals)
2006	Code Request Management (ICES Data Portal)
	DATRAS (Fisheries Independent)
2007	DOME (Marine Environment)
	IROC—ICES Report on Ocean Climate (Ocean Climate)
	InterCatch (Fisheries Dependent)
2008	Ecosystem Data (ICES Data Portal)
2009	vocab.ices.dk (ICES Data Portal)
2010	ICES Metadata Catalogue (ICES Data Portals)
	ICES Spatial Facility (ICES Data Portals)
	Stomach Data v1 (Fisheries Independent)
2011	Historical Plankton (Marine Environment)
2012	Eggs and Larvae (Fisheries Independent)
2013	RDB-FishFrame (Fisheries Dependent)
	Stock Assessment Graphs (SAG) (Fisheries Dependent)
2014	VMS—Vessel Monitoring System (Fisheries Dependent)
2015	SID—Stock Information Database (Fisheries Dependent)
2016	Biodiversity—seals and birds (Biodiversity)
	VME—Vulnerable Marine Ecosystems (Biodiversity)
2017	Acoustic surveys (Fisheries Independent)
	Bycatch portal (Fisheries Dependent)
2018	SMARTdots (Fisheries Independent)
2019	Impulsive Underwater Noise (Marine Environment)
2021	JCDP—Joint Cetacean Data Portal (Biodiversity)
	ICES Data Portal (ICES Data Portal)
	Continuous Underwater Noise (Marine Environment)
2022	ESAS—European Seabirds at Sea (Biodiversity)
	RDBES—Regional Database and Estimation System (Fisheries Dependent)
2023	ASD—Advice and Scenarios database (Fisheries Dependent)
	Stomach Data v2 (Fisheries Independent)
2024	AIMS—Accession Information Management System (ICES Data Portal)
	Fecundity and Atresia (Fisheries Independent)

- All public data are under the Creative Commons (CC BY 4.0) licence
- Is intended to facilitate the production of science-based advice and status reports, and serve the scientific community
- Applies to data managed by ICES

Licences for restricted data include:

- Commercial catch data from the Regional Database and Estimation System (RDBES), Regional Fisheries Database (RDB-FishFrame), InterCatch and protected species bycatch data licence (ICES 2023b),
- ICES Vessel Monitoring System (VMS) and Logbook data licence (ICES 2022a),
- ICES Biodiversity data licence (ICES 2022b).

2002 saw the EU's Data Collection Regulation (DCR) come into effect—prior to this, data collection in EU member states was dependent on the availability of adequately funded national programmes (Doerner et al. 2018). Under the DCR, the national fisheries research institutes of EU member states conducted regionally and internationally coordinated sampling programmes which were co-financed by the European Commission. The DCR introduced provisions specifying the data to be collected, and the transmission of the data to the end-users in response to data calls to EU member states. With these provisions, the DCR established a more systematic fisheries data collection system within the EU. The second EU Data Collection Framework Regulation (DCF) in 2009 (recast in 2017) further improved the access, exchange, and use of EU fishery-dependent and fishery-independent data for scientific advice. The DCF sets out a harmonised approach for the collection by EU Member States of biological, environmental, technical, and socio-economic data for the fishing, aquaculture and processing sectors. Fisheries data collection is enshrined in the EU's Common Fisheries Policy (CFP) as the backbone supporting evidence-based management and sustainable exploitation of marine living resources. The core of this system remains fisheries-related data, complemented by ecosystem and socio-economic information to support integrated advice. Given that many ICES member countries are also EU member states the data collected under the DCF has become a key data source for ICES, and ICES is recognised as an important end-user of that data (EU 2020).

In 2004 the ICES Secretariat was restructured in order to better meet its requirements. The formerly independent sections of Oceanography, Environment, and Fisheries were restructured into a Science Programme section and an Advisory Programme section. ICES also embarked on an ambitious project to integrate its disparate databases into a single ICES Data Centre (ICES 2005a). This was driven by the need for better coordination across disciplines and the increasing complexity of managing large amounts of data. Prior to this formal re–arrangement developers from the three different sections had already started to work together more closely. The creation of the ICES Data Centre was an important step toward modernising data management, as it allowed for more standardised processes and improved collaboration across the three fields. It also established the role of professional data managers rather than accidental, or ad-hoc, data managers. The ICES Data Centre allowed for easier access to data, enhancing scientific collaboration across disciplines and countries.

In 2007 the Working Group on Marine Data Management (WGMDM) and Study Group on Management of Integrated Data (SGMID) merged into the new Working Group on Data and Information Management (WGDIM). WGDIM aimed to provide ICES with advice on all aspects of data management including technical, data policy, data strategy and user-oriented guidance (ICES 2007b). Between 2012 and 2013 WGDIM changed to an ICES 'operational group': the Data and Information Group (DIG), bridging the gap between ICES data and their real-world application, and providing advice to ICES on all aspects of data management, beyond the capability of expert groups (ICES 2021). Figure 8 shows the lineage of the ICES groups that led to DIG—these are groups which took a broad overview of how data is managed within ICES, rather than looking at specific subjects or domains. DIG currently provides ICES with advice on all aspects of data management including data policy, data strategy, data quality, technical issues, and user-oriented guidance. DIG recognised that it could not provide detailed data governance for all ICES data products so from 2017 onwards it has encouraged the creation of data governance groups. 'Data governance' is used as a broad term including concepts such as data policies, data management, access rules, and data standards. These groups act as a bridge between the ICES Data Centre, data suppliers and data users for specific dataflows. They help to ensure that the knowledge and experience of scientists and other domain experts can be combined with the skills and expertise of data managers.

In the 21st Century, marine data collection techniques continued to advance reflecting a trajectory towards greater precision, automation, and integration of technology—from manual sampling methods to sophisticated autonomous systems and advanced data analytics. Uncrewed underwater vehicles have gained significant attention and application over the past few decades in marine research, environmental monitoring, defence, and commercial sectors—these include Uncrewed Surface Vessels (USVs), Autonomous Underwater Vehicles, and ROVs. These advanced vessels can operate autonomously or be controlled remotely without a crew onboard, allowing for enhanced data collection and operational flexibility (see Fig. 9 for some examples). An example of the use of USVs is in fisheries acoustics where they can provide echosounder data at a lower cost and carbon emission per sampling distance when compared to research vessels. One of the key points about USV-based acoustics is that they are generally not equipped to image or capture specimens. Whilst the ICES acoustic database could accept acoustic data without complementary biological data, the interpretation of the data would require model assumptions, predictions based on prior knowledge, or contextual information from other sources (Handegard et al. 2024). An example of the use of USVs was given by a 2025 survey of four of Norway's largest fjords—this was conducted using two USVs together with a research vessel. The purpose was to map the quantity, distribution, and age structure of pelagic fish stocks, with a focus on sprat and herring. The survey showed that the combination of USV-based acoustics and night trawling provided an efficient and high-resolution mapping of pelagic stocks in complex fjord systems (Kvamme et al. 2025).

