Combining the Biocean database for deep-sea benthic data with the online Ocean Biogeographic Information System

Marie-Claire Fabri[1,*], Joëlle Galéron[1], Michel Larour[2], Gilbert Maudire[2]

[1]Département Etude des Ecosystèmes Profonds, Ifremer Brest, BP 70, 29280 Plouzané, France
[2]Département Informatique et Données Marines, Ifremer Brest, BP 70, 29280 Plouzané, France

ABSTRACT: The Biocean database was designed to collate the extremely large volume of data collected from different deep-sea ecosystem studies conducted by Ifremer's department of 'Environnement Profond' (Deep-Sea Environment). This database comes in a 6-application package: 2 of them are used on research vessels to collect operational data, whereas the others are used to link with a core database back on land. The latter are used to: (1) manage taxonomic nomenclature, (2) monitor the identification of faunal collections, (3) fill in chemical analyses results or measurement data files and (4) add or extract data from the database. Biocean was designed to facilitate ecosystem studies in the deep sea. It represents an important new resource for deep-sea ecologists and will have wide applications in biogeography and biodiversity studies at Ifremer, but also for the international community, as faunal data are linked to the Census of Marine Life information system OBIS (Ocean Biogeographic Information System). Biogeographical analyses of Biocean data recovered through the OBIS portal evidence an evolution in the deep-sea sampling strategies more focused in limited areas and is intended to reveal ecosystems functioning.

KEY WORDS: Data management · Deep-sea ecosystems · Biogeography · Taxonomy · Benthos · Biodiversity · Environmental parameters

INTRODUCTION

The deep-sea environment covers 65 % of the Earth's surface and remains, for the most part, unexplored. It is characterised by very low temperature, extraordinarily high pressure and low food availability. Despite such harsh environmental conditions, the deep sea harbours generally very high levels of biodiversity (Bouchet 2000). Extrapolations from quantitative samples taken on the North Atlantic Slope and Rise suggest that there may be up to 10 million deep-sea species (Grassle & Maciolek 1992). In contrast, only 274 000 species have been taxonomically described from the entire marine environment (Bouchet et al. 2002). The discovery of hydrothermal vents in 1977, off the Galapagos Islands (Lonsdale 1977), and the discovery of cold-seep organisms on passive margins (Paull et al. 1984) have brought new knowledge of the deep sea, with these ecosystems characterised by high biomass and relatively low diversity.

Over the past 30 yr, huge numbers of samples have been collected on deep-sea cruises dedicated to benthic community studies. These faunal samples are usually sieved through a series of mesh sizes and separated into taxonomic groups at the phylum, class, or order level before being dispatched to taxonomists for identification at the most precise taxonomic level. The occurrence of species that are new to science is very frequent. Species-level identification and taxonomic description may take 5 to 10 yr after a cruise. The Biocean database was created to help manage the several steps between sampling and species identification.

The deep-sea environment can also be characterised by very strong habitat gradients and close links be-

tween species distribution and physical or chemical parameters. For example, chemosynthetic communities (such as those found at hydrothermal vents or cold seeps) live in fragmented ecosystems distributed either along ocean ridges or on active or passive margins (Sibuet & Olu 1998, Desbruyères et al. 2000). The environmental factors characterising these ecosystems represent a wide range of data, which can be stored in the Biocean database alongside faunal data.

The study of isolated communities in the deep ocean requires the use of research submersibles or remotely operated vehicles (ROVs) that are used, among other things, to capture digital pictures of *in situ* communities. These pictures represent an important information source that can be coupled to faunal identification, physical and chemical factors, as well as geographical positions. These images include crucial ecological information that is useful for habitat description, or to study species distribution and interspecific relationships.

All these data are central for ecological studies and constitute a unique resource that must be organised and permanently archived. The goals of the Biocean database are: (1) collection of operational data from research cruises, (2) organisation of faunal and environmental data in a standardised form and (3) preservation of data for studies of long-term temporal changes.

An additional goal of the Biocean project is to link with other meta-databases that collect biological information at larger scales, for example, those dedicated to biodiversity assessment (e.g. the Ocean Biogeographic Information System [OBIS]; Grassle & Stocks 1999, Grassle 2000) or global networks such as the Global Biological Information System (Edwards et al. 2000).

This paper describes in detail the development and uses of the Biocean database. Examples are provided of how Biocean data can be retrieved through the OBIS web portal and used for biogeographical studies.

MATERIALS AND METHODS

State of the art. At Ifremer's department of 'Environnement Profond', the first step towards a synthetic storage approach for biological data was the creation of a 15-table database designed in 1984. This first database was a compilation of faunal samples collected with classical oceanographic equipments, for example corers, trawls and dredges. Data collated before 1990 were compiled in this database, but neither environmental variables nor submersible data (video stills, photographs and accurate sampling positions) could be associated with faunal observations.

In 1995 a new conceptual database model was created at Ifremer. As requested by scientists, the original biological database was extended to include associated deep-sea environmental variables in a standardised form, as well as images, which have been considered an extremely valuable source of scientific information. The design and building of the Biocean database started in 1996. This crucial step was completed within a year, resulting in 56 relational tables, developed under Oracle 8i. This formed the Biocean core database.

Biocean package. The Biocean package consists of the core database, updated with a suite of applications that manage cruise and dive logs, biological samples and taxonomic names (Fig. 1).

