ICES SGHIST REPORT 2010

SCICOM STEERING GROUP ON SUSTAINABLE USE OF ECOSYSTEMS

ICES CM 2010/SSGSUE:11

REF. SCICOM, ACOM

Report of the Study Group on the History of Fish and Fisheries (SGHIST)

11–14 October 2010

Ponza, Italy

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2010. Report of the Study Group on the History of Fish and Fisheries (SGHIST), 11–14 October 2010, Ponza, Italy. ICES CM 2010/SSGSUE:11. 45 pp.

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Executive summary

Most marine ecosystems have been exploited for many decades, centuries, or even millennia. Industrialised fisheries have developed during different decades in different parts of the world, and within much of the ICES region, date back to at least the 19th Century. Before that, many European countries already had large-scale fisheries, driven by either wind- or manpower, using a wide range of fishing techniques, and expanding or contracting as a result of natural stock fluctuations or from early signs of over-exploitation. However, detailed information collected specifically to determine fish population sizes only exists for recent decades, and the time-series of most fish stock assessments worldwide are less than 30 years long. Still, information on the 'virgin' state of ecosystems (or at least on a state approaching this) is considered highly relevant to assess the current status of exploited marine ecosystems and to provide reference points for management.

The above calls for a more thorough analysis of historical datasets. In this context, the Study Group on the History of Fish and Fisheries (SGHIST) was created in 2009 following a recommendation by the 2008 Workshop on Historical Data on Fisheries and Fish (WKHIST), where it was concluded that ICES should have a role in coordinating historical work on marine systems. SGHIST brings together scientists working on these topics to facilitate and coordinate data recovery and digitisation processes; to exchange ideas and harmonize methodologies on spatio-temporal analysis; to discuss methods for the analysis of technological creep; and to aid the interpretation of historical time-series of cpue when examining long-term fish population and fisheries dynamics.

The second meeting of SGHIST was held on Ponza Island, Italy, from 11–14 October 2010 and was attended by ten scientists working on both sides of the North Atlantic and the Mediterranean. Whilst the first (2009) meeting of SGHIST had focused on data recovery and digitisation, the emphasis of the 2010 meeting was on historical data analysis and methodologies, in particular on fishing power change and spatio-temporal dynamics.

Participants provided an updated inventory, to complement the metadatabase initiated during WKHIST 2008 and SGHIST 2009 providing an overview of data recovery activities and available historical datasets in the group (ToR a). Updates were given on recent data recovery activities. This includes digitisation of historical records for the Mediterranean Sea (EVOMED project; collaboration between Italy, Spain, Greece), the North Sea and Irish Sea (project '100 Years of Change', Cefas/Defra, UK) and the Gulf of Maine (University of New Hampshire).

Two methodology workshops were held. The first workshop treated methods to estimate long-term fishing power change, or changes in the technical efficiency of vessels to catch fish (ToR b). Such insight is needed to (a) help interpreting longer time-series of (especially commercial) catch and cpue data, where changes in fishing power (and hence catchability) are likely to have occurred; and to (b) understand change in the *capacity* (or overcapacity) of fishing fleets, and their potential to exploit (or overexploit) fish stocks, relevant to effective management and sustainable exploitation of stocks.

The second methodology workshop treated methods on spatio-temporal dynamics of fish stocks (ToR c). Such methods can be used to study whether fish populations have shown long-term distribution shifts (such as a north/south response to temperature changes). One contribution aimed at finding an appropriate spatio-temporal scale for

analysis of stock dynamics, if original data were collected unevenly in space and time. Third, non-linear time-series analysis was discussed, as a means to detect non-linear patterns and trends in ecosystem dynamics, which might remain unnoticed with conventional statistical methods.

Further, case studies were presented on historical changes in fish and fisheries in both sides of the North Atlantic and the Mediterranean (ToR d). This included research on historical changes in ecosystem relationships and species dynamics in the Gulf of Maine (from non-linear time-series analysis); fisheries in the Mediterranean and Black Sea, with special focus on the Adriatic (including fisheries and species composition changes); a historical reconstruction of trawl fishing effort in the north-western Mediterranean; and long-term changes in groundfish landings in the North Sea.

The Study Group plans to hold the next meeting in Paciano, Italy, in October 2011 and aims to include a new ToR on the use of historical fisheries data for attempting to disentangle the relative effects of climate change and fishing pressure on fish population dynamics.

1 Opening and closing of the meeting

The **Study Group on the History of Fish and Fisheries** (SGHIST) met at Hotel Ortensia, Ponza, Italy, from 11–14 October 2010. The list of participants and contact details are given in Annex 1. The Chairs, Georg Engelhard (Cefas, UK) and Bo Poulsen (Roskilde University, Denmark) welcomed the participants and highlighted that whilst last year's meeting focused on data recovery and digitisation; this year's meeting had emphasis on historical data analysis and methodologies, in particular on fishing power change and spatio-temporal dynamics. The Terms of Reference (see section 2) were discussed and an agenda proposed largely set up around the Terms of Reference.

1.1 Acknowledgement

The Chairs would like to thank local host Max Cardinale (now Swedish Board of Fisheries, Sweden) for his efforts on the logistics of the meeting.

2 Terms of Reference

2009/2/SSGSUE12 The **Study Group on the History of Fish and Fisheries** (SGHIST), chaired by Bo Poulsen, Denmark and Georg Engelhard, UK, will meet in Ponza, Italy, 11–14 October 2010 to:

a) coordinate the data recovery activities for historical information on fish, fisheries and marine ecosystems;

b) develop methods that can be applied to historical data in order to estimate long-term dynamics of stock, fishing fleet and fishing technologies, including technological creeping;

c) develop methods for the spatial analysis of fish and fisheries historical data;

d) carry out cross-regional comparisons of fish and fisheries in the North Atlantic, focusing on the analysis of species key predator species in the different ecoregions.

SGHIST will report by 15 November 2010 (via SSGSUE) for the attention of SCICOM and ACOM.

3 ToR a) Data recovery activities for historical information on fish and fisheries

Previously during the WKHIST 2008 workshop, an inventory of available historical data had been initiated in the form of a metadatabase. The inventory was updated and extended during the SGHIST 2009 meeting, and again further extended during the 2010 workshop. The updated inventory is available in the spreadsheet *SGHIST 2010 data inventory.xls* on the SGHIST Internet page.

The 2008 Workshop and the 2009 Study Group provided a broad overview of data recovery activities for historical information on fish and fisheries. Here we present new developments during 2009–2010, presented during ICES SGHIST 2010. These include

a) work for project EVOMED (EVOlution of MEDiterranean demersal fisheries), presented by Paolo Sartor and Chato Osio;

b) efforts in Defra project MF1108 "100 Years of Change in Fish and Fisheries", especially data entry on historical surveys carried out by Cefas in the 1960s and before, presented by Georg Engelhard;

c) digitisation of historical records for the Gulf of Maine, presented by Emily Klein.

3.1 An update on data recovery activities for EU project EVOMED (EVOlution of MEDiterranean demersal fisheries)

Paolo Sartor and Chato Osio

Centro Intruniversitario di Biologia Marina (CIBM), Viale Nazario 4, 57128 Livorno, Italy

The EVOMED project aims at a better insight into the 20th Century evolution of Mediterranean exploited demersal resources under increasing fishing disturbance and environmental change. It is an EU-funded project carried out collaboratively by CIBM (Livorno, Italy), HCMR (Athens, Greece), ICM-CSIC (Barcelona, Spain) and UNIMAR (Rome, Italy).

Context. The present picture of the state of the Mediterranean fisheries and marine resources is based essentially on the information collected in the last twenty years. Knowledge of the historical evolution of the exploited populations and marine ecosystems in the last century is scarce and limited to restricted areas. In spite of this, considerable data and information has been produced in the past, in different forms, although at present it is scattered and only partially known and exploited by the scientific community.

For the Mediterranean fisheries there is a strong need: (a) to reconstruct historical trends of the demersal communities; (b) to identify the drivers of the change; (c) to characterize the ecological baseline of, at least, the past 100 years. To allow addressing these questions, in more practical terms there is a need: (a) to identify, collect and organize all the scattered information in order to demonstrate all its potential; (b) to standardize and check all of this information; and (c) to gather information from old fishermen and fishing captains.

The project had its WP2 (led by HCMR) specifically set up to review available historical information in the Mediterranean. An extensive bibliographic research has been carried out with over 460 bibliographic references classified and reviewed in a metadatabase. Importantly a database was created following a common codification system, including:

- Fleet DB (15127 records): data on number of vessels, fishing capacity and fishing activity parameters over time.
- Landings DB (13430 records): data on annual landings (total landing or by species) over time.
- LPUE DB (4166 records): data of landings (total landing or by species) per unit of effort (fishing day or fishing hour) over time.
- Trawl survey cpue DB (8245 records): data on density and biomass indices by species for the MEDITS trawl survey (1994–2008) and for many experimental trawl surveys performed in Mediterranean from 1948 to 1987.
- Environmental DB (44598 records): time-series of environmental parameters, like NAO, SST, Western Mediterranean Oscillation index, wind, chlorophyll.

The project's WP3 (led by CIBM) studied historical fishermen knowledge and carried out interviews with 'old' (older active and retired) fishers throughout Spain, Italy and Greece. Standard protocols included questions targeted at obtaining perception changes on vessels and key fish species. The results indicate a great increase in fleet capacity since the 1940s–1950s, and changes in catch compositions.

The project's WP4 (led by ICM-CSIC) studied the evolution of fishing fleets and gear changes over time. WP5 (led by CIBM) focused on developing and applying adequate modelling tools to analyse the changes in resource abundance and community structure. In the analysis of commercial LPUE data new methods were introduced to account for technological creep over time.

3.2 An update on Defra project MF1108 (100 Years of Change in Fish and Fisheries)

Georg H. Engelhard

Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft, UK

The UK Department for Environment, Food and Rural Affairs (Defra), and its agency the Centre for Environment, Fisheries and Aquaculture Science (Cefas), belong to the world's longest running fisheries research bodies and hold unique historical fisheries data which is potentially extremely valuable in examining climate change impacts. Such data are highly relevant to understanding the long-term effects of fisheries, pollution, and other human impacts on marine living resources. Yet despite this uniqueness, most pre-1970s data are not electronically available.

The *100 Years of Change* project aims to collate and digitise fish and fisheries data, collected over the past 100 years by Defra, Cefas, and predecessors. This includes both commercial data on UK fisheries, and scientific surveys, which were carried out by Cefas beginning in 1905. Ultimately, the commercial data in particular will be used to examine changes in distribution of commercially important fish populations throughout the 20th and early 21st Centuries, in relation to climate change and fishing pressure. The scientific survey data will serve to investigate long-term changes in stock structure, age and size compositions of key fish populations.

Below we give an overview of digitisation efforts as achieved by December 2010.

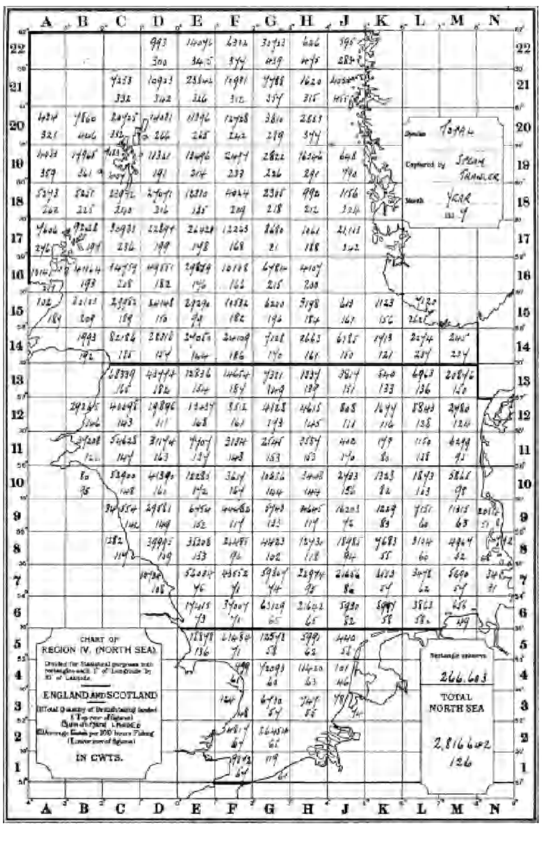

Figure 1. Example of Statistical Chart.