The installation of buoys equipped with sensors has enabled real-time data collection on oceanographic parameters, such as temperature, salinity, and wave height. These systems are crucial for operational oceanography and weather forecasting. The Internet of Things has facilitated the deployment of interconnected sensors throughout marine environments. This networked approach allows continuous monitoring and data collection on various parameters, including water quality and marine life. Advances in data analytics and machine learning have allowed researchers to process and interpret vast amounts of marine data efficiently. This includes analysing acoustic data for fish populations or using machine learning to identify patterns in environmental data or monitoring bycatch of porpoises and birds.

The internet and World Wide Web continued to gain importance for distributing and publishing data, and they are now the default method. As more and more data was published online it was noted that the digital ecosystem surrounding scientific data was preventing society from extracting maximum benefit from the results of research. This led to the development of the 'FAIR Guiding Principles for scientific data management and stewardship'—where the acronym FAIR stands for Findable, Accessible, Interoperable, and Reusable (Wilkinson et al. 2016) (https://www.go-fair.org/fair-principles/). In order to meet the requirements of the 'Findable' aspect of FAIR data, a dataset must be described by rich metadata. Metadata is data about data—it describes data sets and services, thus making it possible to discover, inventory and use them (https://inspire.ec.europa.eu/glossary/Metadata). Metadata harmonisation is essential for long-term data usability—it ensures that data from different sources are described in a standardised way, facilitating interoperability, integration, and cross-disciplinary analysis. By aligning metadata fields, data consumers can more easily compare and merge datasets, enhancing the accuracy and scope of insights (Flynn et al. 2025). ICES has always requested metadata alongside data submissions, but for many years, there were no agreed standards for it. The single biggest change in improving the availability of metadata in the EU was the INSPIRE legislation—see Box 3.

Box 3 Metadata and the INSPIRE Directive

The INSPIRE Directive was published in 2007 with the aim of laying down general rules aimed at the establishment of the

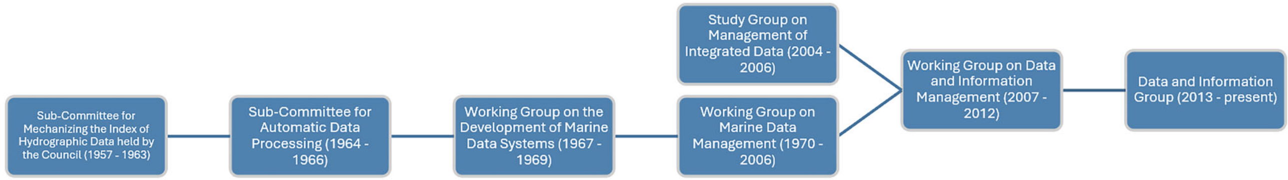

Figure 8. Lineage of ICES groups that focused on data management.

Figure 9. Examples of uncrewed vehicles used to collect data. USV Sounder from Kongsberg Maritime AS, (a) Brage Photo by Helge Sagen (IMR), (b) Photo by Caspar Christie (IMR), (c) Frigg Photo by Geir Pesersen (IMR), (d) A sail drone with an echosounder, used by SLU Aqua, Sweden. Photo: Jonas Hentati Sundberg.

Infrastructure for Spatial Information in the European Community (EU 2007). This marked the first important step on the way to a European-wide legislative framework to achieve a European Spatial Data Infrastructure. Before this point, there had been a number of national and regional initiatives to establish Spatial Data Infrastructures but spatial information in Europe was still fragmented with gaps in availability, lack of interoperability or harmonisation between datasets at different geographical scales and duplication of information collection (Bartha and Kocsis 2011). The INSPIRE Directive meant that geo-spatial data that was published had to be accompanied by metadata. Not only did this increase the amount of metadata published but it also increased organisational capabilities for creating and distributing metadata.

Not all European ICES member countries are also members of the EU; however, there is still a compatibility in their spatial data infrastructures. The UK passed the INSPIRE (Amendment) (EU Exit) Regulations 2018 to enable the continued operability of the INSPIRE Regulations following the UK's withdrawal from the European Union (https://www.legislation.gov.uk/uksi/2018/1338). In Norway, the Norwegian Geodata Act came into force in 2010—this implements the INSPIRE Directive and regulates the establishment of the Norwegian spatial data infrastructure (NSDI) (https://www.geonorge.no/en/infrastructure/norway-digital/spatial-data-infrastructure/).

At the time of writing, ICES is a network of nearly 6 000 scientists from over 700 marine institutes in 19 member countries and beyond. Over 2 500 scientists participate in ICES activities annually (https://www.ices.dk/about-ICES). The ICES Data Centre has 17 employees and provides marine data services to ICES member countries, expert groups, the World Data System, regional seas conventions, the European Environment Agency (EEA), FAO, European Marine Observation and Data Network (EMODnet), and various other European projects and biodiversity portals (ICES 2025a). The ICES Data Centre hosts data collections on marine biological data, marine environment data, oceanographic data, and underwater noise data. Datasets are organised around specific thematic data portals, where everything from data on ocean-related human activities, such as fisheries, to physical oceanography, and data on biodiversity can be found. ICES biggest data collection is for oceanography, with over 9.4 million records with the earliest measurement dating back to 1862 (https://www.ices.dk/data/data-portals/Pages/default.aspx). Maps and spatial layers are also used in ICES to aid in the organisation of data into something more than a collection of numbers and coordinates. ICES manages a number of maps related to the Northeast Atlantic, these are used extensively by the expert groups for the planning of data collection and the visualisation of data. Maps can be downloaded as digital shapefiles or used online (https://www.ices.dk/data/maps/Pages/default.aspx).

