



Centre for Environment
Fisheries & Aquaculture
Science

Trawling Through Time

Cefas Science and Data

1902-2014



Introduction

The Centre for Environment, Fisheries and Aquaculture Science (Cefas) is one of the world’s longest-established marine research organisations. Since 1902, Cefas has advised government on sustainable exploitation of marine living resources, in support of a healthy environment and a profitable fishing industry.

Throughout its history, Cefas has been at the forefront of marine science and produced some of the most influential papers in fisheries and oceanography. To a considerable extent, this has been achieved through our extensive long-term datasets that support Cefas in its mission:

To make a real difference to society as recognised leaders in marine and aquatic science.

“Trawling Through Time” provides an overview of 112 years of scientific excellence by drawing attention to the wealth of historical data and biological material in Cefas’ archives. The account is not exhaustive, but highlights the breadth of our legacy data - realising that these represent “a major national asset” that is “being put to productive use in establishing long-term trends” (Cefas Science Review 2012).

In recent years we have placed high priority on cataloguing and digitising our historical data and archives, and on developing permanent data storage solutions to better understand the past of our marine environment. As a result, the advice we are able to give towards current and ongoing policy questions is enhanced¹.

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Cefas: History and vision

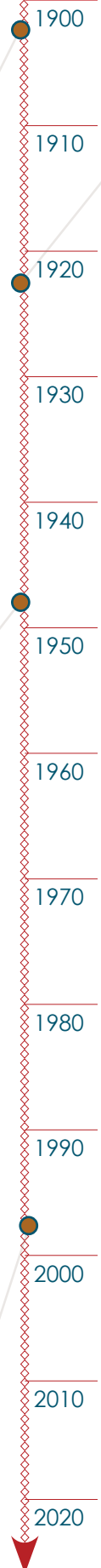
Cefas' origins go back to 1902 when the Marine Biological Association of the UK opened a small research station in Lowestoft, a major fishing port at that time, to study the North Sea plaice fishery. The aim was to support the UK's contribution to the newly created International Council for the Exploration of the Sea (ICES). The first seagoing surveys were carried out in the same year. Initially focussing on offshore fisheries, the work soon broadened to include inshore and freshwater species.



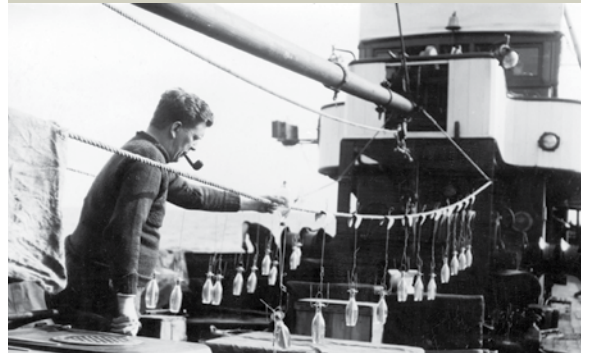
In 1949, the Arctic-going research vessel, *RV Ernest Holt* (above), came into service, and science onboard established an important link between cod abundance and sea temperature. Migration routes of North Sea cod and plaice were investigated, as well as the decline of herring. Meanwhile, radiobiology became a major focus to support advice on safe disposal of radioactive substances in the sea.



Known previously as the Directorate of Fisheries Research, our name and status changed in 1997 to the Centre for Environment, Fisheries & Aquaculture Science (Cefas) when we became an executive agency of what was then the Ministry of Agriculture, Fisheries and Food (MAFF) and is now the Department of Environment, Food and Rural Affairs (Defra).



By 1921 the station had become a laboratory with experimental facilities. Biological studies expanded in the 1920s and 1930s and many aspects of fisheries theory were developed. This was a period of major discovery in all aspects of marine biology from physics to plankton to fish.



In the 1940s-50s, Beverton and Holt (*below*) developed groundbreaking theories of fishing and fish population dynamics that cemented Lowestoft's international reputation for leading fisheries science.