Core database: Within the core database, tables can be considered as 1 of 3 types (Fig. 2). Metadata, for example cruise name, ship name, submersible name and dive number, are listed in the metadata tables. Reference tables list equipment, geographical locations, taxonomic specialists and faunal taxonomy, ecology and natural history observations. These data are accessed through pick-lists. Faunal, chemical and physical factors are stored in result tables. The complete relational database schema is available on the website www.ifremer.fr/isi/biocean/acces_gb/core_database_en.htm.

'Alamer' ('A la mer' or 'At sea') applications: Two 'Alamer' applications are specifically designed to collect metadata while at sea. 'Alamer' can store operations chronologically, either during a cruise or a dive. These applications incorporate pick-lists and pull-down menus that facilitate the entry and storage of key metadata in a rapid and standardised way. 'Alamer' software is designed to reference data both geographically and temporally, which is crucial for the understanding and analysis of data.

'Alamer Campagne (cruise)' collects information about the cruise itself and all the operations carried out on board. Operational data and geographical coordinates can be read in the electronic logbook, and general information, e.g. geographical region, ship navigation file, scientist name, equipment name and sample description, can also be added.

The application 'Alamer Plongée (dive)' creates a chronological report for each dive. General data, such as the geographic coordinate system (map datum), sampling and measuring equipment and the name of scientists on watch, are included. It picks up geographical coordinates directly from the submersible navigation file. Submersible data are still problematic because of the lack of accuracy of absolute geographical positioning, depending on the depth and position of the studied area. To alleviate this problem, markers are disposed on the bottom and their names are used to precisely define locations. In addition, video stills can be selected, either in real time for ROVs, e.g. ROV
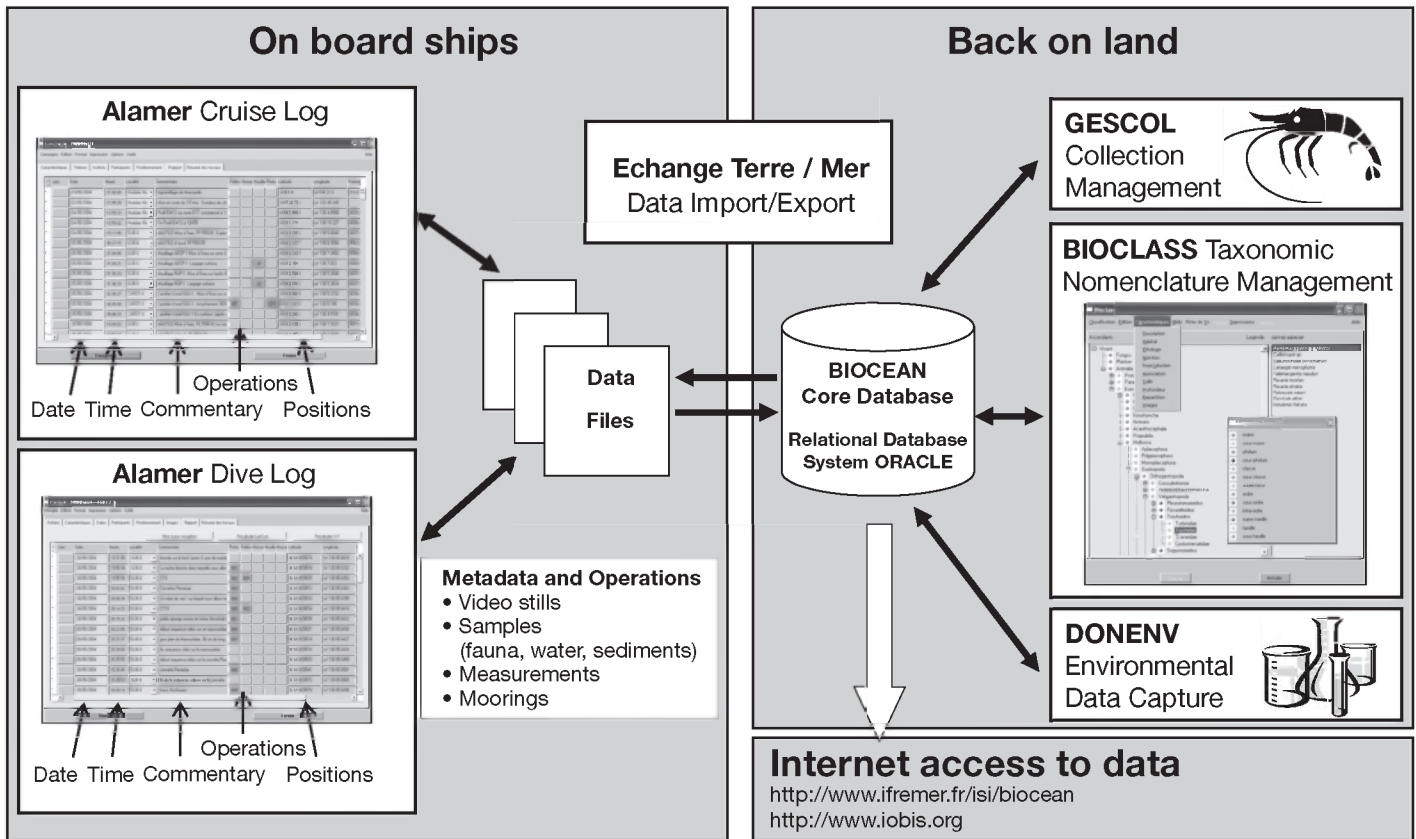
Fig. 1. Organisation of the Biocean application. The 2 Alamer applications are designed for data input directly on board research vessels, without a link to the core database. Echange Terre-Mer permits data exchange between Alamer files and the Biocean core database. Gescol follows faunal samples through their identification process. Bioclass helps to manage the taxonomic nomenclature. Donenv manages results of environmental analyses (e.g. temperature, chemistry)

'Victor', or during dive post-treatment for manned submersibles, e.g. 'Nautile'. Digital pictures are becoming essential to deep-sea ecological studies, and provide an alternative to traditional sampling methods that can potentially impact smaller fragmented habitats with low stability and resilience.