ICES data collections focus on marine biological data, marine environment data, and oceanographic data. Biological data covers commercial fisheries, fisheries independent surveys (such as fish trawl and acoustic surveys), seabirds, marine mammals, as well as fish stomachs. Oceanographic data at ICES covers both eutrophication data and ocean hydrochemistry data. The marine environment data collection comprises plankton and benthos community, as well as fish disease, marine litter, and contaminants data. ICES also hosts data on underwater noise (both continuous and impulsive). Currently, ICES receives data in circa 70 standard data formats, feeding into 31 distinct data flows. The majority of data originates from national institutes that are part of the ICES network. Dataset collections are organised around specific thematic data portals as well as an overarching data warehouse. The ICES Data Centre has been accredited under CoreTrustSeal since 2021, which highlights its ongoing commitment to high-quality, transparent, and sustainable data management (https://www.coretrustseal.org/). CoreTrustSeal is an international, community-based organisation, which promotes sustainable and trustworthy data infrastructures.

As we reach the present day, it is worth looking at the wider seascape of marine data management that ICES is a part of. Marine data is collected by a large number of different organisations and individuals using many different types of equipment, sensors, and techniques. These data are also used by a large number of different people and organisations for a wide variety of purposes. The preceding decades have seen progress made in a number of key areas of data management including collaboration, in particular in the creation of services and networks that can aggregate marine data and make it more widely available. Marine data aggregation services and networks can play a crucial role in harmonising metadata, applying quality checks, and integrating diverse data sets (Schaap et al. 2022, Novellino et al. 2025). ICES plays an important role in many of these networks as a regional data provider.

The IODE (https://iode.org/) now consists of more than 100 National Oceanographic Data Centres (NODCs), Associate Data Units (ADUs), and Associate Information Units (AIUs). These centres manage and make available ocean data products and services including the Ocean Data and Information System (ODIS, https://odis.org/), the Ocean Biodiversity Information System (OBIS, https://obis.org/), and the World Ocean Database (WOD (NCEI 2023). The Global Ocean Observing System (GOOS, https://goosocean.org/) is a coordinated but decentralised system that facilitates data assembly and exchange via regional alliances including EuroGOOS https://eurogoos.eu/(Snowden et al. 2019). The Ocean Best Practices System (OBPS, https://www.oceanbestpractices.org/) is a global initiative aimed at improving and standardising practices for collecting, analysing, and sharing ocean data and information. OBPS is jointly sponsored by IODE and GOOS. In Europe, some of the key data aggregators are the Copernicus Marine Environmental Monitoring Service (CMEMS, https://marine.copernicus.eu/), the European Marine Observation and Data Network (EMODnet, https://emodnet.ec.europa.eu/en), and the SeaDataNet network of data centres https://www.seadatanet.org/.

Looking forward, the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), the "Ocean Decade," aims to generate the data, information and knowledge needed for more robust science-informed policies and stronger science-policy interfaces at global, regional, national and local levels. The Ocean Decade Vision 2030 White Paper 8 (Calewaert et al. 2024, 2025) defined several key tools and services that are still needed to create and make available a digital representation of the ocean, including a global Ocean Data Discovery and Access Service (DDAS). This will need to be a federated global service providing access to multidisciplinary data, data products, and information.

Discussion

As we approach ICES' 125th jubilee it is natural that many significant changes have occurred during its life but the management of data (including its submission, collation, storage, publication, and preservation) has been a key interest of ICES since its foundation. Data are essential for assessing the state of seas and oceans as well as for providing feedback on the effects of conservation and management measures. As we have seen, data management has evolved from paper submissions and analogue databases, via punch cards, to be fully digitised. It is hard to overestimate, the importance of the invention of the internet and World Wide Web and the effect it has had on data management. Within ICES the formation of a unified ICES Data Centre in 2004 was a significant event. Whilst there had been efforts previous to this point to better integrate fisheries, oceanography, and environmental data they had not always proved successful—the creation of the Data Centre paved the way for a more joined-up way of managing data.

It is worth reviewing the current status of ICES data management in relation to the worldwide network of marine data centres. From the establishment of ICES, it became a regional 'data centre' before the term had been invented. It was probably unique and was well-recognised for its work. But where does it stand now? The ICES Data Centre is accredited under CoreTrustSeal meaning that it meets the core characteristics of trustworthy data repositories—at the time of writing 172 data repositories or data centres are accredited by CoreTrustSeal, 16 of which are marine related. The ICES Data Centre participates in a wide range of partnerships, networks, and global collaborations. It also contributes to IODE, as an ADU and a participant in OBIS.

Not all data centres are the same and comparing them can be like comparing apples and oranges. These centres vary in many ways, including mission, size, the variety of data types handled, technical expertise, and diversity of data suppliers. However, a comparison could be made with the IODE NODCs. Currently, IODE has 65 NODCs and 46 ADUs. In the 2024 IODE survey of the health of NODCs (Rickards and Pissierssens 2025), the highest ranking usually had well-developed leadership and specific data or technical skills, and they are often CoreTrustSeal or IODE accredited. Although this survey did not include ADUs, the ICES Data Centre would have a place amongst the top-ranking NODCs.

The ICES Data Centre serves a broad community with their data, expertise, and technical knowledge. Some of the most active users of ICES data are the many ICES expert groups. One of the most effective ways to ensure that the ICES Data Centre is serving the needs of these groups has been the creation of data governance groups. For a given database or system, these groups bring together the data providers, data users, and the Data Centre. This has been seen to be a very effective way of improving systems since it provides a structured way to identify problems and new requirements, discuss and prioritise them, and monitor their implementation. The creation of the ICES Data Science and Technology Steering Group (DSTSG) in 2021 has given more focus to the work of expert groups that consider data—this aims to help advance data science, systems management, quality assurance, and data governance at ICES. Expert groups can also make requests for changes and improvements to data systems directly to the ICES Data Centre by using the ICES recommendation system. All of these efforts help expert groups access the data they need—there are no silver bullets, but these efforts are the path forward for increasing the effectiveness of ICES data systems.

Some categories of data users, e.g. OSPAR, provide regular feedback and continue to contract work to the Data Centre. The ICES Data Centre is recognised as a valued partner and is in high demand in projects such as EMODnet and SeaDataNet, where they are regularly invited to participate in new project phases, often contributing data, data standards and harmonisation.

ICES' position as an important regional data centre, participating in a broad network, providing a range of data, data products and services, has enabled the Data Centre to retain its position in the top tier of marine data centres.