1. *Commercial fisheries data.* We have been able, so far, to digitise a total of 568 Defra 'Statistical Charts', spanning the years 1913–1980 and covering the entire North Sea (see Figure 1 for an example). Each single chart shows, for a given year and fish species, and separately for each ICES statistical rectangle (1°latitude by 0.5°latitude): the catches (landings) as well as the catch-per-unit-effort, by UK trawl fisheries. For a catalogue, see Engelhard (2005).

Digitisation efforts have focused on 10 key commercial fish species for the North Sea (Figure 2). The longest, digitised time-series are for cod, haddock, plaice, and sole (1913–1980 except war years). Further, digitised datasets include those for hake, turbot and whiting (so far 1920s–1950s) and brill, herring and mackerel (1920s–1930s). Also, 93 charts on total fish landings and 83 charts on the spatial distribution of trawl fishing effort were digitised (1913–1980).

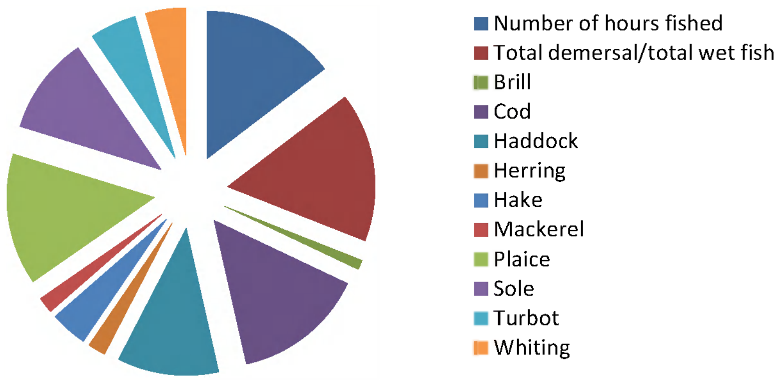

Figure 2. Species composition of 581 Defra 'Statistical Charts', digitised as by 2 December 2010.

2. *Cefas scientific surveys.* In England, Cefas scientists and their predecessors in the Ministry of Agriculture, Fisheries & Food (MAFF) have been collecting information on fish abundance and movement patterns since the laboratory was first established in Lowestoft in 1903. Scientific surveys have been conducted on an annual basis by UK research vessels ever since, and much of this information is still available in logbooks and published manuscripts from the time. In 2001 Goodwin *et al.* produced a catalogue of these logbooks and the accompanying station details, collating information on the geographic coverage, and the types of information contained within each document (www.cefas.co.uk/publications/scientific-series/technical-reports/technical-report-112.aspx).

Over the 100 year period many different research vessels have been utilized and there has not yet been a systematic effort to digitise all of the information available. Some scientists have compared fish abundance estimates from the very earliest period (*RV Huxley*, 1903–1909) with those of more recent years (e.g. Rogers and Ellis, 2000; Rijnsdorp *et al.*, 1996). However, no attempts had been made to digitize survey information for the period spanning 1910 to 1970, although some research vessels operated in a consistent manner and in the same geographic region for many years.

For the current project, Goodwin *et al.*'s (2001) catalogue has been crucial in allowing us to identify and locate the original survey 'logbooks', 'station sheets' and 'cruise reports' in Cefas' library and various storage buildings. We prioritized our initial digitisation efforts on the 1960s, working backward in time. The advantage of working on the 1960s was that this still allowed communication with senior Cefas staff and recently retired colleagues, themselves present on these surveys early on in their careers, about the interpretation of the hand-written records in the survey logbooks.

About 10–15 Cefas surveys were carried out each year of the 1960s in the North and Irish Seas, but only a smaller subset of these were typical fish surveys where quantitative fisheries data were collected using methods reasonably comparable with those on current surveys. Other surveys were targeted at e.g. plankton, hydrochemistry, the collection of fish to be used in laboratory experiments but without records on catches per haul, etc.

Historical surveys have been entered directly into the standard 'FSS' database at Cefas, which holds all information on the surveys currently carried out by Cefas research vessels (back to 1977 before the start of this project). Entered into FSS, the format of historical data entries is as comparable as possible to the contemporary survey data. Table 1 gives an overview of the surveys entered, with the total number of stations sampled, numbers of fish measured, and the numbers of fish where information on sex and maturity was collected.

For 2011, we are planning to continue data entry of historical surveys into FSS, with special focus on North Sea surveys during the 1910s–1920s.

Table 1. Overview of 1960s surveys digitised in the FSS database of Cefas.

Cruise name	Date	Area	Stations	No. fish measured	Maturity data
CLIONE 9/1961	May-1961	North Sea	80	3128	0
CLIONE 13/1963	Aug-1963	North Sea	60	1939	172
CLIONE 6/1964	Apr-1964	North Sea	80	2850	1033
PLATESSA 12/1964	Sep-1964	North Sea	24	13247	0
PLATESSA 3/1965	Feb-1965	Irish Sea	96	5129	2645
PLATESSA 4/1965	Mar-1965	Irish Sea	135	9911	7517
CORELLA 10/68	Jun-1968	North Sea	59	13206	0
CORELLA 11/69	Jun-1969	North Sea	44	14136	2044
ERNEST HOLT 3/70	Apr-1970	North Sea	44	12264	1525
CLIONE 11/70	Aug-1970	North Sea	56	10712	1950
All surveys			678	86522	16886

3.3 An update on digitisation of historical records for the Gulf of Maine (GOM)

Emily Klein

University of New Hampshire, Durham, New Hampshire, USA

The group at the University of New Hampshire (UNH; namely Emily Klein and Bill Leavenworth) are furthering the digitization of historical records in the Gulf of Maine (GOM). Most recently, researchers have begun scanning the series of Canadian Annual Reports for the Bay of Fundy and the GOM Nova Scotian coast, and creating PDFs from these scanned documents. This is the first time these data has been transformed from paper to a digital archive. At the time of this writing, the Annual Reports had been scanned up to the 1940s. In addition, the group has also begun scanning original hand written Canadian Monthly Statistical Returns that are available by county for Nova Scotia and New Brunswick. Again, this is the first time this information has been accessed and digitized. The series is scanned to 1932 at the time of this writing. For both of these reports, scanning will be completed by the end of 2010. The resulting PDFs will be available in digital archives via the University of New Hampshire, the Maine Department of Marine Resources in Boothbay, Maine, and at the St Andrews Bay Biological Station in New Brunswick. Interested parties can contact the group at UNH (Emily Klein or Bill Leavenworth). Finally, in addition to these reports, Bill Leavenworth and Carolyn Hall have scanned and digitized newly accessed Fisheries Statistics for Massachusetts. This data are highly spatially explicit, including maps of fishing gear location.

4 ToR b) Methods on historical data for estimating long-term dynamics of stock, fishing fleet and fishing technologies, including technological creeping

4.1 Why study fishing power and effort?

Sidney J. Holt

Voc. Palazzetta 68, Paciano (PG), Italy

Calibrated fishing effort statistics, and derived catch-per-unit-effort (*cpue*) indices, can be used for two purposes:

1) Detecting and measuring changes in the abundances of exploited fish stocks. By extension, using appropriate population dynamic models they can be extrapolated back in time to estimate the abundances of fish in earlier times, usually before exploitation, or a particular mode of exploitation, began, or forward to predict catch rates to be expected from changes in fishing or possible natural changes.
2) To provide information needed to determine regulation of fishing power and/or effort and intensity for management purposes.

We define **fishing intensity** as the deployed total calibrated effort per unit area; this can be to a defined geographical area of the "fishable area" within a geographical area, defined appropriately. (If the area is not correctly defined analysis of *cpue* can lead to extreme errors of interpretation, as recently illustrated by a recent article in *Nature* about the historical decline of demersal fish stocks exploited by English trawlers). Consideration of intensity is important in the not-uncommon circumstances of the so-called "basin effect", that is the contraction of the range of fishing operations when catch rates decline in the less productive parts of the area of fish distribution. Such contraction commonly causes *cpue* series to underestimate the extent of stock decline. Of course similar considerations apply to other stock changes that depletion by intense and prolonged fishing, including natural changes, for example as a result of change in ocean climate.

So, what do we mean by "calibration"?

The core problem of regulating fisheries for assured sustainable yields is the control – basically the limitation – of the overall values and age-distributions of **fishing mortality rates**, *F*. (This is properly expressed as an exponential but that is easily converted to a percentage rate for non-technical use.)

To that end **fishing effort** – *f* – must be **defined** in terms of the **fishing mortality** it will generate, and calibrated to take account of differences between, and historical changes in the efficiencies of, different kinds of vessels, fishing gears, gear operational methods and deployments of fleets (This can be quite difficult if two or more types of operation are exploiting the same stock or group of stocks, such as trawlers and longliners fishing for cod, primarily because of the difference in size - hence age – selectivity)

Data for fishing effort – such as number of hours spent hauling a trawl of a certain type through a specified time interval, usually a year or an annual season – have to be **calibrated**. There are basically three ways of trying to do this:

a) Examine catch rates of more or less simultaneous commercial operations by different kinds of fishing units (vessel plus gear plus other factors) in the same locality;

b) Conduct "parallel fishing" experiments using chartered commercial vessels or, if available, research vessels that are in fact derived from commercial vessel types:

c) Deduce, theoretically from the empirically determined characteristics of a fishing unit, such as for example area swept by a trawl of a certain size and type.

In practice all three methods have, preferably, to be combined.

If properly defined fishing efforts are additive, so that the fishing mortality rate they will jointly generate is the sum of the fishing efforts of the entire fleet. We define fishing effort as the **deployment** of **fishing power**. The unit of fishing power is thus the fishing mortality that would be generated by the **full** deployment of **potential effort**, for example by fishing as many days of the year as would be operationally feasible in normal circumstances. Hence catch quotas commonly involve the deployed effort being less than the potential effort because a quota has been reached when there remains substantial potential fishing time; this inefficiency may be created for the individual fishing unit and for the fleet as a whole, depending on how catch limits are allocated; it is one of the principle defects of regulation primarily by TACs.

Although properly calibrated fishing effort statistics are additive in the sense of combining the efforts of all units of the fleets operating in an area at the same time, they are not simply additive when combining efforts in each subarea of operation in order to obtain an overall figure. Beverton and Holt, 1957, suggested algorithms for such combinations; essentially the average of all subareas is to be found using weights that are proportional to estimates of the fish density in each area. They also found that if the area of operation does not change, nor the geographical distribution of the effort, the simple average of the effort is satisfactory to indicate changes in the overall effort. Beverton and Holt defined in this way *effective effort* and *overall effective effort.*

4.2 On the need to study fishing power change: challenges and perspectives

Georg H. Engelhard

Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft, UK

Fishing power expresses the efficiency by which vessels have the potential to catch fish. It is well known that fishing power has improved steadily over the past century, but there is very little quantitative information about the speed at which this has happened. Researchers have tried to address this question since the early days of fisheries science: see, for example, Garstang (1900) on the dramatic increase in fishing power when the era of steam-powered trawling followed that of wind-powered. The continual improvement in fishing power is also a question that will intrigue any fisherman, and not the least those senior fishers who have witnessed technological improvements themselves (and who may not always have seen these reflected in better catches, e.g. if stocks began to dwindle).