The 'Alamer' applications constitute the data input interface. The chronological reports can be enriched with event descriptions, including specific operations, such as a sediment core or water sample. Data resulting from *in situ* chemical analyses may be entered through a specific user interface, with appropriate fields for analytical method and the variable corresponding to the measured factor. Descriptions of faunal samples include names of the taxa sorted on board ship, type of preservation, sample holder name and number of individuals collected.
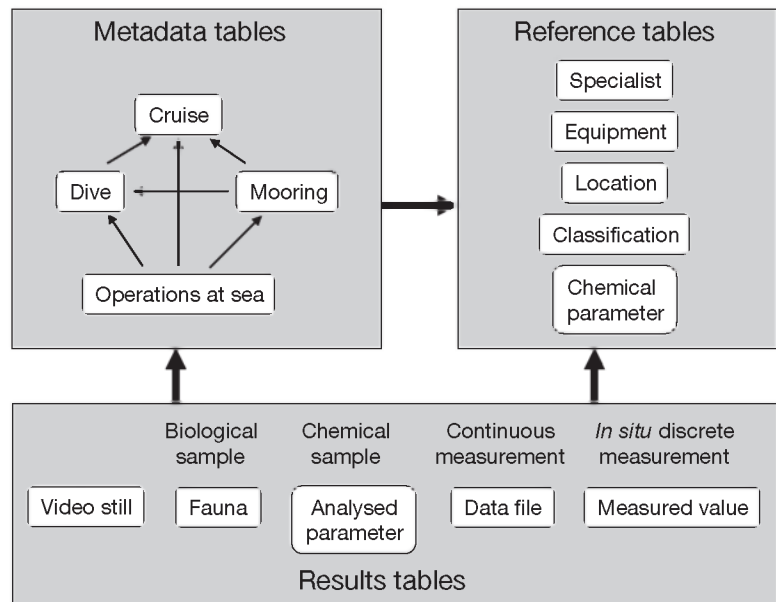

Fig. 2. Main tables of the entity relationship model of the Biocean database. See www.ifremer.fr/isi/biocean/acces_gb/core_database_en.htm for a complete relational database schema

In order to preserve the integrity of the original core Biocean database, and since more than 1 Ifremer oceanographic cruise may be occurring at the same time, all the data gathered by the Alamer applications are saved in separate files at sea. Once these data are received back on land, they can be uploaded to the core database.

'Echange Terre-Mer' application: 'Echange Terre-Mer' is the link between Alamer files and the core database. It helps to control the integrity of newly collected data before they are automatically uploaded to the database. It is used exclusively by the database administrator. This application can also be used to extract data in files for visualisation in Alamer applications.

'Bioclass' application: 'Bioclass' is a taxonomic management system that assigns codes to species or higher taxa (family, order, class, phylum). It acts as a file management system and provides a hierarchical representation of taxa. Faunal records are accompanied by a reference to the original species description and by a variety of key words related to its biology, e.g. habitat, nutrition, behaviour, reproduction and distribution.

'Gescol' application: 'Gescol' is a collection management system used to keep track of faunal samples from their collection to their identification. At sea, and in the laboratory immediately after the cruise, samples are initially divided into higher taxonomic groups (phylum, class, order). After this, they are dispatched to taxonomists and sequentially identified to the most precise level, i.e. specific level when possible. The Biocean core database is regularly updated until an accurate faunal description is obtained. 'Gescol' is also used to maintain and update a contact list of taxonomists working on deep-sea specimens.

'Donenv' application: 'Donenv' is dedicated to the data capture of chemical analysis results and data files corresponding to water or particle samples and physical measurements. These environmental parameters are stored alongside the corresponding faunal data.

Biocean products. *'Alamer' reports:* Individual cruise and dive reports are generated on ship, directly from 'Alamer'. They are used to share information among cruise participants and to convey initial results to scientists and institutions involved in the cruise. In addition, 'Alamer' reports include a list of operations, as well as samples and measurements, that are easily incorporated into geographical information systems (GIS). The video stills and photographs captured by submersibles are readily available for inclusion in the electronic chronological dive reports. 'Alamer' reports can provide complete documentation for each particular cruise; they are available from the website www.ifremer.fr/isi/biocean.

Core database reports: Data collected on past cruises are accessible from the core database, and may be used for ecological studies, or as references in cruise planning, when lists of moorings, markers and previous operations are required. The geographical distribution of a taxon may be retrieved from the database in tabular form, with information about the cruise (equipment, date, depth, position) and the number of individuals collected. This may be restricted to a particular station, to a specific oceanic region, or to a defined geographical area. A list of the taxa collected at a specific location can be obtained, and may be used to compare benthic faunal associations from different geographical areas. Measured physical and chemical factors can also be extracted from the database. For example, specific queries could include a list of oxygen measurements at a particular location. The mix of physical and chemical variables alongside faunal lists at a particular geographical location facilitates interdisciplinary studies that aim to understand the functioning of ecosystems.