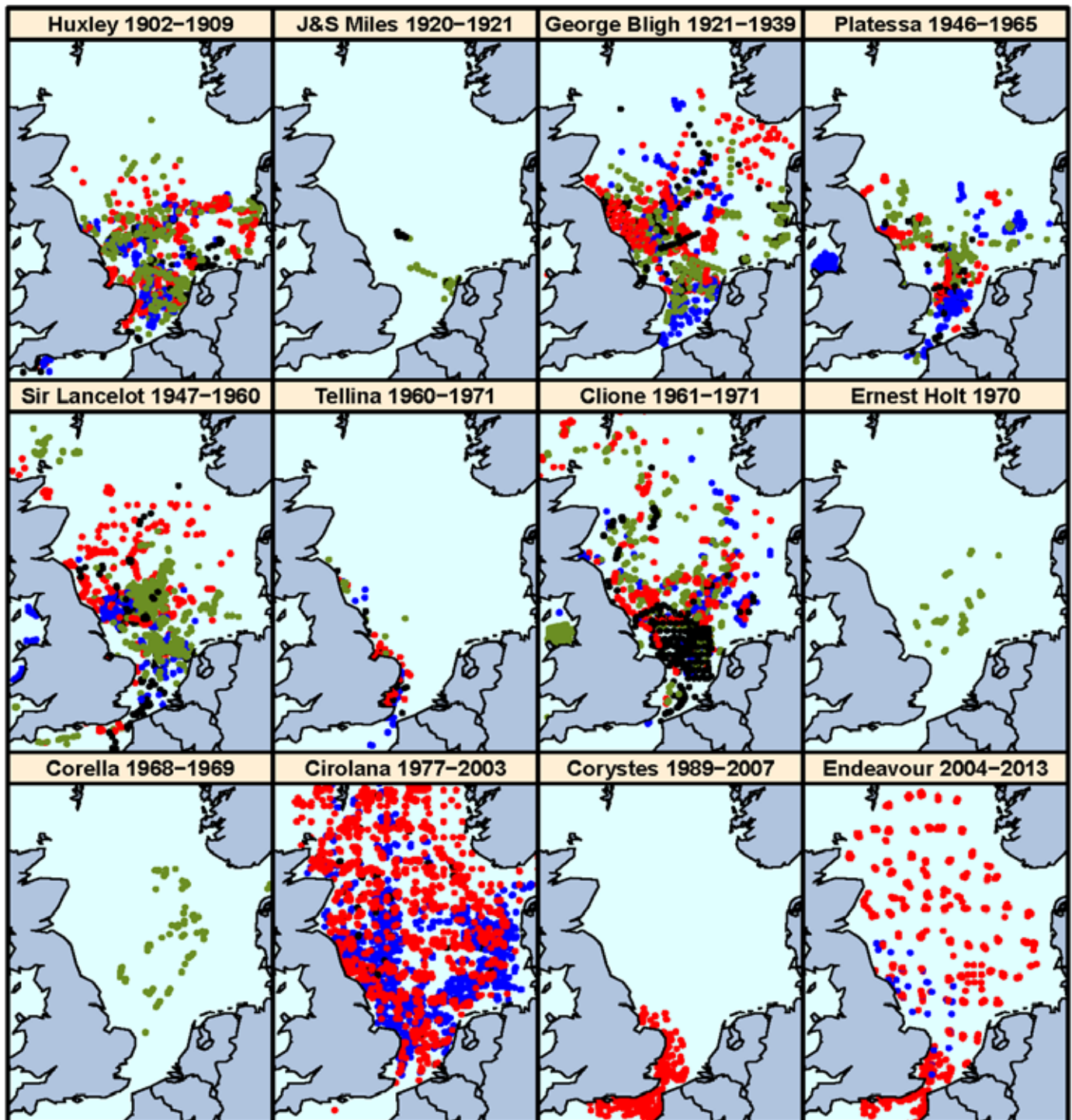


Additional laboratories were established in Conwy (1918), Burnham-on-Crouch (1953) and Weymouth (1969), today consolidated at just two locations (Weymouth, *left*, and Lowestoft, *below*). In total, twelve dedicated sea-going and four inshore research vessels have been used. The vessels have differed greatly in size and power, but all have been equipped to study a wide range of parameters and species.



Trawling through time: Fishery-independent surveys

Ever since 1902 when it was established in Lowestoft, the organisation has carried out numerous ship-based surveys in the North Sea and elsewhere^{2,3}. We have recently completed the digitisation of historical survey data. Our legacy survey dataset covers the years 1902 through 1971; and is contained in the same database as that holding our ongoing surveys, so that the same queries can be used to retrieve any survey data, old and new, covering the past 112 years.



Since 1902, twelve research vessels (RVs) surveyed thousands of sampling stations in the North Sea. Several RVs roamed widely and throughout the year (blue winter, green spring, red summer, black autumn). Others surveyed inshore waters, and some spent most of their working life in other seas, including the Arctic.

Cefas' research vessels

Cefas' RVs included steam trawlers, an ex-WWI hospital ship, small coastal vessels and a distant-water trawler. They reflect Britain's trawling fleet history, from sail-aided steam power to diesel-electric propulsion. Our RVs have evolved to take on an ever-increasing range of monitoring tasks, culminating with our present *RV Cefas Endeavour*.

Huxley



J & S Miles



Platessa



George Bligh



Sir Lancelot



Tellina



Ernest Holt



Clione



Corella



Cirolana



Corystes



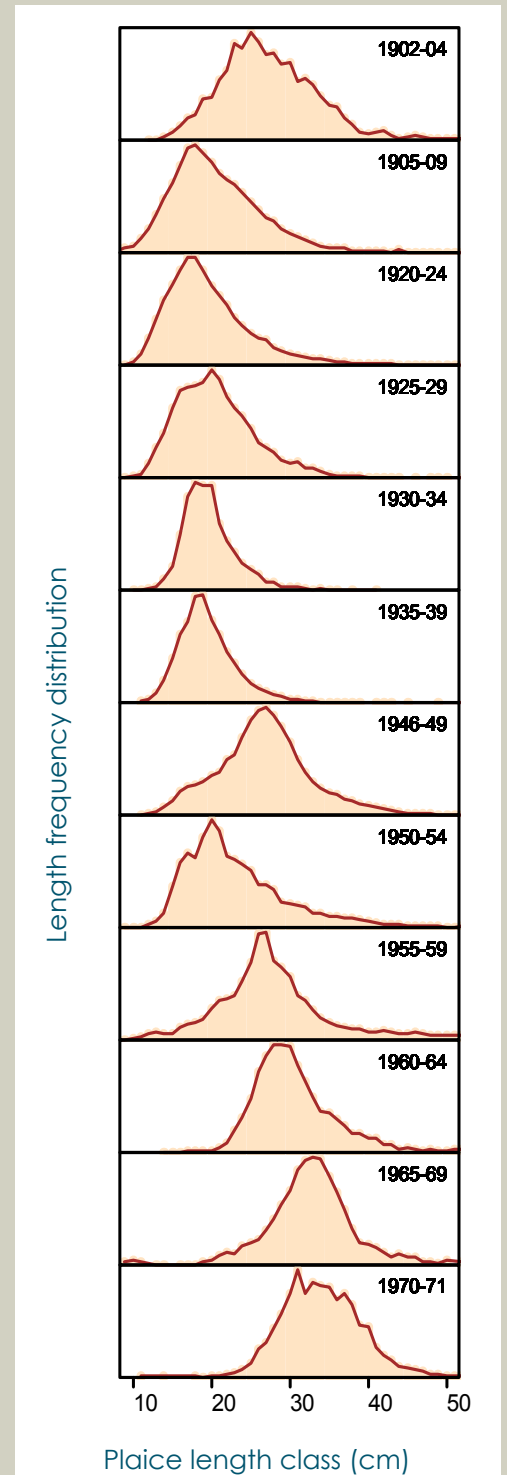
Cefas Endeavour



How can the data be used?

Cefas' most studied fish: Plaice

Our data demonstrate marked changes in plaice length distribution, as sampled during surveys from 1902 to 1971.



Listening in on the past: Otoliths, scales, shells and vertebrae

Cefas have been collecting fish ear-stones (otoliths) for age determination in exploited fish stocks in the UK and surrounding waters for over a century. In recent decades scientists have become increasingly aware of additional properties of otoliths that can be used to interpret the migratory behaviour of wild fish and aid in stock discrimination, for example by isotopic or genetic analysis.

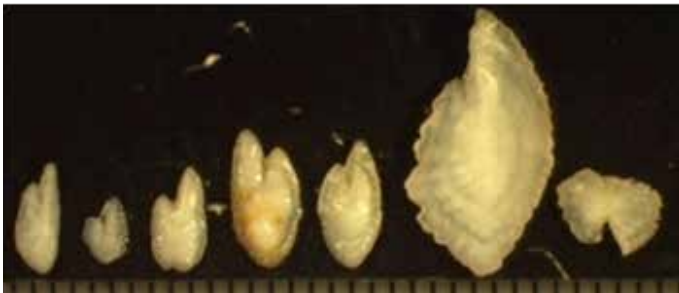
One million plus otoliths

In September 2009, Cefas recorded the “millionth otolith” in our fish sampling database of biological data collected from landed catches at markets around the UK coast. The millionth otolith belonged to a six year old, 25.5 cm male Thames Estuary herring.