Although there is general agreement that substantial changes in fishing power have occurred, quantitative information on the amount and rates of change is limited, especially over multidecadal time-scales (but see Engelhard, 2008; and Pauly and Palomares, 2010). This is surprising given the obvious benefits of research on fishing power change. This section is a plea for more research on the subject, in the following subsections: (1) why study fishing power change? (2) how to define fishing power? (3) an example: long-term fishing power change in North Sea trawlers; (4) how to analyse fishing power change; and (5) some limitations and potential pitfalls with studying and applying fishing power data, to be borne in mind to avoid drawing false conclusions.

4.2.1 Why study fishing power change?

There are at least two important, applied motivations for studying fishing power change:

- To understand change in the *capacity* (or overcapacity) of fishing fleets, and their potential to exploit (or overexploit) fish stocks; such knowledge can be brought to use for effective management and sustainable exploitation of stocks.
- To help interpreting catch and cpue from commercial fisheries data if these are to be used as an *index of stock abundance* over medium to long time-scales, where changes in fishing power (and hence catchability) are likely to have occurred; such knowledge is important for assessing long-term stock dynamics.

4.2.2 How to define fishing power?

Definitions of fishing power (sometimes referred to as catching power) differ slightly among authors. All have the key question in mind: how efficient are different fishing vessels (or fishing fleets) in catching fish? In principle, fishing power expresses *differences in catch-per-unit-effort (cpue)* between fishing vessels (or different fishing fleets) if they would be fishing at the same time and at the same location (hypothetically or realistically). Fishing power can be calculated by comparing the cpue of a base vessel (or base fleet) with data available for a number of years, with the cpue of other vessels (fleet or fleets) that are newly developing. For calculations, a spatio-temporal overlap between these fleets is required. The base vessel or base fleet usually represents a conventional fishing method that is remaining, or has remained, relatively unchanged for a reasonable stretch of time; the study vessel or study fleet may represent a new or different fishing methodology that is being introduced. The cpue can either refer to a particular fish species, or to the catch of all or a number of species combined.

Garstang (1900), to my knowledge, was the first to apply the fishing power concept. He compared the fishing power of the first steam trawlers, fishing in the North Sea during the late 19th Century, with that of conventional sailing trawlers or 'smacks', and hence expressed steam trawler fishing power in terms of 'smack units'. Later on, Beverton and Holt (1957) compared the fishing power of steam and motor trawlers, at a time when steam trawling was gradually giving way to motor (diesel-driven) trawling. Whereas sailing trawlers comprised the base fleet in Garstang's (1900) study, the steam trawl fleet did so in Beverton and Holt (1957).

4.2.3 Example: long-term fishing power change in North Sea trawlers

A few years ago, using the principles of Garstang (1900) and Beverton and Holt (1957), I attempted to reconstruct the development of fishing power in English North Sea trawlers from the 1880s to 2000s (Engelhard, 2008), by combining a range of catch, effort, and cpue data for various periods, where possible taking spatial information into account. The study looked at fishing power for cod and plaice specifically, and it attempted to express the whole change in fishing power as original 'smack units' (but see below for an increasing potential for errors in the estimates once the 'base fleet' of sailing trawlers became extinct during WWII). Here I highlight the three, arguably most important changes in fishing technology that have occurred in the North Sea UK (demersal) trawling fleet.

During the late 18th and most of the 19th Centuries, demersal fish were typically caught by sailing trawlers or smacks, where a wooden beam trawl was towed behind the vessel, manually lowered and taken in. The first major 'leap' in fishing power occurred in the 1880s with the introduction of the first purpose-built steam trawlers (e.g. Robinson, 1996). Garstang (1900) estimated that these first steam trawlers, still using a beam trawl, had a fishing power for total demersal fish that was 4 times higher than that of conventional sailing smacks (i.e. 4 'smack units'). By 1898, steam trawlers had adopted the use of otter trawls, and by then their fishing power for total demersal fish had improved to 8 smack units. The sailing trawl fleet declined rapidly after the introduction of steam trawling and by the 1920s–1930s was restricted to the southern North Sea. Here, steam trawlers had about 4x higher plaice fishing power, and about 10–20x higher cod fishing power than sailing trawlers during this period (Engelhard, 2008).

The second major technological change came in the 1940s–1960s when motor trawlers (diesel-driven) gradually out-competed steam trawlers. However, the change from steam to diesel was more subtle than that from sail to steam. Motor (diesel) trawlers had about equal, or only marginally higher, cod and plaice fishing power when compared to contemporary steam trawlers in the North Sea (Engelhard, 2008), but this was despite on average much smaller vessel size. This related to the far greater compactness of the diesel motor compared to the steam engine. Thus, tonne by tonne, motor trawlers had considerably higher fishing power (see also Beverton and Holt [1957] for similar results on British steam and motor trawlers fishing around Iceland).

Third, the introduction of modern (twin-) beam trawling had profound implications for North Sea trawl fisheries. This method involves two large beam trawls lowered mechanically from the side of the ship, often with tickler chains, and is particularly effective for catching sole, plaice and other flatfish. 'Modern' beam trawling was especially developed by the Netherlands and Belgium during the 1960s–1970s, with the UK following relatively late in the mid-1980s–1990s. A comparison of Dutch beam trawlers with English otter trawlers fishing the southern North Sea in the 1960s–1970s, revealed that the former initially had ~2x, later ~8x higher plaice fishing power; and initially lower, later on about equal cod fishing power (Engelhard, 2008). This was despite the fact that the Dutch beam trawlers were actually targeting sole (de Veen, 1979). During later decades, the fishing power of beam trawlers for flatfish, but possibly not roundfish, increased further, but may have also temporarily declined (Large and Bannister, 1986; Engelhard, 2008).

Although fishing power of English North Sea trawlers, with introduction of new technologies, has several times 'leapt' forward within periods of a few years, there have also been long periods of stagnation in fishing power change (Engelhard, 2008). During both World Wars the majority, and generally the best and most modern, of UK trawling vessels were converted to mine sweepers, and many vessels were destroyed by enemy action (e.g. Robinson, 2000). After the war, many newly built vessels were sent to distant waters with the older vessels remaining active in the North Sea (Robinson, 2000). It is therefore likely that within the North Sea, very little change in fishing power of steam trawlers occurred between the 1910s and 1950s, and possibly a temporary decrease from the 1930s to 1950s. From the 1960s to 1980s, rapid technological developments occurred that must have significantly increased fishing power. Unfortunately, it is for this crucial period in North Sea fisheries history that essential data allowing fishing power comparisons are actually relatively scarce, possibly owing to the fast developments themselves and the absence of a constant, unchanging 'base fleet'. I consider it likely that the European Union's fleet capacity reduction programme of the 1990s–2000s has halted this trend to some extent. Further research is needed to reveal whether this really is the case.

4.2.4 How to analyse fishing power change?

Three approaches are highlighted that can be used to estimate fishing power change (and see also Holt, section 4.1 of this report, on calibration of fishing effort). Each of these requires a calibration time-series of cpue or fish abundance: (1) cpue obtained from a commercial base fleet or vessel; (2) cpue from a scientific survey; (3) fish abundance or fishing mortality estimates from stock assessment models.

Approach (1) can be used if a time-series of cpue data can be identified for a conventional, relatively unchanging *base fleet with presumably constant catchability*; or if one or several vessels can be identified that applied the same fishing method over a reasonable length of time. Cpue data for a study fleet, matching in space and time, are compared with those for the base fleet (Figure 3). Ideally, cpue data matched at least at the spatial detail of ICES rectangles are to be used; comparisons of commercial cpue aggregated over large geographic areas (such as ICES Subareas or divisions) might give misleading results since fleets tend to differ widely in the grounds fished.

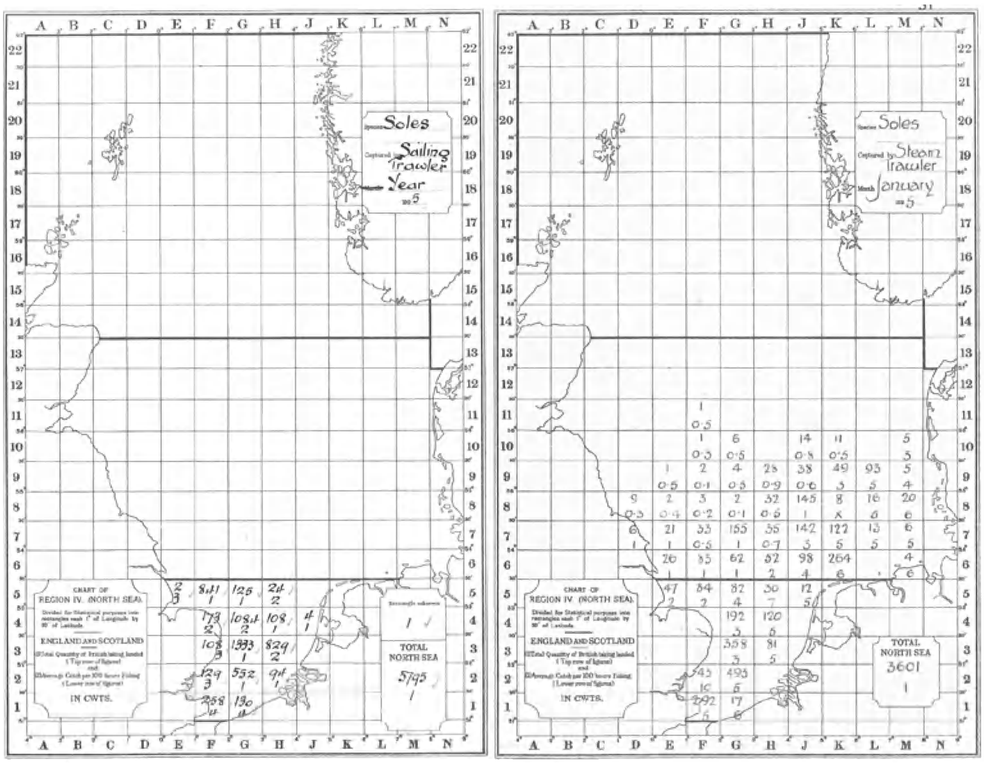

Figure 3. Example of spatially and temporally matched sole cpue data for British sailing (left) and steam (right) trawlers in 1925, allowing a fishing power comparison between the two fleets. In the analysis, only spatio-temporally matched cpue data are included (i.e. data for the southern North Sea, ICES Division IVc). Within each rectangle, the top figure shows the total landings (in cwt), and the lower figure shows cpue (catch [cwt] per 100 hours of fishing).

Approach (2) can be used if a contemporary cpue time-series from a *standardized scientific survey* covering the same locations as the study fleet is available; survey cpue are compared with the cpue for the study fleet. Notice that surveys are typically carried out during one or few specific months of the year. By contrast, commercial cpue data are often aggregated over an entire year. In order to allow a comparison matching in time and space, it is suggested only to include commercial cpue data that are collected during the same month(s) as when the scientific survey took place. This approach was used, among others, by Marchal *et al.* (2002, 2003).