Collection management: The 'Gescol' collection management application facilitates the generation of reports as to the whereabouts of faunal samples, and allows continuous updates regarding the level of taxonomic information (for example, from a collected new species to a published description).

Ecological data: Ecological data is managed through the 'Bioclass' application. Habitat, life-history, feeding ecology, behaviour, size ranges, associations, depth, geographical distribution, morphology (drawings and images) and taxa description can be edited and uploaded to the core database.

Technical design. The Biocean database was designed to gather together all data related to deep-sea ecology from Ifremer cruises: biological, physical and chemical. Because digital images are considered scientific data, they are stored together with the rest.

The fundamental objective that influenced the entire design of the database was an attempt to catalogue all the biological samples collected on each cruise; the process includes recording metadata on samples as soon as they are collated and recording the fate of each individual in the sample until its final identification many years later. According to the same scheme, metadata on environmental parameters are collated on board the ship and scientific data are filled in after being analysed.

These requirements have led to separate functions according to the parties involved; bilingual 'Alamer' applications are used on board by scientists from any country for the metadata collection, faunal identification and taxonomic nomenclature are followed by biologists using 'Gescol' and 'Bioclass', chemists and physicists enter water analyses and measured para-

meters into 'Donenv' and the database administrator's tool for core database manipulations is 'Echange Terre-Mer'.

'Alamer' applications are user-friendly; they provide menus extracted from the core database and adapted to the cruise objectives, e.g. location lists, mooring lists, or lists of faunal groups likely to be encountered, recovered, or recognised. These menus, prepared before each cruise, allow scientists to benefit from the knowledge acquired from previous cruises at the same location.

The Biocean package is considered a multimedia tool, as video stills and digital images are used as scientific data, particularly when a submersible is exploring the deep sea. The multimedia function is also used for species description in the 'Bioclass' application.

Hardware configuration. The 6 applications within the Biocean package are designed to run on personal computers under a Windows interface. Database access is possible through ODBC links. The Biocean database is held on a Unix machine under the Relational Database System (RDBS) Oracle. It is secured by an overall backup every week on magnetic cartridges (DLT), with copies conserved in separate buildings.

Recovering data. Biogeographical analyses were performed on all the Biocean data recovered through the OBIS portal. Scientific name, latitude, longitude, maximum depth and citation fields were used. Information on cruises is held in the citation field. The initial matrix was composed of 3136 species and 65 cruises.

As species occurrence in the data matrix depends on the sampling effort; data were transformed into presence or absence of each species on each cruise.

A preliminary dendrogram for hierarchical clustering of all cruises, using group-average linking, based on the Bray-Curtis similarity matrix, isolated a group of 14 cruises the only shared feature of which was a very low number of species (<15). These were either recent cruises for which taxonomists had not yet identified the species, or cruises during which few specimens were collected and were omitted from the following analyses. The working matrix was composed of 3136 species and 51 cruises.

Statistical analyses were performed using PRIMER (Plymouth Routines in Multivariate Ecological Research, Ver. 5, Clarke & Warwick 2001).

RESULTS

Database content

The Biocean database contains data covering 30 yr of French deep-sea oceanographic research and includes 86 cruises, 285 dives and 442 moorings. Cruises are mainly distributed in the eastern part of the Atlantic Ocean (Fig. 3). All samples and measurements from these cruises are geographically referenced.

Metadata for each cruise are available at www.ifremer.fr/isi/biocean. They are displayed as cruise
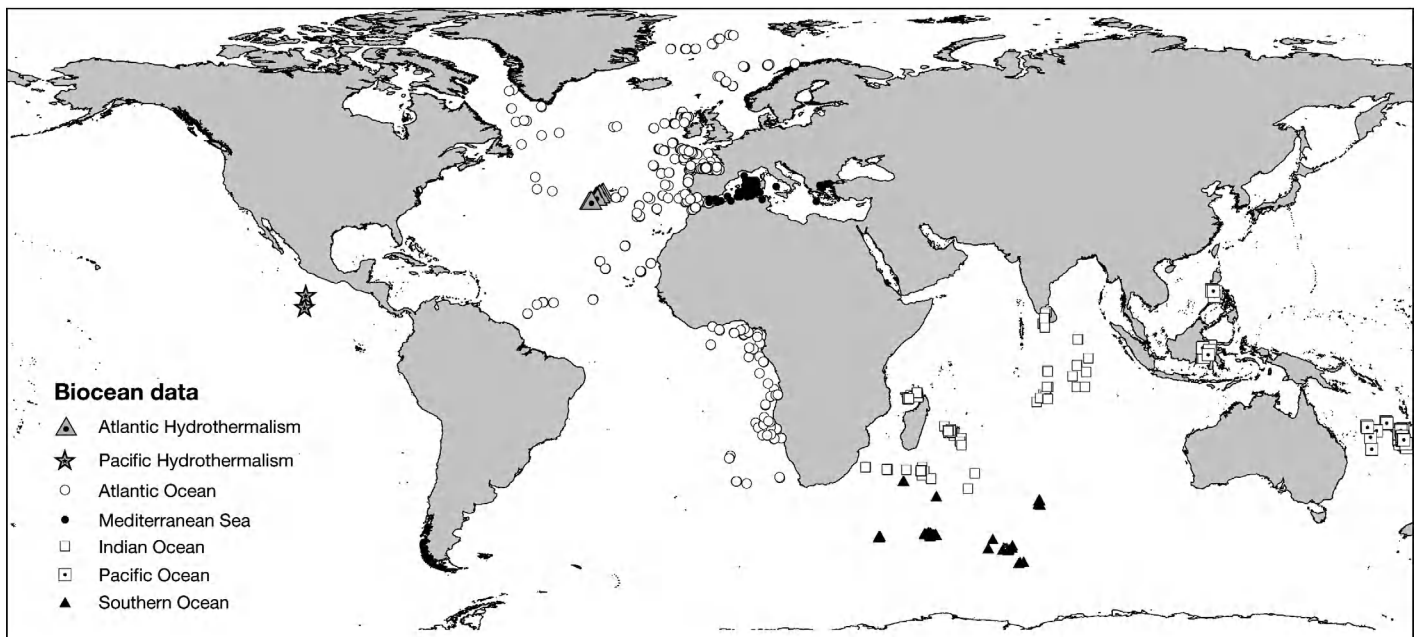