Otoliths from a 40-year old sole (left) and plaice (right).

While a million otoliths sounds impressive, it is still only a fraction of the true number we hold. We are extending our database to include many historical samples including otoliths collected on research surveys and the many other research projects in which Cefas have been engaged.



Mackerel, sprat, herring, pilchard, anchovy, horse mackerel and boarfish otoliths.

Cataloguing the collection

Many analytical techniques applied in otolith science are destructive, so a clear understanding of our available material is essential for planning future studies. Consequently, our digital catalogue now provides geographical, chronological and biological data for every specimen.



Specimens are stored as whole otoliths held in otolith packets.

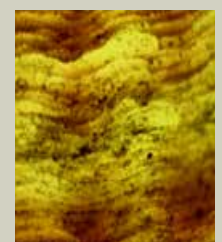
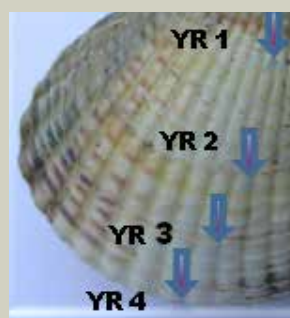


In addition to otolith packets, specimens exist as resin-mounted and as sectioned material.

How can the data be used?

Age reading of shellfish

Crabs and lobsters grow by moulting their hard exoskeleton, so an effective method of age determination has yet to be found. The shells of molluscs like scallops and whelks however, grow throughout their lives and can be used to age them.



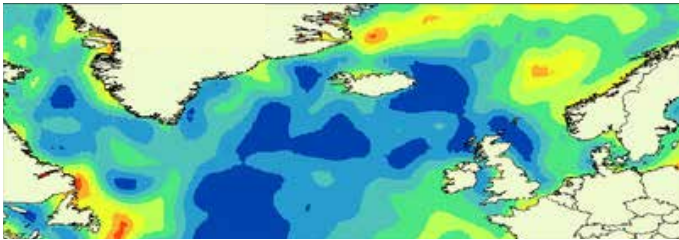
Scallops and cockles have clear winter rings (annuli).

Scallop annuli may require microscopic analysis (*top right*). Possible annuli in the statoliths and opercula of whelks are currently being investigated.



Scales and vertebrae

Otoliths and shells are not the only bio-mineralised materials held in Cefas' archives. Scales and vertebrae can also be used to assist in fish-ageing. Scales are often collected from fish that migrate between fresh and salt water, and recent isotopic analyses of salmon scale time-series have shown how the isotopic composition of scales can yield information on the past location of the fish⁴.

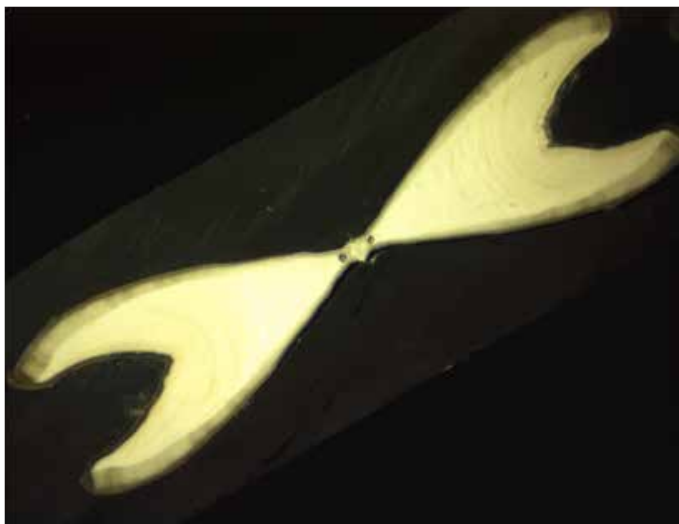


Proposed feeding areas (shaded red) for Atlantic salmon spawning in the River Frome (South-west England), indicated by the strength of correlation between temporal records of sea surface temperature and scale collagen $\delta^{13}\text{C}$ values.

Sharks, skates and rays



Cefas hold a substantial historical collection of shark, skate and ray vertebrae, and are actively collecting new specimens under current projects including species of conservation interest, such as porbeagle, blue shark, common skate, spurdog and smooth-hound. New techniques of age reading are being developed with encouraging results.

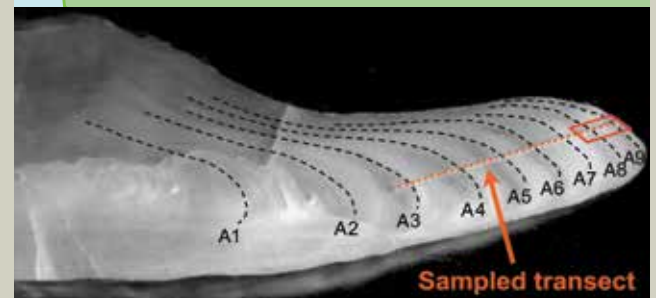
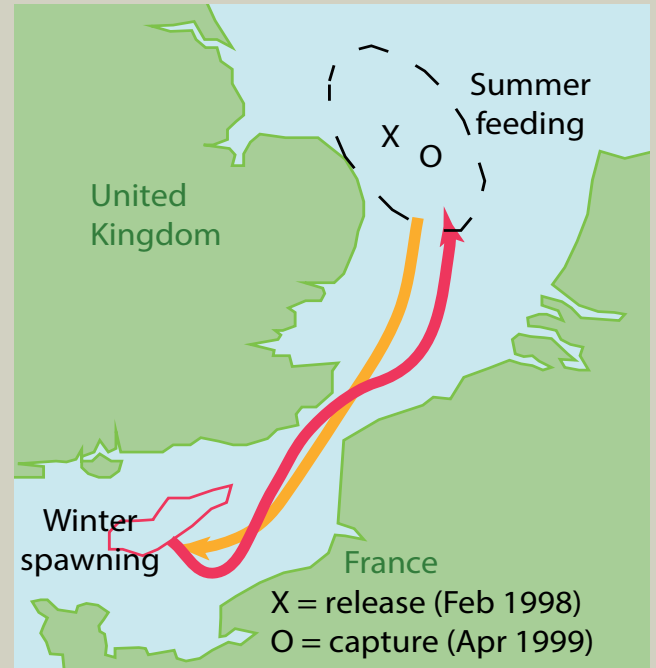


Sectioned vertebra of a blue shark (upper) showing incremental growth (lower).