FAIR

Whilst the FAIR principles were only articulated in 2016, we can interpret the changes in ICES data management as being an increase in the FAIRness of ICES data—see Table 3. The FAIR principles have guided the work of the ICES Data Centre in recent years. For example, in 2017, it was recognised that the ICES data portal did not support newer data types, and that from a user perspective, there was a discontinuity between the existing data portal and the thematic portals (ICES 2018). The data portal was redeveloped, which enabled users to search and explore the data more directly as well as access downloads—thus, better realising the FAIR principles https://data.ices.dk/view-map.

The FAIR principles are also seen to be an important part of the guidelines for ICES advice ('*Principle 6: Data are findable, attributable, researchable, reusable, and conform to ICES data policy. Data flows are documented*.' (ICES 2023c 2025s) . Whilst much of the data that is used to create ICES advisory products is managed by ICES that is not the case for all of it. Where external data are being used it is vital to ensure they are documented—the ICES Data Profiling Tool (DPT) was created to ensure that experts evaluate this data in a structured way (ICES 2025d).

The ICES Data Centre develops and maintains a number of data tools that are used by the community. The development of these tools is guided by the FAIR principles to ensure they are as useful as possible. For example, the Transparent Assessment Framework (TAF) is an online open resource for yearly ICES fish stock and mixed fisheries assessments, as well as other types of assessments (ICES 2026c). The open framework enables anyone to easily find, reference, download, and run the assessment from any stage in the process leading to the published ICES advice. Wherever possible, TAF assessments can use web services to access data; the data being used are documented; different data sets that use common reference codes can be integrated together more easily; and the results of the assessment can be published and made available.

Five V's

We can also consider the changes in ICES data management in terms of the five 'V's: Volume, Variety, Velocity, Veracity, and Value.

Volume

The volume of data submitted to ICES has continued to increase throughout its lifetime and this has triggered necessary changes in how it is managed. For example, the increase in data volumes related to the International Geophysical Year (IGY) 1957–8 necessitated the change to punch card data submissions. By the 1970s, the ICES Service Hydrographique was struggling to cope with the increasingly large volumes of data and ICES twice considered whether to close it. During the 1980s, the increasing volume of data could be stored in computers; however, retrieval of the data was costly—this led to discussion about what data should be stored centrally, and what should remain with the originators. Digitisation of data was also not uniform—the oceanographic data was still being stored in punch card format. In the early 2000s huge back-logs of data again built up at the Service Hydrographique.

As a guide to the increase in data volume, the ICES Central Card Index contained almost 200 000 cards by its retirement in 1956, whereas ICES' current biggest data collection is the oceanography database, with over 9.4 million records.

Variety

ICES' commitment to environmental science began in 1966 and by the 1980s ICES had established a mutually beneficial service role to the OSPAR Commission (OSPAR started in 1972 with the Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft and was broadened to cover land-based sources of marine pollution and the offshore industry by the Paris Convention of 1974). ICES contributed significantly to this work by collecting data on marine pollution, focusing on chemicals and pollutants in the North Atlantic and surrounding seas. Exemplars of this work are the assessments of marine contaminants carried out by OSPAR, HELCOM (the Baltic Marine Environment Protection Commission—also known as the Helsinki Commission), and AMAP (the Arctic Monitoring and Assessment Programme of the Arctic Council), which all base their indicators and assessment on the data managed in the ICES Database on the Marine Environment (DOME). OSPAR and AMAP also have assessment tools managed by the ICES Data Centre (see Fig. 10).

Table 3. FAIR principles at ICES.

Findable	Improvements in metadata and the assignment of persistent identifiers (such as DOIs) make it easier to find what data has been collected. ICES data are indexed in multiple global repositories.
Accessible	ICES data and metadata are accessible via the internet, (either through web pages or web services). Web services allow applications to request data without the need for a human to click a button on a web page https://www.ices.dk/data/tools/Pages/WebServices.aspx.
Interoperable	The continued move to greater standardisation in vocabularies and formats has made it easier to integrate different data sets. ICES publishes its own vocabularies https://vocab.ices.dk/as well as the guidelines it uses for updating reference codes (ICES 2025h)—these state that existing codes should be reused as much as possible.
Reusable	Clarity around ICES data policies and licenses, and the move to a default open license has made data more reusable. Although not all ICES data is openly available it is 'as open as possible, as closed as necessary'. Data meets standards that are relevant to the ICES community.