Fig. 3. Distribution map of deep-sea benthic faunal data stored in the Biocean core database and available through the Ocean Biogeographic Information System (OBIS) portal

and dive logs. Biogeographical data are available through the OBIS portal (www.iobis.org).

Database context

Ecological studies in the deep sea are focused on the structure of benthic communities and their spatial and temporal variations. Biocean holds 4 types of ecosystem data: (1) benthic sedimentary ecosystems, which depend on energetic contributions from photosynthetic production in euphotic layers and (2) deep-sea hydrothermal ecosystems on oceanic ridges, which are based on chemosynthetic bacterial production. Life in this habitat is very unusual, luxuriant and adapted to a toxic and unstable environment. There are also: (3) ecosystems associated with cold seeps on continental margins, which are based on chemosynthetic production from methane-rich fluids. These ecosystems are characterised by high biomass. And finally Biocean contains data on: (4) deep coral reefs, which have been discovered on carbonate mounds on the Irish continental margin. Active mound genesis is due to intense coral growth.

The last 2 ecosystems have been topics of recent studies at Ifremer. Species identifications are not complete, and data are consequently not yet available through the OBIS portal.

Biogeographical analyses of Biocean data

Ordination of cruises in the working matrix

The aim of ordination was to display the biological relationships among the 51 cruises. Similarities between cruises based on species presence or absence are given by the Bray-Curtis similarity coefficients. The ordination maps cruises in 2 dimensions, along which the placement of cruises reflects the similarities of their biological communities. A non-metric, multi-dimensional scaling (MDS) plot was produced by PRIMER (Fig. 4). A stress value of 0.12 was derived by statistical processing. As it is close to 0.10, it indicates good ordination. A cross-check against the results of hierarchical classification was made by superimposition of the groups having 10% similarities, corresponding to the major ocean areas. Interpretation of the cruise ordination leads to the 7 clusters that appear in the figure. The Atlantic Ocean is such a compact group, apart from the hydrothermal-vent cruises, that it is discussed separately below.

The Balgim 84 cruise took place in the Straits of Gibraltar. The Straits of Gibraltar show a species composition of either Atlantic (for epibenthic crustaceans; Abello et al. 2002) or Mediterranean affinity (for Bivalvia; Salas 1995), depending on the taxonomical
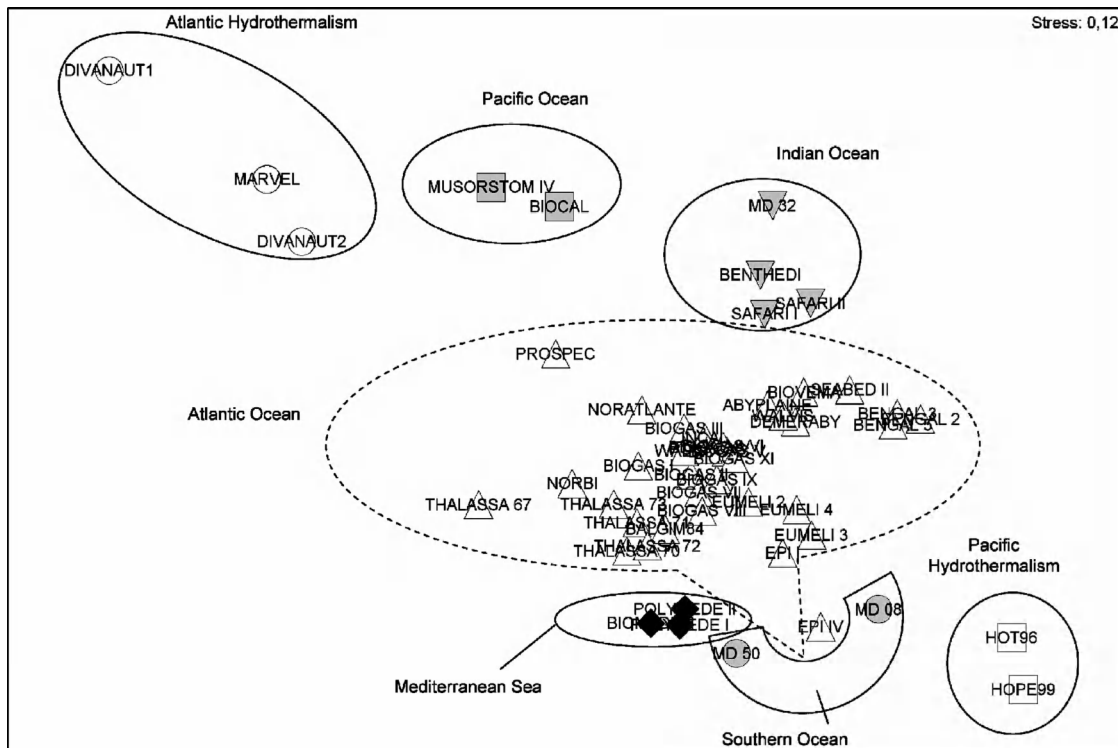