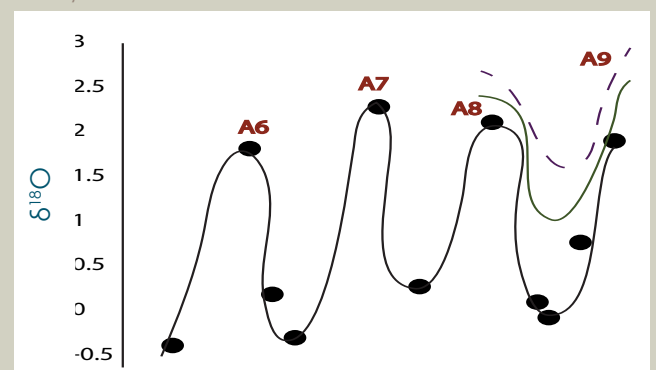
How can the data be used?

The past lives of plaice

As well as being used to estimate fish age, otolith elemental and isotopic chemistry are increasingly used to discriminate different fish stocks and to reconstruct past climate. The environmental and migratory data gathered by Cefas from decades of tagging have been combined with otolith microchemistry analyses to try and reconstruct the migratory histories of individual plaice from hatching to catching⁵.



Reconstructed migration route of a tagged plaice (above upper) and accompanying otolith from the same fish (above lower).



Pronounced inter-stock differences in otolith $\delta^{18}\text{O}$ values (above), notably in summer, provide a robust marker to discriminate plaice stocks and reconstruct annual migration pathways in the North Sea.

Old data, new insights: Commercial fisheries statistics

In the UK, systematic collection of fisheries statistics dates back to the Victorian era, a time when the fishing fleet expanded rapidly. In 1886, records were confined to the value and landings of the 16 main commercial fish species, but data on many more species were soon required. Changes in the fishing fleet were also monitored. By 1906, data included particulars of the fishing grounds, fishing effort expended, and catches by region and gear type. Collection of fisheries statistics in England and Wales is currently the responsibility of Defra, but staff at Cefas continue to play a prominent role in data management and data integration.

Landings and effort data

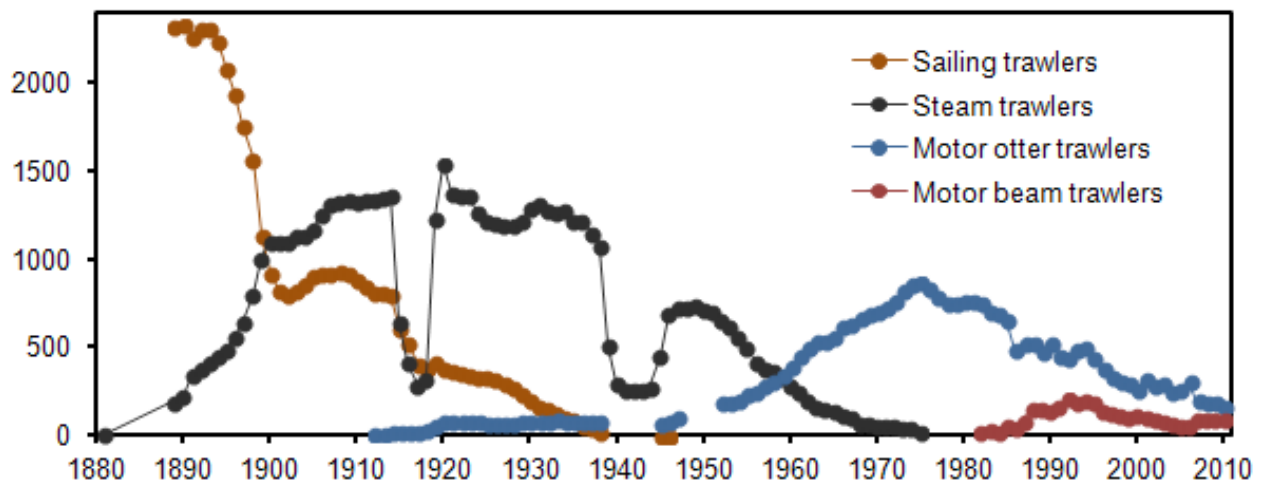
Defra's Fisheries Activity Database (FAD) holds detailed landings and effort data for individual vessels, collected in the ports of England and Wales but only as far back as 1982. For earlier periods, Cefas holds extensive paper records on UK fisheries, including Defra/MAFF 'Sea Fisheries Statistical Tables', which from 1886 onwards provide quantities and value of fish landings, and fishing effort, by port, fleet sector, and fishing region.



Steam drifters landing their herring catches in Great Yarmouth, 1930s.

Fishing fleet data

We also hold data on the composition of the UK fishing fleet, including the size, class, and tonnage of vessels, and the number of vessels by fishing method and port. Catch-and-effort data by fleet are held in 'Statistical Tables', and 'Vessel Lists' contain specifics of individual vessels. These data have been used to reconstruct 130 years of UK trawling fleet evolution, as shown below⁶.



Long-term changes in the trawling fleet of England and Wales. Note the large fleet of small wooden sailing trawlers in Victorian times, followed by predominance of steam trawlers. In both World Wars, trawler numbers dropped when vessels were requisitioned to serve as minesweepers. After WWII, motor (diesel) trawlers replaced steam trawlers. Mechanised beam trawling was adopted in the 1980s, but otter trawls are most widely used.

Market sampling data

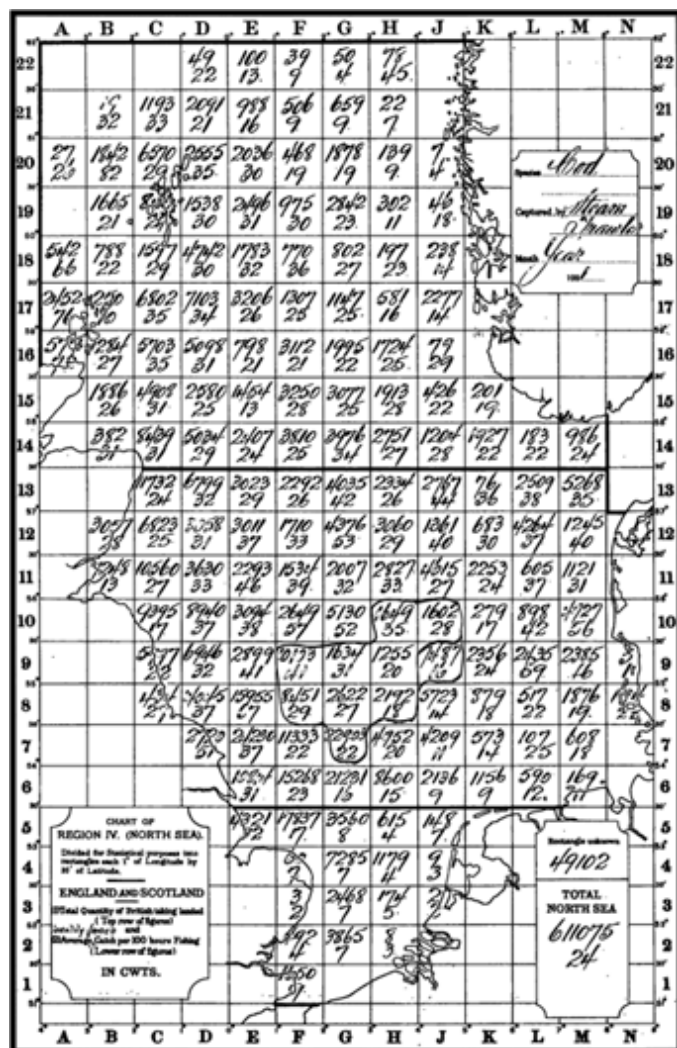
Year-round, Cefas staff go to fishing ports throughout England and Wales to sample the catches of fish landed. They record the age and size distributions for the main commercial species. These data are crucial for stock assessments needed to set the TACs (Total Allowable Catches) and quotas.