Approach (3) requires fish abundance or fishing mortality estimates from stock assessment models, such as virtual population analysis (VPA), and was applied by Millischer *et al.* (1999) who modelled fishing power for the Brittany offshore fleets based on VPA estimates of annual fishing mortality (*F*), and the total fishing effort for these fleets. The calibration cpue time-series is now not provided by a constant base fleet or a standardized survey cpue, but by an abundance time-series from a stock assessment. *Information.* Notice that in stock assessments, fish abundance or biomass is typically estimated on a per-stock basis, i.e. for an entire sea or fishing region, without the spatial detail of localized presence within the region. Lack of spatial detail makes it somewhat less suitable in providing calibration cpue data matched in space and time with the study fleet. On the other hand, there is no need to rely on an assumption of constancy of base fleet or survey catchability. There is usually large uncertainty in stock estimates for the very most recent years or year classes, but estimates are typically much more reliable further back in time.

With a spatio-temporally matched cpue dataset for the base and study fleet (such as illustrated in Figure 3), fishing power can be modelled using various linear models. As cpue and fishing power data tend to be multiplicative, they can be modelled using log-transformed data (or e.g. log(x + 1) to account for zeros), or using an appropriate link function. One relatively simple way is to calculate for each rectangle, a local estimate for study fleet fishing power as the ratio of the cpue for the study fleet and that for the base fleet. In this example, steam trawler fishing power is expressed in sailing trawler units:

$$\mathrm{P.SMT} = \mathrm{cpue}_{\mathrm{steam,rect}} / \mathrm{cpue}_{\mathrm{sail,rect}} \quad (1)$$

These can then be averaged to obtain overall mean steam trawler fishing power. However, if a linear mixed model is used to calculate overall mean fishing power, the advantage is that the 'rectangle effect' can be accounted for, if it is included as a random effect. In the R package, the form of the model is:

```
lme(log(P.SMT)~1, random= ~1|factor(rect), data=data))            (2)
```

where the resulting estimate of the intercept will provide an estimate of ln(steam trawl fishing power); P.SMT are ratios of cpue for study and base fleets by rectangle.

Yearly estimates of fishing power can be estimated by including year as a factor:

```
lme(log(P.SMT)~as.factor(year), random= ~1|factor(rect),
data=data))                                                        (3)
```

A linear temporal trend in fishing power can be estimated by including year as a covariate:

```
lme(log(P.SMT)~year, random= ~1|factor(rect), data=data))         (4)
```

The above method (yearly estimates of fishing power) has been applied, e.g., in Engelhard (2008). However, it could be argued that it is not recommendable to use cpue ratios as the basic data for the linear models. This is because (1) cpue data are already a ratio (catch/effort) and therefore P.SMT is a ratio of a ratio; and (2) cpue outliers could have a quite strong effect on P.SMT (cpue outliers are especially likely if effort in a rectangle was very limited, but a high fortunate catch obtained).

Alternatively, fishing power could be modelled, using the cpue data by rectangle for both fleets (as also proposed by C.C. Osio, pers. comm., during ICES SGHIST, 2010). The log(cpue) for the base fleet is included as an offset (in R this is not supported for linear mixed models and a general linear model without the area effect is suggested):

```
glm(log(cpue.SMT)~1, offset=log(cpue.SLT), data=data))        (5)
```

The resulting estimates are likely to be similar, but not identical, to those from equation (2): the estimated intercept will describe ln(steam trawl fishing power).

Yearly fishing power estimates and multi-annual linear trends can be calculated, analogously to equations (3) and (4).

4.2.5 Limitations and potential pitfalls with fishing power data

A number of limitations and potential pitfalls with fishing power calculations and fishing power estimates are highlighted here, that should be borne in mind to avoid drawing incorrect conclusions when such data are applied.

- Fishing power is not equivalent to *engine power*. Although fishing power is generally improved with engine power, this does not necessarily scale in a proportionate way; i.e. doubling of the engine power does not equate to twice higher catch rates – this can be more, also less.
- Fishing power is really influenced by a variety of factors other than engine power and vessel size; these include targeting ability as well as the desire to target particular species, the size and material of nets, skipper skills, familiarity with grounds, fish finding devices, etc..
- Fishing power is *species-specific*. If the fishing power for one particular fish species is doubled this is not necessarily the case for other species. Fish species differ widely in behaviour, size, shape, swimming speed, depth, habitat, etc. Fishing power is also species-specific because it relates to fishers' ability to target particular desired species, and/or to avoid targeting other undesired species (such as those with low market value, or over-quota species). Therefore, the extrapolation of fishing power data from one species to any other species (as was done in Thurstan *et al.*, 2010) should be avoided.
- Fishing power change can be *area-specific*, and specialisation of a fleet to particular fishing grounds might actually reduce its fishing power on a different ground.
- In fishing power calculations, it is worth to question the assumption of *constancy of the base fleet*. Also old, conventional fishing methods might undergo changes that are not always recorded.
- Where fishing power data are used to 'calibrate' cpue time-series to estimate a fish biomass trend, any *spatial changes in the fishing grounds* of a fleet over the study period should be properly accounted for. Unfortunately, in the above-mentioned study (Thurstan *et al.*, 2010) landings data for a wide range of present and former fishing grounds of UK trawlers were 'lumped' into a single time-series. Owing to major changes in British fishing grounds (including complete abandonment of the highly productive, former Arctic fishing grounds), their resulting time-series of "landings per unit fishing power" provides a misleading

picture of the fish biomass trend, even if an attempt was made to calibrate aggregated cpue data for fishing power change (Thurstan *et al.*, 2010).

- Where an attempt is made to express long-term fishing power change as a single historical unit (such as the 'sailing smack unit' in Engelhard, 2008), several calculation steps may be needed where a technology change was introduced. It should be noted that with each calculation step, an added uncertainty is introduced.
- Ideally, fishing power or cpue calibrations should be attempted using a combination of approaches (*fide* Holt, Section 2.1).

It is hoped that the above obstacles are no more formidable than it is the case with such fields in fisheries science as fish stock assessment and/or multispecies modelling techniques, which have received considerable attention in recent decades.

4.3 Case Study: Estimation and correction of fishing power in the Mediterranean Sea

Chato Osio

Centro Intruniversitario di Biologia Marina (CIBM), Livorno, Italy
University of New Hampshire, Durham, USA

To date in the literature, information is lacking on the change in fishing power of Mediterranean trawl vessels over short time frames, and there is even less over the scale of centuries. In this context we aimed to reconstruct the evolution of fishing effort over the past 300 years and have assembled trawler cpue data from single sail trawlers during the 18th Century, from pair sail trawlers during the 19th Century, and from steam and motor trawlers during the 20th Century. To be able to compare these relative abundance estimates in a realistic way we need to know what was the efficiency of one vessel type relative to the other and to do this we need to have trawlers with different technologies fishing at the same time in the same areas as explained in prior sections. The key periods are the 1920s when the first motorized vessels (steam and motor) quickly displaced sail pairtrawlers that 150 years before had displaced single sail trawlers from the North-western Mediterranean. The period around and after the 1960s is also important for technological change as synthetic nets, better deck equipment and navigation systems were introduced.

As an example, Ermirio (1932) reported the catch rates of individual trawlers fishing in 1926 on a bank southwest of the Lampedusa island in the Sicilian Channel, less than 50 miles away from the Gulf of Hammamet in Tunisia. Here, Italian steam, sail and one motor trawler operated simultaneously during one summer. The cpue (kg/number fishing days) of each vessel was compared fitting a GLM where kg per fishing day was modelled as a function of vessel type and tonnage. The model is used to predict the catch rates for a standardized trawler of 90 tons for each vessel type and the predicted cpues are used to build catching power rates (Figure 4). The model estimates that a motor trawler catches 3.9 times more than a pair sail trawler with auxiliary engine, and 2.53 times more than a steam trawler. A steam trawler catches 1.55 times more than a pair sail trawler with auxiliary engine.

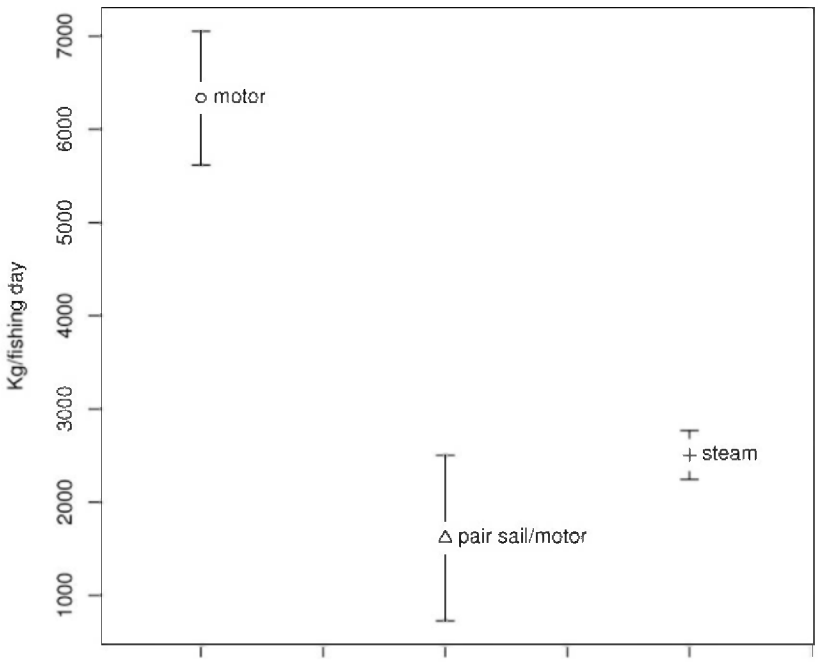

Figure 4. Catch rate (kg/fishing day) comparison between motor trawlers, steam trawlers, and pair sail trawlers with auxiliary engines, fishing in the Sicilian Channel during 1926.

We derived other catch rates between older and newer trawling vessels for more recent period, these are the first such estimates derived in the Mediterranean region and are not presented here. Overall these indicate that over the past 50 years trawling fishing power can have increased at a 2–3% per year.

4.3.1 Standardization of commercial cpue data and correction for fishing power

For the standardization of commercial cpue data we simulated a theoretical increase in fishing power building a set of scenarios ranging from 0 increase (fishing power considered constant) to 3% per year. A similar approach was used by Cardinale *et al.* (2009, 2010) to derive standardized indices for North Sea turbot and plaice scientific survey cpues. Note, survey cpues are typically subject to less fishing power/catchability change than commercial ones.

The increase in fishing power can be simulated in different ways, by using a catchability coefficient as a scalar. Alternatively an increase in effective fishing effort can be simulated by fitting a power function on fishing effort, in this case fishing days. In practice the uncorrected cpue in kg is corrected dividing by the power function on fishing days for each vessel. In the case of a simulated fishing power increase of 1% per year the corrected cpue is:

$$CPUE_{corrected} = \frac{CPUE_{uncorrected}}{1.01^{(year_{current} - year_{initial})}}$$

The same applies for the 2% and 3% scenarios. To visualize the increase of fishing effort (fishing days) by the power function a plot was made to show the different scenarios over time (Figure 5). For example, at the 3% increase scenario, a fishing day in 1956 evolves with technological change to result in nearly 4.5 effective fishing days fifty years later. Here we applied a constant increase over time and this is acceptable as we compare two distinct periods at the beginning and at the end of the series.

Technological change however is more realistic to follow a step function and in cases with cpue data over the entire period this second type of correction should be applied.