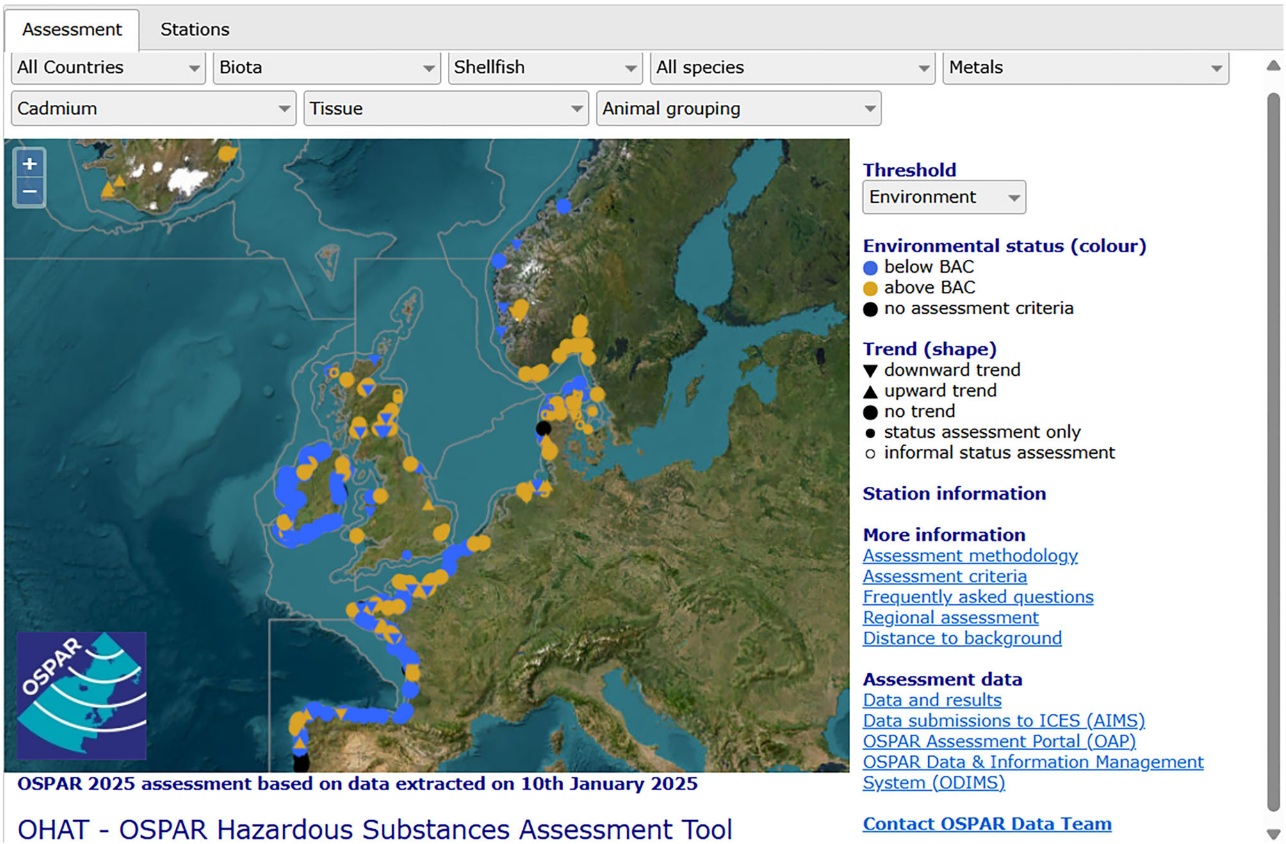

Figure 10. OSPAR Contaminants app hosted by ICES https://www.ices.dk/data/assessment-tools/Pages/ospar-cat.aspx.

In 2007, the ICES Study Group on Biodiversity (SGBIODIV) noted that biodiversity science did not feature strongly in the Science or Advisory Committees of ICES, but that it did form an important component of several active expert groups (ICES 2007a). They identified that ICES could play a key role in long-term safeguarding of biodiversity data. Mutually beneficial cooperation on the topics of data, science, and advice has continued between ICES and OSPAR. ICES currently hosts a biodiversity data portal in order to support OSPAR in providing information that will feed their regional assessments of biodiversity. ICES also currently works with HELCOM in a number of areas. For example, the Joint OSPAR/HELCOM/ICES Expert Group on Seabirds (JWGBIRD) is composed of experts with an interest in seabirds and the implementation of the Marine Strategy Framework Directive. JWGBIRD acts as a data governance group for the European Seabirds at Sea database (ICES 2025i). HELCOM assessments also make use of ICES data collections.

ICES has stated that ecosystem-based management (EBM) of human activities is key to achieving long-term sustainable use of marine resources and it has committed to developing the evidence base and advice to inform EBM decision-making. There are data challenges related to operationalising EBM, including: data used to support EBM may vary greatly in format, precision, availability, spatial and temporal scale, quality, and confidence; and social data relating to marine systems are not routinely collected, have limited temporal and spatial scopes, and are often not interoperable (Roux and Pedreschi 2024).

Velocity

Velocity is the rate at which data flow into a system. Within marine science, there is a large range of data collection velocities. For example, *in-situ* sensors might provide data in real-time—this can be contrasted with age reading of fish where otoliths must first be collected, then prepared and read, which may happen weeks or months after collection. However, since ICES does not directly collect data, it is not the velocity of the original data collection that we should consider, but the velocity of its submission to ICES. ICES typically works on annual cycles so that data collected in one year are submitted in the following year. For data that is used in annual advisory outputs, there is a strict timetable for when data must be made available—typically detailed in ICES data calls (ICES 2025c). One area of ICES data management where the velocity has significantly increased is in data validation. When data had to be validated and corrected by sending paper copies via post, it could take weeks. Then, computerised screening programmes were introduced at ICES meetings, and the validation could be done in hours. The next step was to send the screening programme to the laboratories of ICES member countries, which allowed the validation to be done before the meeting. Now, validation can be integrated into online data submission portals and done in minutes or seconds.

We can see that the velocity of ICES data management has not increased uniformly across all areas of work. The annual collation and release of data has not changed significantly since timely publication of data was always one of ICES' strengths, but the velocity of the data submission and validation process has increased significantly.

Veracity

Veracity refers to how trustworthy and reliable data are. This is not a singular state but a composite of several known characteristics of the data—some of the most common characteristics used include accuracy, consistency, completeness, and validity (ICES 2024a).

Checking the veracity of the data submitted to ICES has always been a key activity. During the early period this was predominantly done by individuals using their experience and expert judgement. In 1968, ICES decided to push the ultimate responsibility for data quality back to the data submitters, which is where it stays under the current ICES Data Policy: '*The data provider retains overall responsibility for data quality*' (ICES 2025g). Today, data quality checks occur at multiple points throughout the data life cycle and are performed by a number of different participants, and ICES plays a key role. An important task of the expert community is now to define which quality checks are required—often this is coordinated by the ICES data governance groups. These checks are then implemented by the ICES Secretariat and documented in the ICES Quality Control Database. Data validation checks performed upon data submissions are automated, and inform the data submitter if the data need any corrections. The ICES Data screening utility (DATSU) facilitates data validation for a variety of datasets—DATSU currently has 3 283 QC rules implemented and screened 11 750 files in 2025 (ICES 2025f). When data are processed for uses such as stock assessment, this can be documented in the ICES Transparent Assessment Framework (TAF).

Errors that are present in data can have significant impacts on ICES outputs, including advice. As part of its quality action plan the ICES Advice Committee (ACOM) has underlined the importance of data transparency and alignment with the FAIR principles. This is in addition to improvements to quality control mechanisms, such as increasing consistency checks across ICES databases, and streamlining data flows (ICES 2025m).

Whilst individual expert knowledge is still important in ensuring the scientific robustness of the collected data the quality checking has become more automated, transparent, and documented over the lifetime of ICES.

Value

The value of ICES data relates to what benefits its users receive. ICES has always been an organisation, which looks to apply science to real-world problems hence the data managed by ICES has often been collected for a specific purpose, such as fisheries stock assessment. To this end, the data (and the advice built on that data) have an immediate and significant value to the users. ICES data support ecosystem-based decisions aimed at the management of human activities in seas and oceans, as well as fisheries, aquaculture, and emerging sectors such as marine spatial planning and offshore renewable energy (ICES 2025b). One aspect that has changed over time has been the greater number of secondary uses of data—where data collected for one purpose can be re-used for different purposes. Recent innovations including digital twins and artificial intelligence rely on having a large amount of data to support them. ICES follow the FAIR principles for the data it manages, which assists in making it as reusable as possible.