John Gulland, a famous fisheries statistician from the 1960s, records while a colleague measures fish, at Lowestoft fish market.

Defra/Cefas “statistical charts”

Our archives hold more than 36,000 “Statistical Charts” with detailed information on the spatial distribution of fishing effort and fish catches by different fleet segments⁷. This unique spatial time-series is available for the North Sea (1913-1981) and other UK fishing grounds (post-WWII), including the historically important Icelandic and Arctic waters.

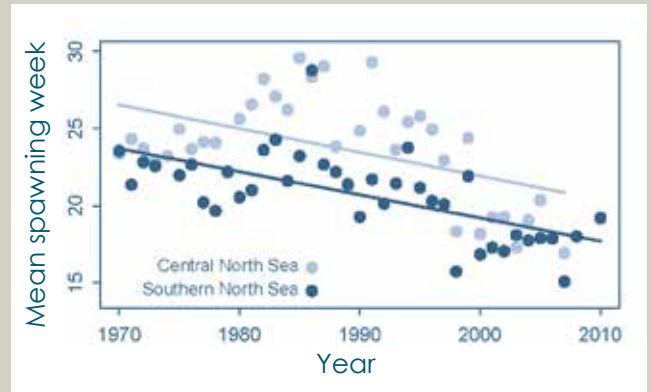


Statistical chart showing cod catches (in cwt) and catch-per-unit-effort by British steam trawlers in 1931, for each ICES rectangle in the North Sea.

How can the data be used?

Sole spawn earlier

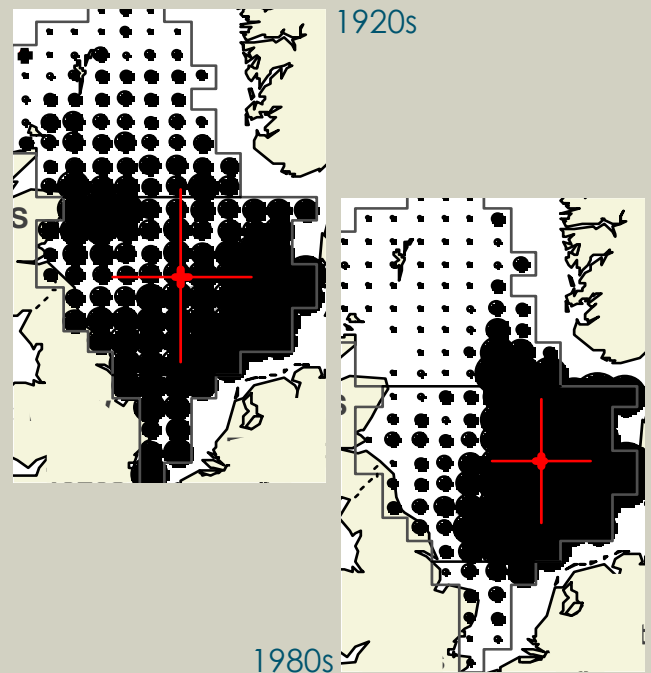
Cefas market sampling data were used to demonstrate that over the past 40 years, warming sea temperatures have resulted in sole shifting their timing of spawning earlier in the year.



Shifts in the timing of spawning have taken place both in the central (light blue) and southern (dark blue) waters of the North Sea⁹.

Fish distributions are shifting

Cefas ‘Statistical Charts’ have been used to demonstrate shifts in the distribution of North Sea fish species over the past 90-100 years. The work has shown that both climate change and fishing pressure have been drivers of change, with fishing pressure being especially important for the most heavily exploited species, sole and cod⁹.



Turbot distribution in the 1920s and 1980s, where the red cross highlights the centre of distribution. Note the stock’s disappearance from an important historical ground off Scotland, which is still named Turbot Bank although turbot are presently scarce¹⁰.

Tagging through time: Fish tags at Cefas

In order to manage fish stocks effectively, scientists need to describe and explain seasonal changes in the distribution and migration of fish. To try to address this, Cefas scientists have been tagging fish that cannot be directly observed in the open sea since the laboratory was founded in 1902. For many decades, simple external marker tags were attached to fish and released. Silicon chip technology later allowed Cefas to develop the first electronic data storage tags (DSTs) with onboard sensors. The environmental data recorded by DSTs while the fish are freely swimming allow scientists to interpret their movements and behaviour when the tags are returned. Cefas continue to innovate tagging technology to the present day¹¹.

Mark-recapture data and experiments

Historical tagging data are maintained by Cefas in our in-house Tagged Fish Database¹². The database contains information for over 40 species, and details more than 200,000 releases and over 50,000 returns.

The external markers attached to fish come in many different forms. Tags are sequentially numbered to identify the fish and associated release data, and provide information as to where to send the tag when a fish is re-caught. Posters distributed around principal ports advertise tagging programmes and rewards for returned tags.



What does tagging tell us?