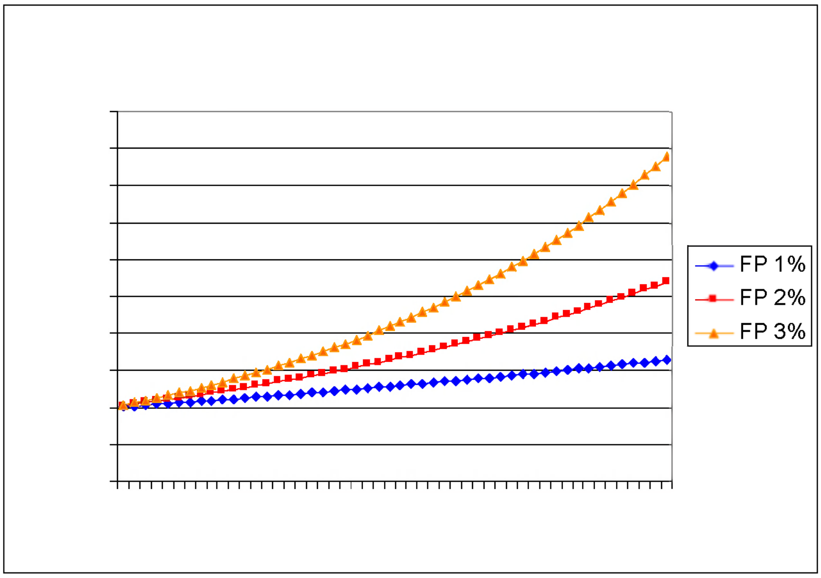

Figure 5. Power function applied to fishing days to display different fishing power (FP) scenarios for 1%, 2% and 3% rate of increase per year.

For the cpue standardization we used detailed daily landing statistics from individual trawlers that have been collected in the port of Blanes (Catalonia, Spain) for the historical period between 1956 and 1965 and for the modern period between 1997 and 2004. Vessel information like GRT, HP and Age were available but not fishing areas or specific gear information like size of the net.

In R 2.10, running on a Linux 64 bit machine, the *lme* function (package nlme, Pinheiro and Bates, 2000) has been used to fit Linear Mixed Models with a random intercept on vessels. We chose these models as they correctly account for the autocorrelation generated by repeated measures emerging from the same vessels.

The trend in the grouped species, or total biomass landed, was calculated using a stepwise selection of the best fitting linear mixed model, we then predicted the mean cpue for a standardized vessel and applied scenarios of fishing power increase ranging from 0–3% per year. The results indicate a large decline in total biomass even if fishing power did not increase substantially (Figure 6). Of course the decline is much larger under increasing fishing power scenarios. Under the highly unlikely scenario that fishing power of vessels has not increased over time, and then total commercial biomass appears to have declined by at least one third. At the other end of the scenario spectrum, if a 3% fishing power increase is assumed; total commercial biomass is down to less than 20% of levels at the beginning of the series.

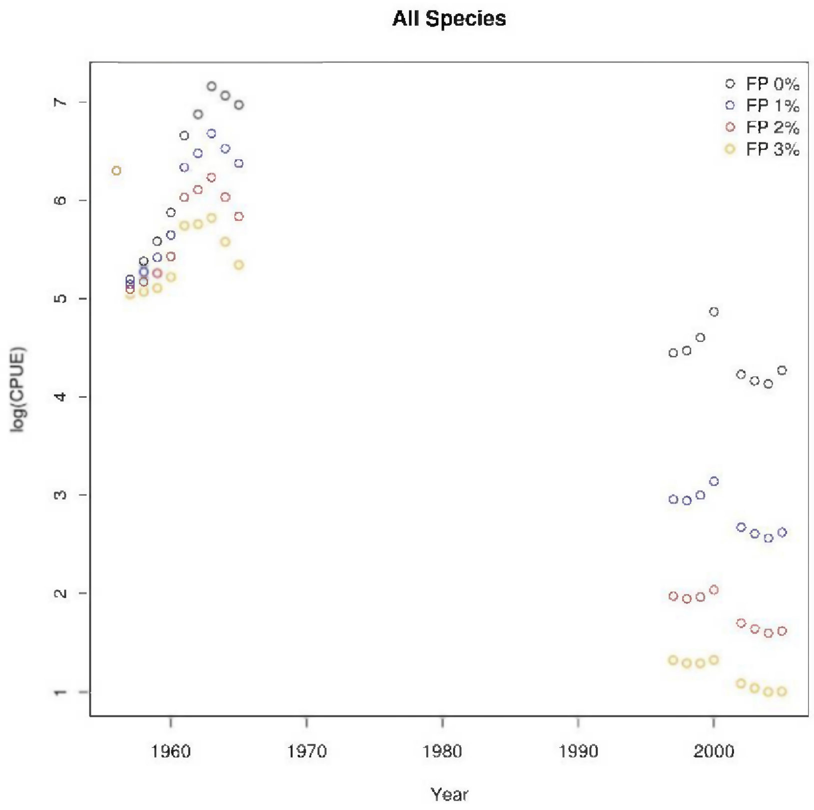

Figure 6. Predicted mean log(cpue) for all species combined for a standardized vessel fishing in the port of Blanes (Catalonia, Spain) according to different scenarios of fishing power yearly rate of increase (FP 0%,1%, 2%,3%).

Second we investigated trends in abundance by fitting linear mixed models to commercial data for landings of the main target species. Similarly standardized yearly estimates were predicted according to different scenarios of fishing power increases. Taking the scenario of a 3% increase, the results for the Catalan area show over the past 50 years a large decline of biomass of *Aristeus antennatus*, a slight decline of *Merluccius merluccius*, a moderate decline of *Nephrops norvegicus* and *Scyliorhinus canicula* and a steady or increasing trend of *Mullus barbatus.*

This work was carried out with colleagues in the EVOMED project and with support from the OAK Foundation to Chato Osio.

5 ToR c) Methods for spatio-temporal analysis of fish and fisheries historical data

5.1 Finding the appropriate scale in the analysis of historical data

Valerio Bartolino, Massimiliano Cardinale

Department of Earth Sciences, University of Gothenburg, Sweden

Institute of Marine Research, Swedish Board of Fisheries, Sweden

Increased knowledge of both the spatial distribution of marine resources and the temporal trend in fish stocks during the last centuries of exploitation is crucial for the implementation of a true ecosystem approach to management and the conservation of marine organisms. This implies the analysis of historical data that have been collected for different purposes across a number of surveys and sampling programs. In these circumstances, an analysis of the appropriate scales is necessary. Thus, identifying an appropriate scale of analysis represents one of the main challenges of analysing historical data and the scale of investigation should be coherent from sampling to analysis and it is usually determined by the process of interest. As no unique temporal and spatial scale of investigation has been set before sampling, it is not obvious which is the real amount of information available for reconstructing the temporal and spatial dynamics of the populations studied. Usually, the amount of information available is not homogeneously distributed in time. In some years and periods, available observations are numerous, while these may be scarce or missing in other years. Similarly, certain areas contain more observations than others, and the spatial resolution affects the amount of information available in each spatial unit. Here we want to understand if there is a combination of temporal and spatial aggregation more appropriate to the analysis of our historical dataset (1901–2007, covering the Kattegat and the Skagerrak) also because predictability of natural systems generally increases at larger scales. It is also expected that predictability is larger when the scale of a particular process is matched. We used a linear model with a random effect to investigate if certain temporal and spatial aggregations of the data are more appropriate than others. In practice we studied if and how the performances of a spatio-temporal model changed across different temporal and spatial scales. In the case of our dataset, there is an "optimal" combination of time and special scale that corresponds to 12 years and 0.15 degree of latitude.

5.2 Nonlinear dynamics in natural systems

Emily Klein

University of New Hampshire, Durham, New Hampshire, USA

Nonlinear dynamics in natural systems are a critical, yet less well-known, explanation for system behaviour and variance. The theory behind non-linear dynamics in ecology, namely chaos theory, was pioneered by May (1974), and May and Oster (1976), but not generally accepted until recently (Schaffer and Kot 1985). In the last twenty years, research into chaos theory and non-linear dynamics has increased dramatically, uncovering mounting evidence for these behaviours in natural time-series (e.g. Schaffer 1984, Schaffer and Kot 1985, Dublin *et al.*, 1990, Sugihara and May 1990, Sugihara *et al.*, 1990, Sugihara 1994, Pascual and Ellner 2000, Hsieh *et al.*, 2005, Hsieh *et al.*, 2008). Current research finds them ubiquitous in terrestrial (e.g. Schaffer

1984, Hastings *et al.*, 1993, Ito *et al.*, 2004), freshwater (e.g. Carpenter *et al.*, 1999, Knowlton, 2004) and marine environments (e.g. Sutherland, 1974, Dixon *et al.*, 1999, Hare and Mantua, 2000, Pascual and Ellner 2000, Knowlton 2004, Hsieh *et al.*, 2005)

The prevalence of non-linearity and chaos in natural systems alone highlights their significance for understanding spatial and temporal dynamics. However, fluctuations resulting from non-linearity are aperiodic, i.e. they do not repeat, and can appear random over time (Schaffer and Kot, 1985, Sugihara *et al.*, 1990, Scheffer *et al.*, 2001) (Figure 7). Despite this, there is an identifiable signal in the behaviour of these systems, e.g. "order in chaos," that is in fact deterministic, described as *deterministic chaos* (Schaffer and Kot, 1985). This has serious implications for analysis, as time-series appear arbitrary at first glance. It is thus doubly important that investigations include detecting non-linear signals via statistical means, as time-series with identifiable and significant structure could be discounted as random if such methods are overlooked.

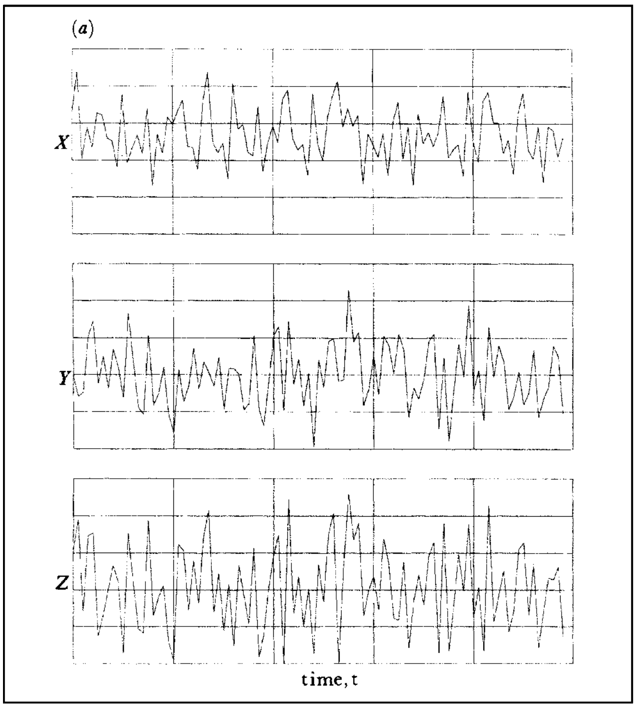

Figure 7. Examples of deterministic non-linear time-series that appear randomly. From Sugihara *et al.*, 1990: "Simultaneous time-series for the three variables of the Lorenz system: X, Y, and Z as functions of time."

In addition to its importance for understanding ecosystem dynamics in general, identifying non-linear behaviour has further implications for understanding relationships in dynamic ecosystems. Traditionally, cross-correlation or cross-spectral analysis identified such relationships, or correlations, between variables (Pascual and Ellner 2000). However, statistically significant correlation does not necessarily signify causation (Hare, 1997, Garcia *et al.*, 2007), and lack of correlation does not imply lack of causation (Sugihara *et al.*, 1990). These statements apply to linear systems, but are even more critical for non-linear ones, where influences acting on one period may cause a response in one or more different periods (Pascual and Ellner 2000). In the resulting time-series, variables may appear correlated for years, and then lose correlation, even if the fundamental dynamics have not significantly changed, i.e. a causal relationship still exists (Figure 8). In other words, although variables may be dynamically coupled in time, significant correlation in the conventional sense may not exist. Therefore, traditional time-series methods are ineffective at identifying causation within non-linear dynamics and may fail to detect significant relationship in these systems (CAMEO, 2009).