Fig. 4. Ordination plot of cruises in the working matrix. The multi-dimensional scaling (MDS) was constructed from Bray-Curtis similarity coefficients of the presence or absence of species on each cruise
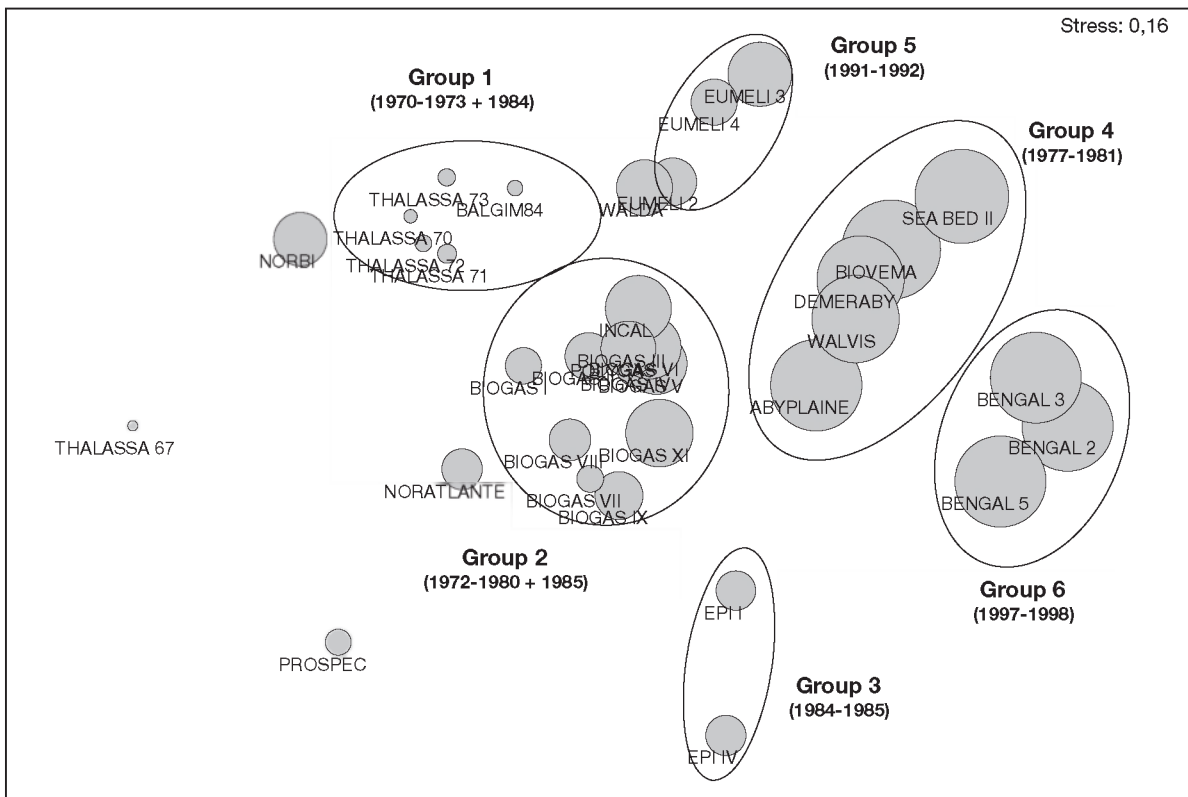
Fig. 5. MDS ordination of Atlantic cruises stored in the Biocean database. Bray-Curtis similarity coefficients of species presence or absence were used for the ordination. Clusters formed at the 15% similarity level and mean depth as circles of differing sizes were superimposed on the MDS plot

group considered. MDS ordination groups the Balgim 84 cruise and Atlantic cruises, suggesting that biological samples from the Straits of Gibraltar are composed mainly of Atlantic species.

Ordination of Atlantic cruises stored in the Biocean database

The cluster of 35 non-hydrothermal Atlantic cruises was analysed with Bray-Curtis similarity coefficients as above and MDS ordination. A stress value of 0.16 gives a potentially useful 2-dimensional picture. A cross-check against the results of hierarchical classification was made by superimposition of the groups having 15% similarities. The dendrogram suggested a division of the cruises into 6 main clusters and 5 isolated cruises. For each of the cruises, 8 abiotic variables obtained through the OBIS portal were calculated: mean depth, mean latitude, mean longitude, their standard deviations, year and number of species.

The selection of the abiotic-variable subset maximising rank correlation between biotic and abiotic similarity matrices was conducted with the BVSTEP procedure of PRIMER software (Clarke & Warwick 2001).

The best 2-variable combination involved the mean depth and the year of the cruise. The Spearman rank correlation coefficient ($r = 0.65$; $p < 0.001$) gave a significant result. The most graphic representation of the result involved superimposing the mean depth on the biotic ordination as circles of differing sizes depending on the value (Fig. 5). The distribution of groups and isolated cruises in the Atlantic Ocean were mapped for better interpretation (Fig. 6).