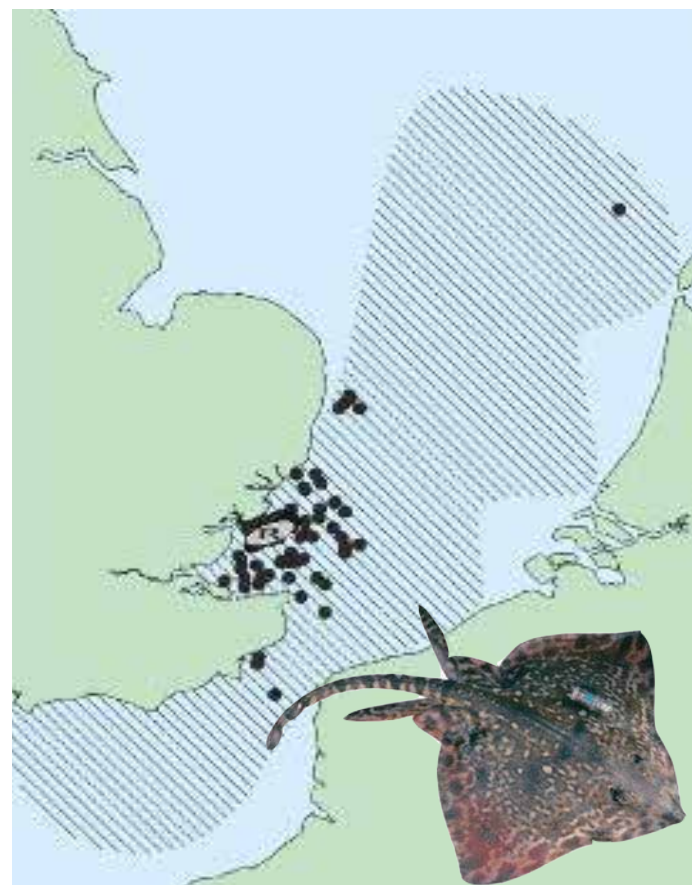
Mark and recapture experiments provide valuable information about the movements and growth rates of fish, stock structure and mixing, and how these might affect fishery management. Historical tagging data can also help us identify changes related to decadal changes in intensive fishing pressure or climate and warming seas around the UK.

Fisheries scientists have released cod tagged internally with distinctive **ELECTRONIC TAGS**

Internally tagged fish are easy to spot, as they have bright coloured external tags. Please return the tags and whole fish, together with the details of time and place of capture, to:
Centre for Environment, Fisheries & Aquaculture Science (Cefas),
The Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk
NR33 0HT UK Tag hotline: +44 (0) 1502 524526
www.cefas.co.uk/fishtagreturns

THANK YOU

*Reward for the electronic tag and for the return of the whole fish. In addition your name will be entered into a UK cash draw for **£1000**.



Tagging with DSTs revealed that dispersion of Thornback rays was over a much wider area (shaded) than was suggested by mark-recapture (dots), and the localised recapture pattern (black dots) was the result of seasonally migrating rays interacting with the local Thames fishery^{13,14}.

1902-present: simple marker tags

1960s - tracking with acoustic tags

1990s - first electronic data storage tags (DSTs) and mass releases since the 90s including through EU-funded programmes

Mid-1990s - fishery independent data recovery - first "Pop-off" satellite (PSAT) tags

Mid-2000s - first 'flotsam' tags

2010 - launch of "behaviour" tags

eeliad

CODYSSEY

How can the data be used?

Go west! The march of the crabs

Results from tagging studies carried out in the 1970s (*bottom right*) indicated that mature female crabs generally moved from east to west through the English Channel.

In the 40+ intervening years much has changed, including warming seas, increased fishing effort and an expansion of the fishery to the south of Devon and Cornwall.

The left side of the image shows a map of the English Channel with red arrows indicating westward migration of crabs. A large crab is shown in the foreground. The right side shows the cover of a historical leaflet titled "THE CRAB FISHERY OF SOUTH WEST ENGLAND" by D.B. BENNETT AND C.G. BROWN, published in 1971. The leaflet cover features a detailed illustration of a crab and text from the Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research.

New experiments with DSTs between 2008 and 2012 reaffirmed the westward migration of female crabs (red arrows) and revealed new details concerning the location, timing and duration of egg incubation¹⁵.

Cefas' Arctic legacy: 1930-1970

The productive cod stock in the Barents Sea supported one of the UK's major fisheries throughout much of the twentieth century. Cefas began investigating the stock in the 1930s. Initially, scientists boarded commercial trawlers fishing in the Spitsbergen region, until a research vessel was built in 1949, designed specifically to work in polar regions. *RV Ernest Holt* carried out surveys in the Arctic from 1949 to 1970.

The logbooks from these Arctic cruises are still held at Cefas, and have so far been digitised from 1930 to 1959.

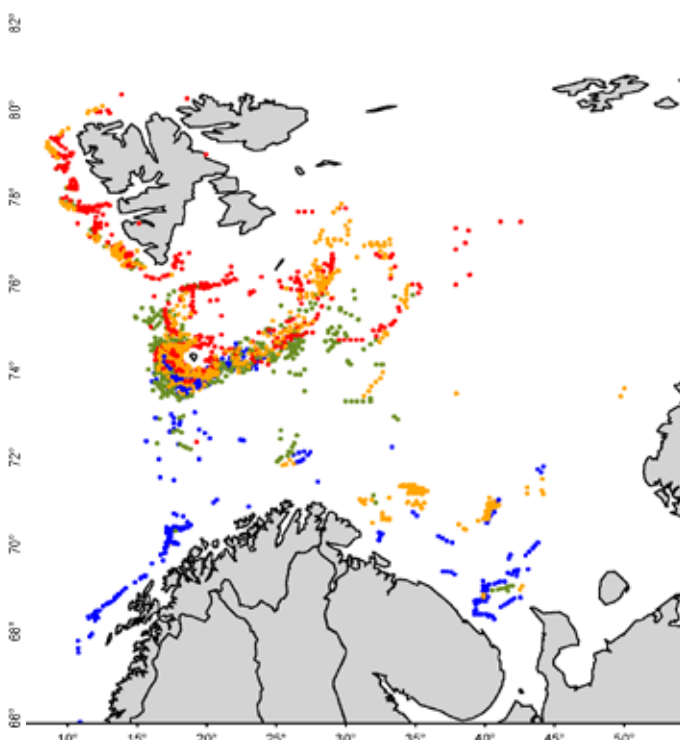
Biological data include:

- Catch species
- Catch weight or number
- Length distribution
- Fish stomach contents

Hydrographic data include:

- Surface temperature
- Bottom temperature
- Salinity
- Depth

We are now using these data to investigate historical changes in cod distribution and prey consumption. Cod numbers in the Barents Sea are currently at a high level not seen since the 1950s, and the fish from this area are still an important part of the diets of UK inhabitants. These data are invaluable in determining what affects the cod stock and its availability to fisheries.



Station locations 1930 to 1959.

Decadal changes in fish diets

Food-webs have become a major focus for EU research and maritime policy. However, comprehensive diet composition datasets are lacking for many fish species and this has hampered development of multispecies fisheries models and the formation of effective food-web indicators.