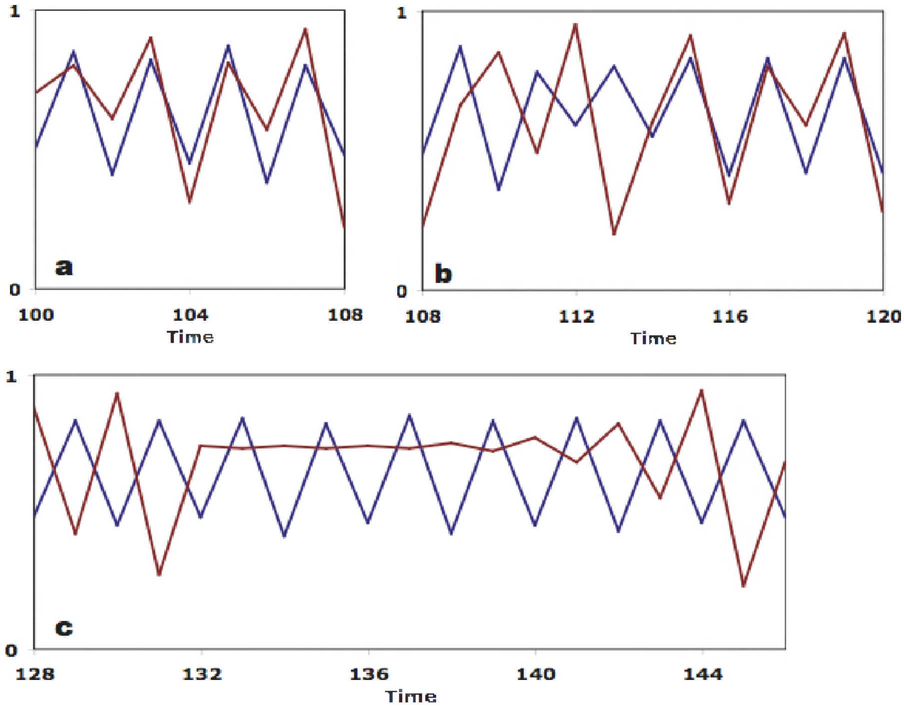

Figure 8. Time series generated from a simple deterministically coupled two-variable logistic difference system. In 3a, the series appear correlated, but this correlation breaks down in 3b for a period of time before returning by the end of the series. In 3c, over long time periods, the correlation appears to be lost. Thus, the variables are not always correlated in the traditional sense, but are coupled. From the CAMEO Project Narrative (2009) – G. Sugihara.

George Sugihara and his group at Scripps Institute of Oceanography are developing methods for exploring non-linear dynamics and relationships. These non-linear time-series analysis (non-linear TSA) approaches investigate whether variables and time-series are 1) determined by linear or non-linear dynamics, and 2) *dynamically coupled*, as opposed to correlated (see Dixon *et al*., 1999, CAMEO, 2009). Resulting groups of dynamically coupled variables within an ecosystem are referred to as *functionally coupled units*. In theory, functionally coupled units may be functional groups within the ecosystem, or groups of species with similar fisheries. In general, they will be assemblages that reflect similar influences that will presumably be environmental, biological, anthropogenic, or a combination. The identified units often exemplify aspects of overall system behaviour, and are thus significant for understanding the ecosystem itself. Please see the following for more information on methodology: Sugihara and May (1994), Sugihara (1994), Hsieh *et al*.(2005), and Hsieh *et al.* (2008). Additional publications on methods and theory are forthcoming (contact Emily Klein for more information).

Distinguishing functionally coupled units has further application in ecosystem model development and forecasting, areas of significant interest to marine ecology and fisheries science. For ecosystem modelling, complexity is a major issue, as some traditional practices strive to parameterize as much of the system as possible, resulting in often exhaustive data needs and difficult construction. In contrast, modelling functional units resulting from non-linear TSA approaches has great potential to decrease model complexity. This is done by using the significant functional groups within a system and their dynamics to define model structure. In addition to this importance for constructing ecosystem models, these non-linear TSA methods have additional use in prediction. Once functionally coupled units have been identified, the behaviour of the underlying dynamics of these units can predict any one of the dependent variable, i.e. one species, out-of-sample by an explanatory variable or set of variables, i.e. other species. Doing so can also be used to "predict," or interpolate, missing single observations, or time-series of specific variables over a longer period. For these reasons, the techniques developed by Dr Sugihara and his group can aid in building models with low complexity and decreased data needs, but with high predictive power and based on strong ecosystem understanding (Pascual and Ellner 2000, CAMEO, 2009).

Exploring non-linear behaviour in marine environments offers novel and exciting avenues for further study into ecological fluctuations, dynamics, and relationships (Schaffer and Kot 1985, Scheffer *et al.*, 2001, Hsieh *et al.*, 2008).However, these theories and approaches have yet to be applied to historical data, despite the fact that they hold considerable potential for understanding the past. First, as for more contemporary data, it expands the tools available for identifying signals and dynamics within time-series, as well as for building ecosystem models. This is particularly pertinent for building models of past ecosystems, as these approaches decrease model complexity and data needs, considerable advantages for historical sources that may be limited. Second, the non-linear TSA approaches are also relevant to historical information by providing avenues for missing data, both in terms of single observations and entire time-series. These approaches draw strength from previously determined non-linear relationships to predict for unavailable information, thus providing more robust data for further analysis. For these reasons, the benefits of non-linear approaches for understanding historical data are considerable. At the University of New Hampshire, Emily Klein will be applying these novel techniques to information on the Gulf of Maine ecosystem, beginning in the mid 1800s (please see ToR-d for more detail).

6 ToR d) Case studies on history of fish and fisheries representing both sides of the Atlantic and the Mediterranean

6.1 Historical species dynamics and ecosystem relationships in the Gulf of Maine examined using non-linear time-series analysis

Emily Klein

University of New Hampshire, Durham, New Hampshire, USA

Emily Klein's present research utilizes non-linear time-series analysis (TSA), a novel method developed by George Sugihara and his team at the Scripps Institute of Oceanography, to understand underlying species dynamics and ecosystem relationships for the historical nearshore Gulf of Maine. Her work will investigate the non-linearity of system dynamics, and use results to develop an ecosystem model for previous systems going back to the 1800s. The methods also provide an avenue for interpolating missing data observations and time-series (see ToR – b for more information on methods). The aim is to understand how ecosystem dynamics and system structure have changed over time, and to use this knowledge to inform current management decisions by providing baseline data and insight for recovery scenarios.

In the first phase of this work, univariate non-linear TSA methods will determine if specific species dynamics are non-linear, and define the basic dynamic structure. Time series will also be analysed for different temporal periods to determine if dynamics have changed significantly over time. If the species exhibits different underlying dynamics between periods, this would indicate distinct intervals that should be treated as such. Second, non-linear TSA will be applied to select species at different locations to determine if dynamics change spatially. This is important not only for general understanding, but also because data from another location can be used as a proxy for missing data points if the dynamics are similar. For example, the Canadian historical catch statistics are more complete than those available for the US. If areas in Canada, such as near the border and Grand Manan, are dynamically similar to areas in Maine, the series can be used a proxy, thus allowing more complete temporal coverage.

Following univariate analysis, multivariate methods will explore greater ecosystem structure and dynamics. These approaches identify candidate functionally coupled units within a system. It is here that qualitative historical information becomes vital, as decisions between candidate units must be informed by prior knowledge. Results provide evidence for the functionally coupled units of a system, as well as fundamental driving forces. Multivariate non-linear TSA will identify possible units among the historical data, as well as possible co-predictive variables that may be driving the system. These methods are novel in application and use, as previous studies have focused on univariate analysis and contemporary systems (e.g. Hsieh *et al.*, 2008).

Once non-linear TSA is complete, Ms Klein aims to explore past ecosystem structure by developing ecosystem models of the GOM. These models will employ the Multiscale Integrated Model of Ecosystem Services (MIMES) simulation framework developed by the Gund Institute for Ecological Economics at the University of Vermont and various partners. MIMES is a framework for constructing models integrated via an interactive and dynamic interface for the spatial representation of an ecosystem or ecosystems. The general representation is similar to a concept map: objects are connected by flows describing the elements and relationships of a system. These objects and flows are defined by the mathematical submodels and available data. The structure was built to be straightforward, user-friendly, and easy to modify given new information (Boumans and Costanza, 2007). Research will use historical information to assess and alter the existing MIMES model for the GOM ecosystem developed by Les Kaufman, Roelof Boumans, and others. Results from the non-linear TSA will also be used to inform functionality and dynamics by linking species and environmental variables. Gaps in understanding can be filled by current knowledge or the qualitative literature to develop assumptions or update equations. Taken together, this approach will be used to construct potential ecosystem structures of the past and how they may have changed over time.

In addition, as MIMES specifically addresses environmental resources and ecosystem services, ecosystem structure can be related directly to the human community. To inform the services aspects of the model, the work here will use the qualitative historical information to alter current understanding of human services already available in the MIMES framework. This will allow the model to address not only ecosystem structure change, but how it directly relates to people via ecosystem services as well as anthropogenic drivers. Explicitly including services allows insight into services available in the past that may be gone or diminished today. Such information can be valuable to current management in terms of future possible services, if certain aspects of the ecosystem are encouraged to return. Finally, this work can explore which services people valued in the past and how that valuation may have changed.

Many of the analytical approaches described here mirror work being done as part of a collaborative CAMEO (Comparative Analysis of Marine Ecosystem Organization) working group. Scientists from the University of New Hampshire (UNH), Scripps Institute of Oceanography (SIO), Boston University (BU), and the Northeast Fisheries Science Center (NEFSC) are applying the non-linear time-series analysis methods and MIMES ecosystem model to understand and compare the contemporary Northeast Shelf large marine ecosystem (LME) with California Current LME. Ms Klein's doctoral work will provide background information to this modern study, making historical information immediately and directly relevant to current research. Further, work will be connected to management via presentation of results to interested parties. One such agency is the Office of National Marine Sanctuaries (ONMS), under the National Oceanic and Atmospheric Administration (NOAA). Collaborative projects with both the Stellwagen Bank National Marine Sanctuary (SBNMS) and the Papahānaumokuākea Marine National Monument (PMNM) are already under development.

6.2 Past to Present: 105 years of cod, haddock, and plaice fisheries in the North Sea

Tina Kerby

School of Environmental Sciences, University of East Anglia, Norwich, UK

This study's objective is to analyse changes in exploited fish populations of the North Sea over the past 100 years and to try to disentangle the relative contribution of fishing effects and climate change on these changes. As the interactions in an ecosystem are complex, the cause–effect relationships of climate change and fisheries on fish populations cannot be studied individually and should be investigated in context (Rijnsdorp *et al.*, 2009, Harley *et al.*, 2006). Previous studies have been based on relatively short time periods (e.g. Clark and Frid, 2001; Brander, 2000; Dippner, 1997; Halliday and Pinhorn, 2009; van Hal *et al.*, 2009; Weijerman *et al.*, 2005), which may be insufficient to fully analyse the relationship between climate change and fishing effects.

Records of commercial fishery data (e.g. landings, hours spent fishing, value of fish species etc.) have been collected and archived since 1866 by the UK Sea Fisheries Statistics Archive (Fisheries Statistics Unit and Marine Management Organisation, 2010), but the vast data collected for this period have not been fully analysed. As fishery scientists are more frequently being asked to comment on the long-term impacts of climate change and/or increased fishing pressure, and most fishery-independent survey time-series do not extend back beyond the 1970s (Pinnegar *et al.*, 2006), this UK time-series might represent a rich and thus far largely neglected data source.