Current challenges and opportunities

The ICES Data and Information Group evaluates and monitors current and future challenges and opportunities in data management (ICES 2025n). Some of these challenges and opportunities might have been familiar to many of the people and groups that considered ICES data management throughout its lifetime—the move to greater standardisation has certainly been a common theme, and ICES has also often moved to adopt new technologies. Other challenges and opportunities are more rooted in contemporary times.

Opportunities

One of the major identified opportunities for ICES data management is the adoption of new technology to improve capabilities. For example, there have been significant developments in artificial intelligence (AI) in recent years and extending its use in ICES and the wider marine domain is seen as an opportunity. There is now an unprecedented amount of processing power compared to ever before in the history of ICES. There have also been increases in the volume and variety of marine data being collected. Whilst improved technology generally leads to higher quality data, sometimes the increased volumes are obtained by trading off quality for quantity (e.g. when replacing an expensive full Research Vessel acoustic survey, with a much cheaper autonomous platform). AI systems can now be used to solve complex tasks and widen the analysis bottleneck. These systems can be used to emulate human expertise; carry out analyses that are too complex for humans; gain new scientific insights; and make scientific outputs more reproducible by removing human subjectivity (Malde et al. 2020). (Kühn et al. 2025) reviewed machine learning (ML) use in fisheries (where ML refers to mathematical models that can perform a specific task without explicit instruction). Examples seen included genomics, individual fish identification and measurement, catch identification, on-board processing, stock assessment and dynamics, spatial mapping, and ecosystem dynamics. (Rubbens et al. 2023) observed that applications of ML in marine ecology were seen to have closely followed the development of techniques in computer science—transferring innovations from computer science to the marine domain was thought to be dependent on efficient collaboration across disciplines. It was argued that interdisciplinary training would be a potential solution to many of the current shortcomings of ML applications in marine ecology.

Challenges still exist in marine AI, including making data available in a form suitable for analysis; embedding AI systems in existing infrastructure and pipelines; and developing new expertise and methods (Malde et al. 2020). Sun et al. (2024) observed that challenges in implementing practical AI included missing data; preparing data for use in AI systems; reducing the costs; combining AI and physics-based approaches and making the AI model operational. They state that the key factor in making AI practical and usable is the availability of high-quality data. (Kühn et al. 2025) highlighted that when adopting AI systems for fisheries measures must be taken to avoid undermining the trust of scientists, fishers, managers, and other stakeholders. In particular, the privacy issues and ethical concerns of fishers must be considered. They also highlight that these AI systems are at different stages of operational readiness, and that a key challenge is to reach an acceptable level of performance in varying environments.

In terms of the scientific applications within ICES the Workshop on Applying AI in ICES (WKAAII, ICES 2026d) considered a number of use cases including using AI in remote electronic monitoring of fishing vessels; Large Language Models being used for advice; analysis of calcified structures such as otoliths; and estimating fishing effort. Generally, input data quality was seen as the main challenge. Applying AI to remote electronic monitoring was considered to take the most effort, but also to have the biggest potential impacts. Risks identified included the lack of guidance related to the use of AI within ICES. The use of AI is still at an early stage and concerns have been raised particularly related to ensuring appropriate use of source data without violation of privacy or license agreements; making clear when content has been generated by AI; and determining if ICES published data and reports can, and should, feed into generative AI. Preliminary ICES guidance on the use of AI has now been issued (ICES 2025k) and this states that when using AI technology in ICES work you must not present AI-generated content as wholly original or unassisted work; rely solely on AI for decision-making in areas with social, economic, or ethical implications; or input personal, confidential, or sensitive information into AI tools without consideration of data-handling practices. The ICES Working Group on Machine Learning (WGMLEARN) is developing a list of relevant topics and tasks for the application of artificial intelligence with an emphasis on unmet challenges specific to the marine domain, and potential benefits (ICES 2025e). AI tools and systems are improving rapidly so this is a topic that will undoubtedly see much change within the near future. As has been discussed, making the right data available in the right format is a key requirement, alongside ensuring people have the correct skills and knowledge to use these techniques.

AI systems often require large amounts of computing power to achieve results and it is foreseen that the ICES Data Centre will not be able to provide the amount of computing power required for some of these demanding AI applications. Instead, the approach being taken is to look for collaborations, particularly with infrastructures of 'digital twins' of the ocean. A digital twin is a virtual replica of a physical object, which uses real-time and historical data to represent the past and present, and models to simulate future scenarios. The aim is to create a virtual representation that can mirror its corresponding physical entity (Schaap et al. 2022, Chen et al. 2023). The EU Digital Twin of the Ocean (https://www.edito.eu/) brings together data from services such as EMODnet and CMEMS with supercomputing power in the cloud—rather than downloading the data locally, virtual machines within the digital twin infrastructure run code and applications which use these data. As ICES makes data available via EMODnet and other interoperable infrastructures such as the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/), it can be used within digital twin environments, along with data from other sources.

Challenges

Some of the major data risks identified for ICES are related to a lack of funding, and a lack of data availability—these are problems which have been encountered many times before, albeit in different circumstances. More novel risks include the slow adoption of cloud services.

Funding

Whilst it is difficult to compare like-with-like when looking at the costs of data management, there are some illustrative figures available—see Table 4. It can be seen that the inflation-adjusted cost has increased by more than 1700% from 1959 to 2020. Although the cost per computing unit (e.g. megabyte) has decreased significantly during this time period, the volume and variety of data managed by ICES have increased significantly, which has led to a commensurate increase in costs. The 1959 cost only refers to the mechanical processing of punch cards, while the services in 2020 include a full digital infrastructure offering much greater functionality. This has made more marine data easily available to all users e.g. ICES currently makes over 300 million measurements available to download from its website—this would simply have been impossible even in the late 20th century.