DAPSTOM is an ongoing initiative supported by Defra and the EU to digitise and make available fish stomach content records from the Cefas archive¹⁶. The online database contains information on 188 predator species (226,407 records from 254,202 individual predator stomachs) and can be searched by predator name or by prey name for given sea areas and years. The current database contains information from 449 distinct research cruises spanning Greenland in the west, to Spitsbergen in the east and from the Bay of Biscay northwards to the Arctic.



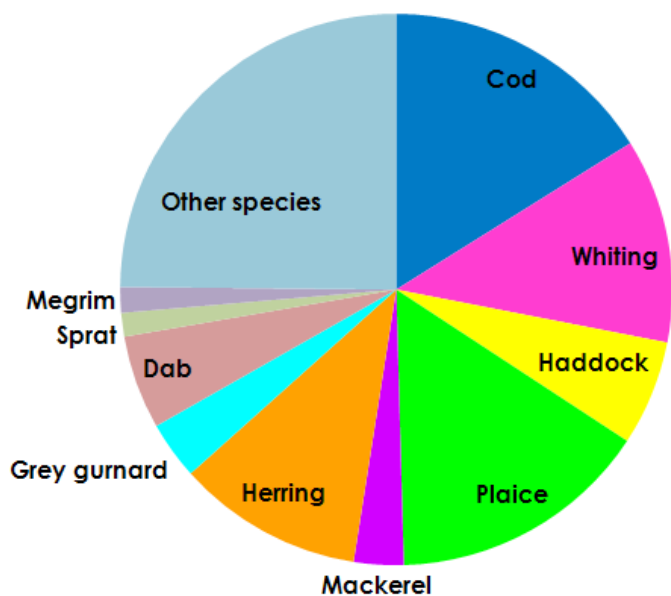
The data

The earliest records in the DAPSTOM database are for 1837, the most recent is from 2012.

30% of all records (16% of stomachs) relate to cod. Large numbers of whiting, plaice and herring have also been sampled.

Sampled individuals range in size from 0.1 cm (a herring larva) to 768 cm for a basking shark caught in 1947.

Data are available for many rare and now critically endangered species.



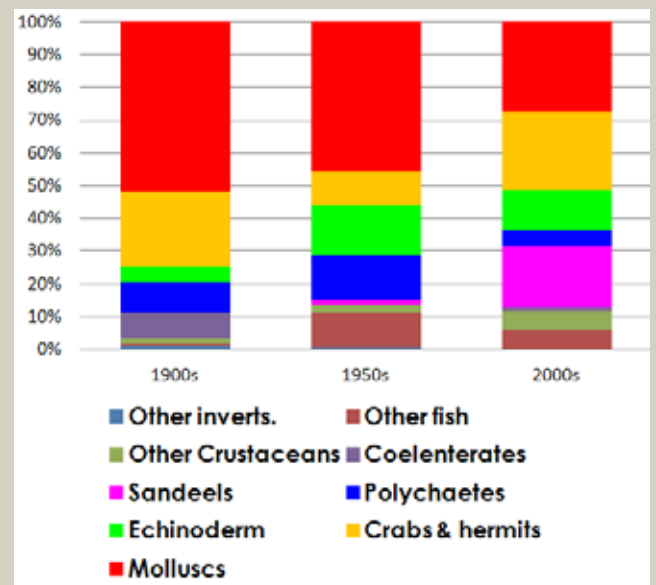
Number of stomachs per species in records.

How can the data be used?

Changes over time

On the whole, researchers have used the online portal to look at the diet of their favoured predator species - however there has also been some interest in making use of historical datasets to determine long-term changes in fish diets at particular localities.

The importance of large bivalve molluscs (*red, below*) as a prey item for plaice, dab and haddock has declined dramatically on the Dogger Bank since the early 20th Century, whereas sandeels, crabs and polychaete worms have increased in importance.



Changes in diet composition of dab at the Dogger Bank.

How clear was the North Sea?

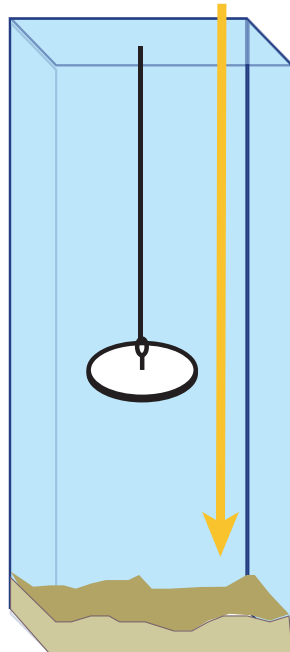
Secchi disk legacy

Developed by Angelo Secchi in 1865, the Secchi disk is a simple tool for measuring water transparency in oceans (white disk) and lakes (black and white disk). The disk is lowered into the water until it cannot be seen anymore - at which point the 'Secchi depth' is recorded. Secchi depth measures water transparency; it is greater in clear water, and less in turbid, plankton- or sediment-rich water.

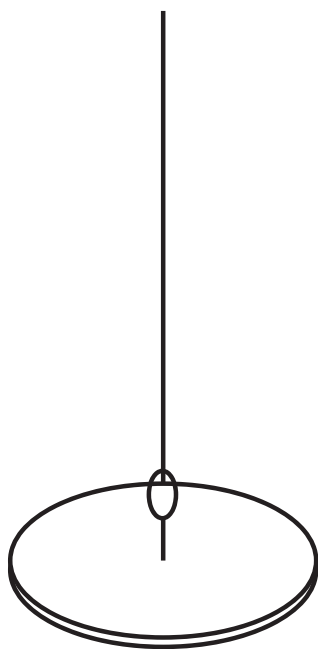
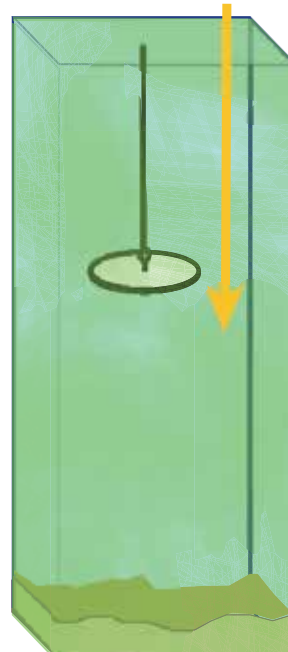
Recently, we discovered 469 historical Secchi depth measurements in Cefas survey logbooks, collected from the North Sea in 1931, 1937, 1946-50, and 1968. Previously unpublished, these data provide the only known Secchi data for the North Sea during this period.