North Sea landing data for England and Wales from 1903 to 1982 were obtained from the annual "Sea Fisheries Statistical Tables" of the Department for Environment, Food and Rural Affairs (Defra; former Board of Agriculture and Fisheries, Ministry of Agriculture and Fisheries, and Ministry of Agriculture, Fisheries and Food). For the period between 1982 and 2008 electronic data were available through the Fisheries Activity Database of Defra. Data on North Sea landings into Scotland and into The Netherlands for the period 1903–2008 were available from ICES catch statistics (www.ices.dk/fish/catchstatistics.asp).

Here, landings of three commercially exploited North Sea species – cod, haddock, and plaice – are presented over a timeline of 105 years, and further analysis for correlations with climate change is in progress.

Haddock

Haddock occurs mainly in the northern North Sea, and is therefore in better operating range to Scottish fishing vessels. Nevertheless, at the beginning of the last century, markedly greater amounts of haddock were landed at English and Welsh ports than at Scottish ports (9). However, a steady decline in English landings occurred, only being interrupted by World War I, with a concurrent recovery of the stocks. Nevertheless, the rapid decline of haddock landings continued immediately after World War I when fishing re-commenced, and English and Welsh landings have remained low since then. It is notable that the patterns of English haddock landings are not reflected by the Scottish landings, which remained fairly constant in the pre- and post-war years of both world wars. While then Scottish landings overall increased, considerable fluctuations took place, until the landings finally decreased in the mid-1980s. Dutch haddock landings were minor throughout the study period.

Reason for the high English landings at the beginning of the 20th century could be the overpowering number of English steam vessels, compared to Scotland, equipped with efficient otter trawls and fishing in the entire North Sea. But this does not explain why English landings rapidly declined after World War I and remained extremely low, while Scottish landings increased thereafter.

Cod

Before World War II, English and Welsh cod landings were lower than haddock landings; however, in the post-war decades cod landings were double those of haddock until the 2000s. Except in 1914, the Scottish exploitation of cod followed the same trend as haddock, though landings were always lower than haddock landings. As with haddock, cod played a minor role in The Netherlands but only until the 1960s.

From the 1960s onwards, for all three nations, the "gadoid outburst" led to exceptional increases in cod and haddock landings, which lasted for about two decades, but was followed by a decline since the mid-1980s.

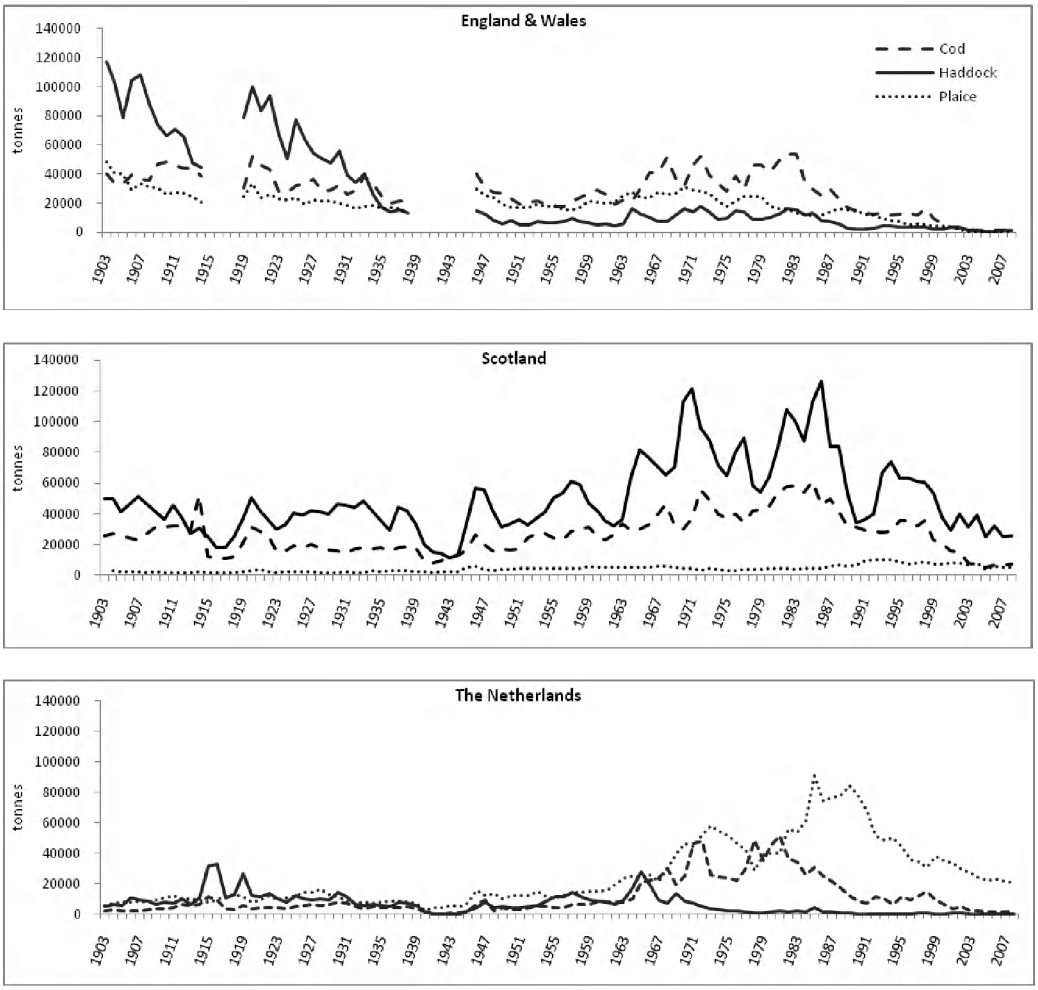

Figure 9. Commercial landings data of the North Sea of three different species (cod, haddock, and plaice) caught by three countries (England and Wales, Scotland, and The Netherlands). Data for the English and Welsh fishery were extracted from "Sea Fisheries Statistical Tables" and the Fisheries Activity Database of Defra. Scottish and Dutch data were taken from ICES catch statistics. Gaps in English and Welsh landings are due to missing data in the two world wars.

Plaice

During the study period, plaice landings remained low in Scotland. Catches were also small in the Dutch fishery until the mid-1960s, when new and increasingly powerful mechanized beam trawlers in the Dutch fishing fleet led to a marked increase in plaice landings. In the English fishery, plaice landings exceeded haddock landings after World War II and then remained relatively stable until they declined in the 1990s.

Some changes in the landings described here can be explained by biological abundance fluctuations (e.g. the gadoid outburst) or on a country level (e.g. the initial English lead in vessel technology or the later development of the powerful Dutch beam trawl fleet). However, additional factors for changes in landings such as the fleet development in each country (e.g. number and total engine power of vessels, gear developments), fishery regulations (e.g. introduction of total allowable catch) and eventual distribution changes (e.g. due to climate change) must be considered.

In the next phase of this study, questions to be investigated include: why were the English haddock landings so high at the beginning of the last century, why did they undergo such a marked decline before World War II, and why did landings remain low thereafter? On the other hand, why did Scottish haddock landings increase so substantially after World War II, exceeding those of the English fishery?

As well the different patterns in cod and plaice landings need to be studied in a historical context of developments in fisheries. However, to fully understand the described landings e.g. catch-per-unit-effort of each country has to be analysed; yet, these data are only available for England and Wales.

6.3 HMAP Mediterranean and the Black Sea project

Sasa Raicevich

Istituto Superiore per la Proteziona e la Ricerca Ambientale (ISPRA), Italy

6.3.1 Overview of the project

In the framework of the History of Marine Animal Populations (HMAP) Mediterranean and the Black Sea project (HMAP M&B), coordinated by Professor Ruthy Gertwagen, several initiatives attempted to reconstruct the history of fish and fisheries in the Mediterranean and the Black Sea. The detailed documentation and related publications are on the HMAP M&B website (http://hmapcoml.org/projects/m&b/), including information and updates on case studies development.

The different initiatives carried out in this framework included, among others:

- the I HMAP M&B International Workshop held in Barcelona (20–23 September 2004);
- the II HMAP M&B International Workshop entitled "Human-environment interactions in the Mediterranean Sea since the Roman period until the 19th century: an historical and ecological perspective on fishing activities" organized in Chioggia, Italy (27–29 September 2006), whose proceedings have been published by ISPRA (formerly ICRAM; Gertwagen, Raicevich, Fortibuoni, Giovanardi (Eds.), 2008);
- the International Workshop on "Nets and Fishing Gear in Classical Antiquity: A First Approach" – Cádiz, November 15–17, 2007 whose proceedings have been published as a Monographs of the Sagena Project (Bekker-Nielsen and Bernal Casasola Eds., 2010);
- the HMAP M&B International Summer School held in Trieste from 31 August–4 September 2009 entitled "When Humanities Meet Ecology: historical changes in Mediterranean and Black Sea marine biodiversity and ecosystems since Roman period until nowadays. Languages, methodologies and perspectives", whose proceedings are scheduled to be published by ISPRA within this year edited by Gertwagen, Fortibuoni. Giovanardi, Libralato, Solidoro and Raicevich (2010).

Moreover, a synthesis of present knowledge of the history of human-environment interactions in the Mediterranean Sea since pre-historical time, in particular fisheries, can be found in a paper that provides a review of work carried out in the framework of the Census of Marine Life in the Mediterranean Sea focused on "The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats" (Coll *et al.*, 2010).

6.3.2 Key findings from the Adriatic Sea case study

The analysis of the case study on history of fish and fisheries of the Adriatic Sea has been the target of direct research activities since 2004. In that year, two communications on the subject were presented during the first HMAP M&B workshop held in Barcelona. The communications presented a first attempt to reconstruct changes in fishing activities and landings over the period 1850–2000 in the Northern Adriatic Sea (Raicevich *et al.*, 2004), as well as the use of ecological modelling to describe the effects of fishing and other environmental drivers in the area (Libralato *et al.*, 2004). These studies highlighted the high potential of historical and scientific sources in the area, and received the attention of the HMAP project in order to support more in-depth research.

Historically, Chioggia was the port with the most important fishing fleet in the Adriatic Sea; a first activity was therefore dedicated to the description of fisheries and fishermen migration in this basin, from the 19th up to the early 20th Century. The analyses focused on fishing vessels and fishing gear adopted in marine fisheries, along with the biological, economical, ecological and political reasons that induced and allowed Chioggia's fishermen to migrate throughout the whole Adriatic Sea in order to exploit fishery resources (Botter *et al.*, 2006). According to the authors, fishermen migrated seasonally from the eastern to the western coastline of the Adriatic Sea, in order to follow the biological cycles (migrations) of most valuable fishery resources and to reduce the risk of shipwrecks. Chioggia's fishermen were considered very skilled, and adopted a wide range of fishing gears, including static and active gears, in particular otter trawl (with pair trawling) and fishing vessels, in particular the "bragozzo" a decked sailing vessel that replaced the formerly used "tartana" (a larger sailing fishing vessel) that was abandoned due to its higher construction costs and the larger number of fishermen to be enrolled for fishing. Notwithstanding the political differences and rule on the eastern and western coasts of the Adriatic, agreement between countries allowed Chioggia's fishermen to fish in the Eastern Countries (although they were not allowed to fish within 1 mile from land) and to sell the fish at the local markets (Botter *et al.*, 2006).

Regarding the catches, preliminary analyses of landings data showed the presence of a possible decline in the mean trophic level over the whole 20th Century (Raicevich *et al.*, 2005) with a reduction in the percentage and absolute presence of elasmobranchs. However, the limited data available did not allow presenting a comprehensive picture on this subject as well as on the development of fisheries in the area.