ICES relies on four main funding streams for its data management activities: funding from the ICES member countries; payments from the recipients of ICES advice (including the EU, UK, and Norway); data services contracts from organisations including OSPAR and HELCOM; and external project grants. In 2022 the total contributions to ICES from member countries was ∼23.8 million DKK, with ∼21.7 million DKK received from products and services, and ∼5.6 million DKK from other contracts, projects, and the ICES Journal of Marine Science (ICES 2023d). Of course, this income is used to fund all of the activities of ICES, not just its data management. As well as direct financial funding, ICES also relies on the participation of scientists and experts (from its member countries and beyond) in expert group work. With the reduction in the number of ICES member countries (ICES 2025j) causing a reduction in income it is important to look for alternative funding sources. In 2020, equity was released by ICES

Table 4. Comparative costs of some aspects of data management at ICES over time. 2024 DKK values calculated using https://www.dst.dk/en/Statistik/laer-om-statistik/prisberegner.

Year	Description	Original cost (DKK)	Approximate inflation adjusted cost (2024 DKK)
1959	Mechanization of hydrographic data (ICES 1960)	11 800	186 000
1981	Expenses for machine-handling of data (ICES 1982a)	155 433	475 000
2020	IT expenses (excluding salaries) (ICES 2022c)	3 049 609	3 500 000

and used to fund some data management developments (ICES 2020)—however, this was a one-off source of money so it can't be relied upon. In recent years, ICES began moving to a full-cost recovery model for its advisory work, which includes indirect costs like data management (CM 2016 Del-3.2: ICES 2016, CM 2019 Del-Doc 3.2:ICES 2019). Alongside full cost recovery, ICES is also working to increase the money it receives from competitive project funding. The ICES project policy (ICES 2011) ensures that ICES does not compete against its member countries for project funding, but targets opportunities where it can have a beneficial impact on the outcomes and complement its member countries. The ICES Operational Group on Science Programming (SCIPROG) aims to strengthen the coordination of future funding, and amplify the strategic benefits of project participation by ICES (ICES 2025o).

Reduction in data availability

The potential reduction of the amount of relevant marine data being made available for use in ICES and beyond is currently seen as a key challenge. There are a number of different facets to this issue which we will summarise.

The concept of 'digital sovereignty' is an emerging challenge for ICES—this refers to the digital self-determination by states, companies or individuals (Pohle and Thiel 2020). A related concept is 'data sovereignty', which refers to the ability of a person, or group of people, or organisation, or country to meaningfully own and control the use of their data (Hummel et al. 2021)—the CARE Principles for Indigenous Data Governance https://www.gida-global.org/care (Jennings et al. 2023) are an example of data sovereignty. This topic is particularly important for ICES when member country governments might have different approaches from each other—e.g. see (EPRS 2020) for the EU approach and (Clark 2026) for the UK approach. The consequences are that data flows that work presently might not work in the future. It could also mean that stricter controls and more granular management of digital assets will be required in the future, which is likely to also lead to higher costs.

Commercial fisheries data is data that are collected from commercial fishing activities and typically includes information on the vessel's fishing activities, and biological sampling of the catch and bycatch. Commercial fisheries data are a key input to many important ICES activities, including fish stock assessment. Since these data are linked to living people and the commercial activities of business, there has long been an understanding that confidentiality rules must be applied and the data can only be used in a suitably aggregated form. The rules that different institutes in different countries follow vary, which makes it difficult to create a universal rule that is acceptable without simply adopting the most restrictive rules of all the institutes. In some cases, this has led to more stringent rules in how the data can be used by ICES, and subsequently published (ICES 2025n). If even aggregated versions of the data that support ICES outputs can't be published, then this can reduce the trust in those products. Maintaining the balance between the confidentiality of people and businesses while making the data as useful and available as possible is a difficult balancing act.

ICES member countries are key data submitters to ICES so any reduction in membership has the potential to reduce the amount of data available. The most recent example of a country leaving ICES is Russia whose ICES membership officially ended on 9 December 2025 (ICES 2025j). Russia had been one of the ICES founding member countries and stayed a member until World War I and the Russian Revolution—following a break of 40 years the USSR joined ICES in 1956 ('*Russia, USSR, and ICES: For Years A Tricky Proble*m'; Smed 2016). The withdrawal of Russia could have a significant impact on some ICES outputs, such as stock assessments where Russian fishing fleets operate. In the Working Group on Widely Distributed Stocks (WGWIDE) group, some alternative data routes were used to mitigate this problem—e.g. biological data from Russia were made available via the Faroe Islands (ICES 2025p).

Since 2025 the USA has seen budget cuts to federal science funding along with policy changes, which affect content related to topics including environmental policy, climate research, and environmental monitoring. This has led to loss of data. On the topic of environmental data NOAA's National Environmental Satellite, Data, and Information Service maintains a list of planned changes to its information products and services (NESDIS 2026). 'America's Essential Data' https://essentialdata.us/classify the data losses into three categories: Terminated datasets; Removed variables; and Discontinued digital tools. In response, members of the scientific community both within and outside the USA have identified data sets that are at risk of loss with the aim of preserving them. This can be considered as emergency curation, which is a type of digital preservation mobilised rapidly in response to anticipated threats (Rothfritz 2026). Some examples of these initiatives include the Data Rescue Project https://www.datarescueproject.org/; the Public Environmental Data Partners https://screening-tools.com/; and the Environmental Data & Governance Initiative (EDGI) https://envirodatagov.org/(Nost et al. 2025). PANGAEA, the Earth and environmental data repository, have also archived various NOAA datasets that were scheduled to be decommissioned to ensure they remain publicly accessible. https://www.pangaea.de/news/data-rescue.php

As data systems, funding avenues, and governance structures change, data can be at risk of being accidentally lost. To address issues of data storage and data security, ICES have developed a data preservation plan (ICES 2023a). The latter recognises ICES as a custodian of a long-standing and well-curated collection of datasets, and defines the approach to how these data are stored and managed into the future, including provisions for ensuring data are preserved even if ICES ceases to exist. Examples of data rescue efforts include digitisation and online publication of historical records, such as the ICES historical plankton dataset (ICES 2013, 2026b), which resulted in an online data portal for seven historical ICES volumes spanning the years 1902–12. To plan for data rescue efforts, organisations can encourage best practice by using tools such as Repository Crisis Scorecards (Gum et al. 2025, 2026) to measure resilience of the datasets. By understanding current gaps in data maintenance strategies and best practices for data services, architecture, and collaboration models, data centres can plan for resilience in the face of future technological and governance changes.