Group 1 included cruises (1970 to 1973 and 1984) representative of the bathyal zone, with mean depths between 700 and 1000 m. Samples from these cruises were all from the top of the continental slope of the NE Atlantic, including the Straits of Gibraltar.

Group 2 included cruises carried out in the NE Atlantic during 8 yr (1972 to 1980 and 1985), at mean depths of around 2500 m and high depth variation, representing the bottom part of the continental slope.

Group 3 included the 2 Epi cruises (1984 to 1985), which were expected to cluster with Group 2 as they sampled the same location in the Bay of Biscay. The reason for their isolation was probably the very low number of species identified from these cruises; the Epi programme dealt with faunal-group densities, and few species were identified.
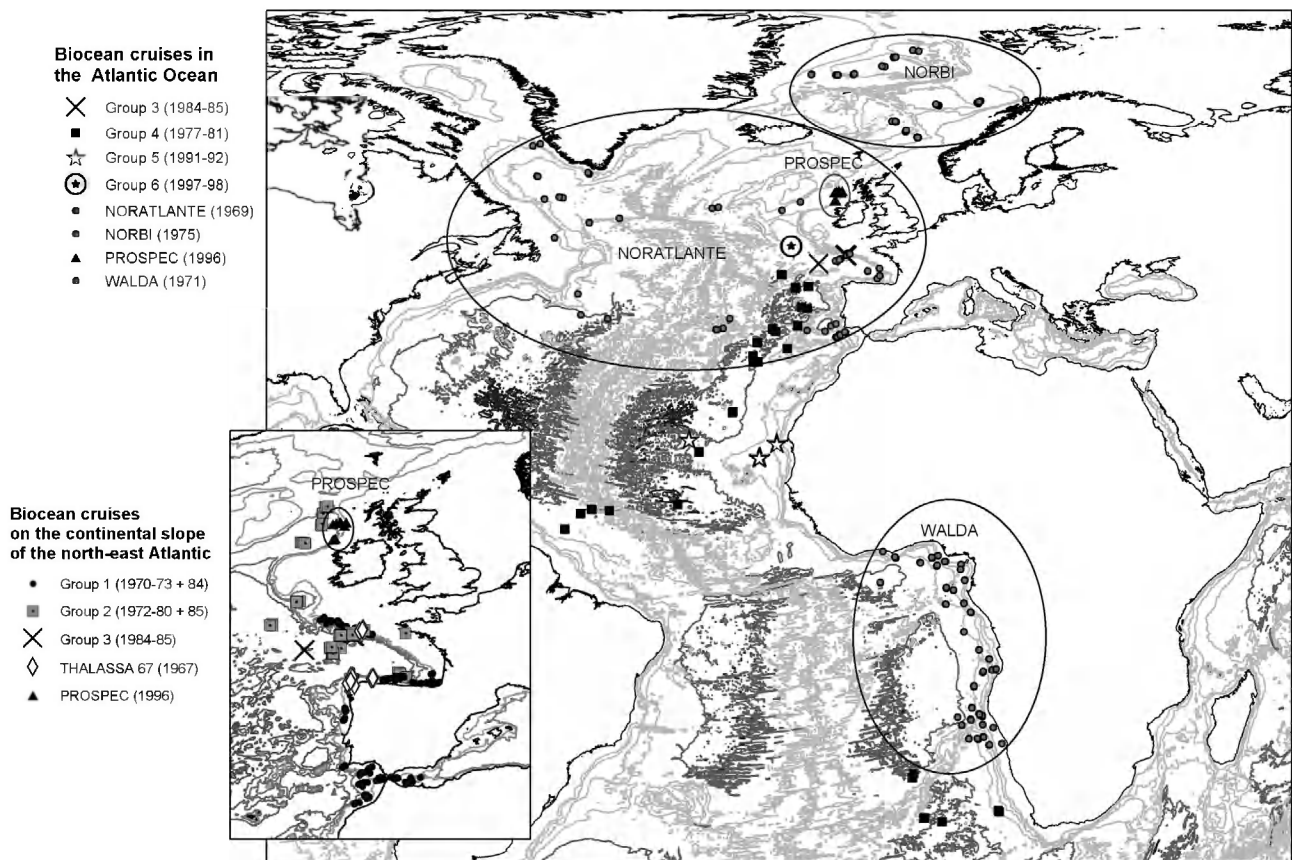
Fig. 6. Distribution map of Atlantic cruise sampling points stored in the Biocean database. Cruises are grouped with Bray-Curtis similarity coefficients based on species presence or absence

Group 4 included Atlantic cruises (1977 to 1981) that were explorations of the deep sea (4800 m), at a wide variety of latitudes and longitudes.

Group 5 included 3 Eumeli cruises (1991 to 1992) that sampled the abyssal plain in a study of the influence of particulate fluxes at 3 sites designated eutrophe (1800 m), mesotrophe (3000 m) and oligotrophe (4500 m), located near one another.

Group 6 was composed of the 3 Bengal cruises (1997 to 1998), which sampled the same point on the Porcupine Plain, characterised by a great and constant depth (4800 m). Their goal was to study seasonal effects on benthic fauna.