Moreover, prior to the early 20th Century, little quantitative data were available to describe former abundance in marine species; therefore, reconstruction of previous abundances of marine species was not straightforward. Accordingly Raicevich *et al.* (2004; 2008) suggested that the use of naturalists' descriptions might contribute at least to derive information on previous fish abundance in the area, since many naturalists' descriptions were available since the early 19th Century. In this framework, semi-quantitative information on the perceived abundance of shark species from 1820 to 1998 was compared based on naturalists' records and trawl survey data.

The history of fish and fisheries in the northern Adriatic Sea and Venice Lagoon was further investigated in the framework of a research entitled "Fisheries in the Adriatic Sea from the fall of the Serenissima up to nowadays, an historical and ecological approach" funded by the Regione Veneto (Italy) and Associazione Tegnue di Chioggia that, in particular, included a grant for PhD co-funded by HMAP that was enforced in 2007 and accomplished by Tomaso Fortibuoni (Fortibuoni, 2010).

In the framework of this project, the history of fisheries in the Adriatic Sea was reconstructed taking into account technological changes of fishing gear and fishing vessels over time, both in the eastern and western sides of the Adriatic, including the Venice Lagoon (Fortibuoni *et al.*, 2008a). The research was based on collections and analyses of historical, scientific and grey literature sources in many archives and libraries both in Italy and Croatia (Fortibuoni, 2009; 2010). The results highlighted that most of the technological changes in the area, that in turn affected the fishing capacity, effort and power of the fishing fleet where accomplished immediately after the Second World War. This included the spread of the motor engine (although a first experiment of using such technology was carried out in 1912 and after the First World War some fishing vessels had adopted it), the consequent change in fishing vessel features (the shift from traditional sailing fishing vessels to modern motorized ones) and new technologies (including the use of further mechanical devices, freezers, and radar; Bullo *et al.*, 2009; Fortibuoni *et al.*, 2009a,b; Fortibuoni, 2010). Moreover, further increase in fishing power was observed with the adoption of midwater pelagic trawls, rapido trawls, modern otter trawls and hydraulic dredges, which became increaseingly widely used in the area more recently (Bullo *et al.*, 2009; Fortibuoni *et al.*, 2009a,b; Fortibuoni, 2010).

With regards to historical changes in the fish community in the area, this issue was investigated by integrating information provided by early naturalists with landings data for the period 1800–2000 (Fortibuoni *et al.*, 2008b; Fortibuoni *et al.*, 2010). In particular, a new method was developed to code early naturalists' accounts (1800–1950) on a semi-quantitative scale that was intercalibrated with landings data (1875–2000). This allowed the reconstruction of a time-series spanning two centuries on fish community structure indicators in the investigated area.

This approach enabled to highlight that the structure of the fish community was subject to relevant changes, with a significant decrease in the perceived percentage abundance of elasmobranchs as well as large-sized and slow-growing species over time (Fortibuoni *et al.*, 2010). Moreover, these changes were recorded even before the onset of industrial fishery, pointing to an early effect of this driving force at fish community level. However, the study did not allow to disentangle the different effects on fish community structure from other driving forces (e.g. eutrophication and benthic anoxia, habitat disruption, climate change) that are likely to have affected the investigated ecosystems, especially since the middle of the 20th Century (Fortibuoni *et al.*, 2010). It is worth noting that this research also provides a useful methodology to integrate qualitative historical records with modern records, which might be used in further historical ecology studies to extend backwards in the past the analysis of ecological changes in marine communities.

6.4 Historical reconstruction of trawl fishing effort in the North-western Mediterranean

Chato Osio

Centro Intruniversitario di Biologia Marina (CIBM), Livorno, Italy
University of New Hampshire, Durham, USA

Understanding the duration and intensity of human exploitation of demersal marine resources is an important key to identifying when the resources were in a virgin and unexploited state. In addition, from the history of fishery development, which is ultimately a proxy for fishing pressure and fishing mortality rates, and fluctuations in the stocks we can infer past responses to human exploitation and the potential for recovery. The goal here was to quantify vessel growth rates, HP growth rates, and expansion of fishing grounds over the past 300 years to understand changes in fishing pressure. Different sources of historical data were collected for Italy, France, Spain and Tunisia with the first quantitative record of trawling dating back as far as 1634. The first vessels capable of trawling at the time were single sail trawlers towing a net while drifting sideways. These trawlers operated, depending on the areas, between 1600 and the early 1800s and were substituted by more efficient pair sail trawlers in most areas of the NW Mediterranean by the 18th Century. The beginning of the 20th Century saw the technical competition of steam, sail and motor trawlers, which by the 1930s was clearly won by motor trawlers. After WWII the motor trawl fleets rapidly expanded numerically, in vessel HP and in fishing power.

After WWII there was a rapid expansion of motor trawl fleets in number of vessels that peaked in the 1980s. The major increase of vessel engine power began in the 1960s, and has still not reached its peak. The fishing effort evolution seems comparable in France, Italy and Spain while for other countries less data are available to reconstruct the temporal evolution of trawling.

The historical trawling effort shows that the Mediterranean demersal communities underwent a much longer and systematic exploitation than previously thought. All fishing effort between 1600 and 1900 was on waters shallower than 100 m and likely the impact on nearshore fish communities was already high before the development of motorized trawling.

Figure 10. *Bragozzo* sail trawler in Venice Lagoon, ca. 1880. The net can be seen hanging between the two masts.

Since the onset of trawling almost 400 years ago there has been strong criticism from within the fishing community as well as from scientists, of the non-selectivity and habitat damage caused by trawling as many authors report. In the past this has led to sequential short-term bans of trawling in various countries. Nevertheless, over the last century trawling has been accepted and has become the dominant fishing gear.

The numbers are striking, with changes in the number of vessels of 2 or more orders of magnitude and of course the shift from sail to motor vessels. This means that the coastal ecosystems have been impacted at least since the 17th Century. In general, the analysis of the data available for the Catalonian, Italian and French areas showed a clear emerging pattern: fishing capacity increased in Mediterranean EU countries up to and through the 20th Century until the 1980s. From that period on, the fleet size has been decreasing steadily, as a result of different national and European decommissioning programs. It is unclear, however, whether this decrease in vessel numbers in the last 20 years has been accompanied by a decrease in fishing power and fishing mortality on the stocks because engine power is usually underestimated in the entire region and fishing technology has much improved over the last decades.

Figure 11. Two *Bragozzi*, pair trawling in the Adriatic during the early 1900s.

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Annex 1: List of participants

Name	Address	Phone/Fax	Email
Georg H. Engelhard (**Chair**)	Centre for Environment, Fisheries & Aquaculture Science (Cefas), Pakefield Road, Lowestoft NR33 0HT, UK	+44 1502 527747	georg.engelhard@cefas.co.uk
Bo Poulsen (**Chair**)	Roskilde University, Universitetsvej 1, building 03.2.2, DK-4000 Roskilde, Denmark	+45 2058 2859	bopo@ruc.dk
Massimilano Cardinale	Institute of Marine Research, Swedish Board of Fisheries, PO Box 4, SE-453 21, Lysekil, Sweden	+46 730 342209	massimilano.cardinale@fiskeriverket.se
Paolo Sartur	Centro Intruniversitario di Biologia Marina (CIBM), Viale Nazario 4, 57128 Livorno, Italy	+39 058 6260723	psartur@cibm.it
Sasa Raicevich	Istituto Superiore per la Proteziona e la Ricerca Ambientale (ISPRA), Italy		sasa.raicevich@isprambiente.it
Sidney J. Holt	Voc. Palazzetta 68, Paciano (PG), 06060 Italy	+39 075 830 7035	sidneyholt@mac.com
Emily Klein	University of New Hampshire, 8 College Road, Durham NH 03824, USA	+1 603 8623213	emily.klein@unh.edu
Tina K. Kerby	School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK	+44 1603 591383	t.kerby@uea.ac.uk
Christopher P. Lynam	Centre for Environment, Fisheries & Aquaculture Science (Cefas), Pakefield Road, Lowestoft NR33 0HT, UK	+44 1502 524514	chris.lynam@cefas.co.uk
Giacomo Chato Osio	University of New Hampshire, 39 College Road, 3824 Durham, USA		chatoosio@gmail.com

Annex 2: Agenda

Place: **Hotel Ortensia, Ponza Island, Lazio, Italy**

Monday 11 October

Day	Participants travel to ferry port in Formia, Lazio
Evening	Participants meet on ferry from Formia to Ponza Island, welcome by host upon arrival

Tuesday 12 October

9:00–9:45	Start of meeting, welcome by hosts
9:45–12:00	Presentations providing research updates on history of fish and fisheries (15 min, with 5 min discussion)
13:00–17:30	Methodology Workshop I: Estimating long-term fishing power change

Wednesday 13 October

9:00–10:00	Research updates talks about fish distribution shifts
10:00–17:30	Methodology Workshop II: Accounting for spatio-temporal dynamics/distribution shifts
Evening	Dinner together

Thursday 14 October

9:00–12:30	Discussion on further opportunities for collaborative research, continuation of Methodology Workshops I and II where needed
14:00–17:30	Work on draft Study Group report
Late afternoon	Optional excursion

Friday 15 October

Participants travel home.

Annex 3: SGHIST terms of reference for the next meeting

The **Study Group on the History of Fish and Fisheries** (SGHIST), chaired by Bo Poulsen, Denmark and Georg Engelhard, UK, will meet at Paciano, Italy, 24–27 October 2011*) to:

a) Coordinate data recovery activities for historical information on fish, fisheries and marine ecosystems;

b) Discuss and report on long-term dynamics of fishing fleets and fishing technologies, including methods for estimation of technological creeping;

c) Discuss and report on research linking climate change and dynamics of fish populations from historical data;

d) Present case studies on history of fish and fisheries representing both sides of the Atlantic and the Mediterranean.

**) The exact dates still need to be confirmed.*

SGHIST will report by 24 December 2011 (via SSGSUE) to the attention of SCICOM.

Supporting Information

Priority	The activities of this Group will improve the understanding of the long-term changes in fish stocks productivity and structure of the marine ecosystems. Consequently these activities are considered to have a high priority.
Scientific justification	There is growing interest in historical data on fish and fisheries and the past marine ecosystem in general. The interest is on the discovery, recovery, digitization and analysis of historical data. The analyses of historical data are expected to give insight in long-term historical trends in fish stocks and fisheries which can be related to exploitation and long-term changes of the marine environment. The work links to the History of Marine Animal Populations project that is funded under the Census of Marine Life and which aims to discover historical data sources. Several fisheries research institutes in Europe have started to make inventories of historical information and the meeting is intended to bring these initiatives together. SGHIST 2009 and 2010 have recommended that a project should be set up to recover the historical information that has been collected by marine research institutions and zoological museums around the North Atlantic and the Mediterranean. SGHIST will oversee that project. SGHIST will link with methodological experts to advance the methodologies for analysing historical data including methods for using meta-information from different areas. SGHIST will attempt to disentangle the effects of climate change, fisheries and other potential drivers on fish population dynamics.
Resource requirements	No specific requirements.
Participants	The Group should be attended by some 15 members and guests. Attendance from the Mediterranean countries is foreseen.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	Linked to ICES proposal for the digitization, analysis and interpretation of plankton data for pre-1914 ICES sampling in the North Sea and adjacent waters.
Linkages to other committees or groups	Relevant to the Working Group on Ecosystem Effects of Fisheries and the groups of the Fisheries Technology Committee.

Linkages to other organizations	The work of this group is closely aligned with similar work in FAO and in the Census of Marine Life Programme.