Data are also at risk of malicious removal—e.g. in June 2024, the ICES Secretariat suffered a ransomware cyber-attack. The attack affected all in-house network and storage infrastructure. During the weeks after the attack, ICES worked to bring the website back online and restore access to online tools and resources—these were all available again by July 2024. As part of the recovery process, ICES rebuilt its systems, ensured that no traces of the ransomware remained, and enabled active monitoring systems. This attack had a significant impact on ICES in terms of direct costs, unavailability of systems for carrying out the business-critical tasks of the Committees, and communications and information sharing between ICES and its Member Countries. The ICES Workshop on Improving Cyber Security (WKCYBER, ICES 2025q) used the lessons learned during the attack and recovery process, and subsequent analyses, to make recommendations to improve cyber security in the ICES community. In particular, the recovery was made more difficult due to the large amount of 'unstructured' data that was held by ICES. (Unstructured data refers to data that is not stored in a database and can include data stored in documents and spreadsheets.) Recommendations from the workshop included: (i) ICES Council and Bureau to take an active role in cybersecurity by requiring regular reporting on key cybersecurity metrics; (ii) reducing the file content storage footprint of ICES by implementing clear retention policies; (iii) developing and practicing an information systems incident response plan; (iv) adopting a 'secure by design' philosophy; and (v) that the ICES Secretariat should adopt a cyber-security framework (such as 'CIS Controls' https://www.cisecurity.org/controls).

Slow adoption of cloud services

The identified risks also include the slow adoption of cloud services such as the ICES Transparent Assessment Framework (TAF). Some of the reasons for this include users not being familiar with TAF, and not having time to migrate existing code to a new framework. ACOM has identified actions to improve the use of TAF: implementing standard diagnostic and quality control templates in TAF; automating outputs from TAF to other databases; continuing to drive uptake of TAF by stock assessors through training, and by providing resources and support; and developing guidelines to assist experts in auditing stock assessments conducted using TAF templates (ICES 2025l). At the ICES 2025a Annual Science Conference a network session was held to tell the ICES community about TAF and highlight examples of good practice (ICES 2025r).

ICES data plan

As ICES looks ahead and formulates a new organisational strategy to be launched in 2027 as part of the 125th anniversary of the ICES' creation, the emerging ICES data plan takes into account six major drivers (Fig. 11). External drivers include: Adapting to policy, both regional marine policy managed by the Regional Sea Conventions, European policy such as the Marine Strategy Framework Directive (MSFD), Marine Spatial Planning Directive (MSPD), and the more recent Nature Restoration Regulation (NRR), as well as international policy such as Biodiversity Beyond National Jurisdiction (BBNJ). Building and maintaining strategic data partnerships, exploiting information technology, and developing/adopting standards and best practices are other key external driving forces. Internal drivers (within the organisation) are focused on improving data literacy, capacity, and skills of the scientific experts working through ICES expert groups, and ensuring the data infrastructure is resilient to challenges faced by funding sources, cyber security, and changes in personnel.

Conclusion

This paper captures some of the major trends in data management at ICES since its foundation. We situate the changes at ICES within the wider context of societal trends in data management. We discuss changes in data management in terms of data collection, data policy, groups at ICES, metadata, data storage, and data rescue. Through the lens of the five V's, volume, variety, velocity, veracity, and value, we see that the volume and variety have increased significantly, and some aspects of the velocity have increased. Checks of data veracity have become more automated, transparent, and documented over time. ICES data have always been of value to its users but the number of secondary uses of the data have also increased. We have also seen how ICES data more clearly reflects the FAIR principles over time, going from closed systems to more accessible systems from the 1990s to the 21st century. We can also see how ICES is approaching the ongoing challenges and opportunities of the 21st century in the spirit of international cooperation and collaboration. ICES will continue to build on its demonstrated capacity and expertise in managing, preserving, analysing, and interpreting data to provide a variety of tools and data services, including easy access to data holdings, for a wide range of users.

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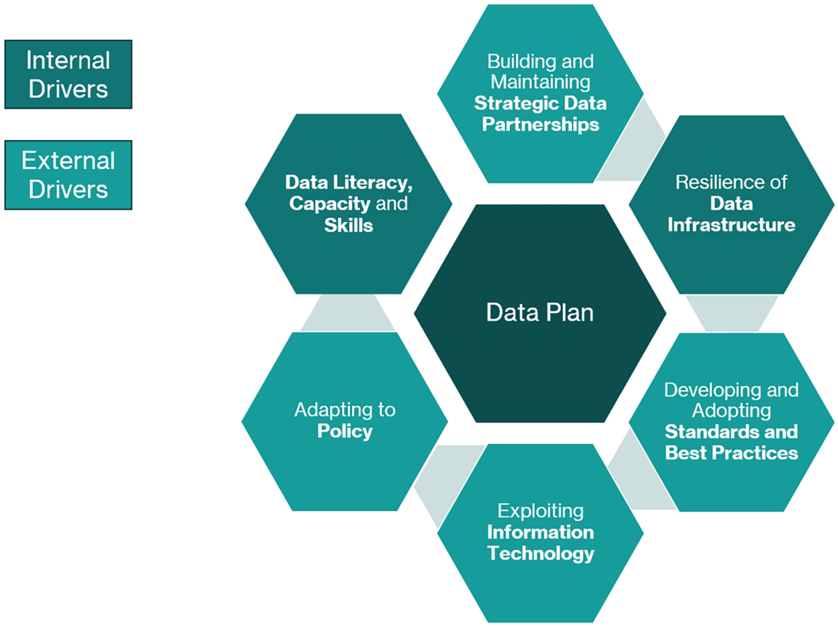

Figure 11. Internal and external drivers considered in the new organisational strategy for ICES, to be launched in 2027.

The concept for this paper came up during discussions at the ICES Data and Information Group.

Author contributions

David James Currie (Writing – original draft [equal], Writing – review & editing [equal]), Ingeborg de Boois (Writing – review & editing [equal]), Talya Ten Brink (Writing – original draft [equal], Writing – review & editing [equal]), Neil Holdsworth (Writing – review & editing [equal]), Jens Rasmussen (Writing – original draft [equal], Writing – review & editing [equal]), Lesley Rickards (Writing – original draft [equal], Writing – review & editing [equal]), Helge Sagen (Writing – original draft [equal], Writing – review & editing [equal]), Malin Werner (Writing – original draft [equal], Writing – review & editing [equal])

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