The 5 isolated cruises have extreme characteristics. Thalassa 67 (1967) is the shallowest cruise of the Biocean database and the oldest one. It sampled the very top part of the continental slope. Noratlante (1969) has the greatest variation in depth, as well as in latitude. It covered the eastern and western part of the North Atlantic Ocean. Walda (1971) extended along the whole west coast of South Africa, and represents the largest variation in longitude. Norbi (1975) covered in the deep Norwegian Sea, north of the threshold of Rockall. Thresholds usually create natural geographical barriers

and therefore separate distinct faunal groups. Prospec (1996) is also geographically different from all of the other cruises. It studied deep-sea fishery resources on the continental slope north-west of Ireland. Species were not identified for all taxonomic groups.

DISCUSSION

Biocean package

The Biocean package and the database that is acquired, managed and archived with it were designed to optimise the organisation and accessibility of metadata, reference lists and results from shipboard sampling and shore-based analysis of marine faunas and environments. The experiences of other institutions that have developed data-management systems with similar objectives were taken into account during design. The Video Annotation and Reference System (VARS) is a software interface and database system that provides tools for describing, cataloguing, retrieving and viewing the visual, descriptive and quantitative data associated with MBARI's deep-sea video archives (www.

mbari.org/vars/vars_overview.html). The 'Alamer Plongée (dive)' and 'Bioclass' application were drawn, respectively, from the MBARI's annotation interface and the taxonomic part of MBARI's knowledge base. The Biocean multimedia function was strongly inspired by MBARI's VARS, but Biocean's fundamental objective is to track faunal samples through their successive identification steps, which is not a goal at MBARI. Applications for this purpose were influenced by the Ocean Drilling Program (ODP) Curation Janus database (http://www-odp.tamu.edu/database), which contains 450 tables of ODP's marine geoscience data that were adapted to biological deep-sea cruises and samples.

Environmental data management is an original element added to the former biological database. Chemical and physical data have long been archived in data centres such as the French National Oceanographic Data Centre SISMER (www.ifremer.fr/sismer), which designs and operates scientific information systems and databases for national and international projects in the marine domain. Environmental data management in Biocean was designed to be compatible with this national and international framework.

Databases oriented toward species distribution and taxonomy are numerous, and many are available on the Internet (e.g. CephBase at www.cephbase.utmb.edu and FishBase at www.fishbase.org). They generally deal with 1 group of taxa, whereas Biocean deals with all benthic taxa encountered in the deep sea.

Biocean differs from all other databases in that it integrates physical and chemical data with data on biology. To our knowledge, no system equivalent to Biocean exists that centralises metadata from entire cruises; that tracks samples through to their final analysis, whether taxonomic or chemical; and that can be used to retrieve faunistic data and environmental attributes.

Short-term advantages

Past decades have seen tremendous growth in data acquisition capability, arising from the use of new submersibles, such as the ROV 'Victor' 6000 and the development of improved sensors, cameras and sampling tools. The increasing amount of data collected during each cruise creates new challenges for finding solutions for the storage, access, organisation and synthesis of data.

The data management strategy of the Biocean package is to collect cruise data directly onboard using Alamer applications, so that a comprehensive and standardised dataset can be made available directly after the cruise on the website (www.ifremer.fr/isi/biocean). The applications are useful onboard to increase the efficiency of the cruise and can be used to get a precise overview of the scientific programme, as well as the data and samples collected during a specific cruise. Alamer applications can collect chronological events, print thematic lists of operations and retrieve metadata related to these operations.

Alamer applications designed to collate cruise and dive logs are available on every Ifremer ship and have been used by most of the European teams working in the deep sea. This logbook initiates a collaborative work between biologists from several fields to establish comprehensive information on a specific study area.

Long-term advantages

Data acquisition in oceanographic sciences is carried out both on cruises and during sample analyses following a cruise. Because many deep-sea habitats have only been recently discovered and harbour high biodiversity, it can take 5 to 10 yr before taxonomic data is made available for input into the database. The structure of the Biocean package allows continuous data input for many years after the cruise, and permits valuable environmental and geographical data to be linked to taxonomic information in perpetuity. The Biocean package is an essential tool to follow the ecology of a studied area with respect to aspects such as seasonal variability in abyssal plains or temporal evolution of hydrothermal vents.

Data are retrieved under tabular forms; hence, they can be easily plotted and mapped in GIS. The technological evolution of Biocean is ensured by Ifremer's Marine Technology and Information System Direction; the relational database is continuously upgraded as new versions of RDBS Oracle are released.

Internet access

This global management system is meant to archive and centralise multidisciplinary data dealing with abyssal ecology in a standardised form. To answer the increasing international demand for a census of biodiversity data, Biocean contributes to the European programme Biodiversity Collection Access Service for Europe (BioCASE 2002) and to the network Census of Marine Life (CoML; www.coml.org). Biogeographical data are available through the CoML web portal of OBIS (www.iobis.org). Metadata for each cruise are available at www.ifremer.fr/isi/biocean, as are the database model and contact details for anyone seeking scientific collaboration or requiring technical information on how to obtain the applications.

Biogeographical analyses

The bathymetric distribution of species is a concept widely expressed in local studies (Howell et al. 2002, Olabarria 2005) and obviously influenced ordination of Atlantic cruises. The ordination suggested also the influence of cruise date, which reflected evolution of sampling strategies. Older cruises, conducted during the earliest days of deep-sea oceanography, were essentially exploratory expeditions along the continental slopes. Since the 1980s an important change in the approach of deep-sea biological research has taken place. Descriptive oceanography has given way to more comprehensive studies. Sampling strategies have become more focused on limited areas in the deep sea and are intended to reveal the functioning of ecosystems.

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