SECCHI DISK

LIGHT PENETRATION
with clear water



LIGHT PENETRATION
with turbid water



Secchi disks are deployed from over the side of the ship and the Secchi depth reduces with increasing turbidity. This process has remained unchanged, as demonstrated (right) by Cefas pioneer J.N. Carruthers operating on the RV *George Bligh* in the 1920s.

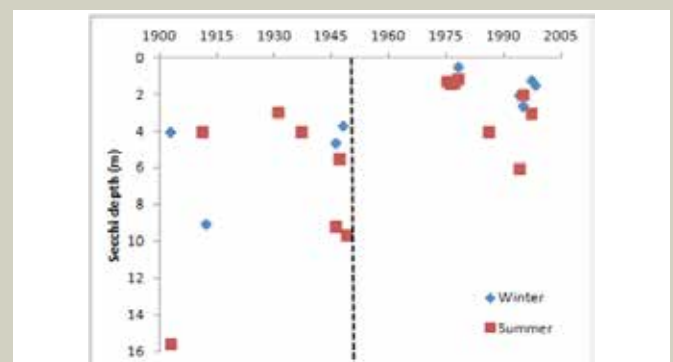


How can the data be used?

Identifying changes in water transparency

The retrieved Cefas Secchi data, when collated with other available measurements, have played an essential role in demonstrating changes in water transparency in the southern North Sea over the course of the 20th Century.

As well as helping interpret past environmental conditions, these data also support predictions of future changes in the North Sea in relation to climate change.



Combined Cefas and ICES Secchi data, measured during summer (red) and winter (blue). Note the marked reduction in Secchi depths over the course of the century.

Safeguarding Cefas data for the future

Recent emphasis on the publication of datasets with scientific papers, “Open Data” and audit/evidence trails has dramatically changed how we approach data management in Cefas. The rescue of legacy data, the coupled preservation of current data for future generations, co-working and public accountability all require future-proof mechanisms of data stewardship.

Cefas Master Data Register

Cefas now maintain a Master Data Register (metadata catalogue) with data management procedures integrated within the lifecycle of individual projects, which automatically channels data access and use restrictions.

From our Master Data Register, Cefas formally publish discovery metadata to, e.g. data.gov.uk, MEDIN and INSPIRE. We are currently developing methods for the formal citing and publishing of data for scientists, interested users and the general public.

Fisheries Data Archive Centre

Cefas is an accredited Fisheries Data Archive Centre (FishDAC) through the Marine Environmental Data and Information Network (MEDIN); www.oceannet.org. As a FishDAC we offer a trusted storage facility for our own fisheries data and also for data and samples from other institutes. In pursuit of best practice we are always interested in techniques currently being applied in other laboratories, and we collaborate with other fisheries laboratories nationally and internationally.



Key documents

- [1] Pinnegar, J.K. and Engelhard, G.H. (2008) The ‘shifting baseline’ phenomenon: a global perspective. *Rev. Fish Biol. Fish.*, **18**: 1-16.
- [2] Rogers, S.I. and Ellis, J.R. (2000) Changes in the demersal fish assemblages of British coastal waters during the 20th century. *ICES J. Mar. Sci.*, **57**: 866-881.
- [3] Goodwin, N.B., Dare, P.J., Belson, S.J., Gunstone, K.L., Ellis, J.R. and Rogers, S.I. (2001) A catalogue of Defra historical research vessel data. *Sci. Ser. Tech Rep.*, Cefas Lowestoft, 112: 32pp.
- [4] MacKenzie, K.M., Palmer, M.R., Moore, A., Ibbotson, A.T., Beaumont, W.R.C., Poulter, D.J.S. and Trueman, C. (2011) Locations of marine animals revealed by carbon isotopes. *Sci. Rep.*, **1**: 21.
- [5] Darnaude, A.M., Sturrock, A.M., Trueman, C., Mouillot, D., EIMF, Campana, S.E. and Hunter, E. (2014) Listening in on the past: what can otolith $\delta^{18}\text{O}$ values really tell us about the environmental history of fishes? *PLoS ONE*. In review.
- [6] Engelhard, G.H. (2008) One hundred and twenty years of change in fishing power of English North Sea trawlers. In: Payne, A., Cotter, J. and Potter, T. (eds) *Advances in Fisheries Science 50 Years on from Beverton and Holt*. Blackwell Publishing, 1-25.
- [7] Engelhard, G.H. (2005) Catalogue of Defra historical catch and effort charts: six decades of detailed spatial statistics for British fisheries. *Sci. Ser. Tech. Rep.*, Cefas Lowestoft, 128: 42pp.
- [8] Fincham, J.I., Rijnsdorp, A.D. and Engelhard, G.H. (2013) Shifts in the timing of spawning in sole linked to warming sea temperatures. *J. Sea Res.*, **75**: 69-76.
- [9] Engelhard, G.H., Righton, D.A. and Pinnegar, J.K. (2014) Climate change and fishing: a century of shifting distribution in North Sea cod. *Global Change Biol.*, doi: 10.1111/gcb.12513
- [10] Kerby, T.K., Cheung, W.W.L., van Oosterhout, C. and Engelhard, G.H. (2013) Entering uncharted waters: long-term dynamics of two data limited fish species, turbot and brill, in the North Sea. *J. Sea Res.*, **84**: 87-95.
- [11] Metcalfe, J.D., Righton, D.A. and Hunter, E. (2011) *Fish & Chips: The development of electronic tags for fish and their application in fisheries research at Cefas*. Cefas, Lowestoft.
- [12] Burt, G., Goldsmith, D. and Armstrong, M. (2006) A summary of demersal fish tagging data maintained and published by Cefas. *Sci. Ser. Tech Rep.*, Cefas Lowestoft, 135: 40pp.
- [13] Hunter, E., Buckley, A.A., Stewart, C. and Metcalfe, J.D. (2005) Migratory behaviour of the thornback ray, *Raja clavata* L., in the southern North Sea. *J. Mar. Biol. Ass. UK*, **85**: 1095-1105.
- [14] Hunter, E., Berry, F., Buckley, A.A., Stewart, C., Metcalfe, J.D. (2006) Seasonal migration of thornback rays and implications for closure management. *J. Appl. Ecol.*, **43**: 710-720.
- [15] Hunter, E., Eaton, D., Stewart, C., Lawler, A., Smith, M.T. (2013) Edible crabs “Go West”: migrations and incubation cycle of Cancer pagurus revealed by electronic tags. *PLoS One*, **8**(5): e63991.
- [16] Pinnegar, J.K. (2014) *DAPSTOM - An Integrated Database & Portal for Fish Stomach Records*. Version 4.7. Cefas, Lowestoft, UK. February 2014, 39pp.

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