Vanden Berghe E., M. Brown, M.J. Costello, C. Heip, S. Levitus and P. Pissierssens (Eds). 2004. p. 77-89
Proceedings of 'The Colour of Ocean Data' Symposium, Brussels, 25-27 November 2002
IOC Workshop Report 188 (UNESCO, Paris). x + 308 pp.
– also published as VLIZ Special Publication 16

Seamountsonline, an online information system for seamount biology

Karen I. Stocks

San Diego Supercomputer Center and Scripps Institution of Oceanography
9500 Gilman Drive, MC 0505, La Jolla, CA 92093-0505, USA
E-mail: kstocks@sdsc.edu

Abstract

Seamounts (undersea peaks in the ocean's floor) support unique biological communities that are of interest both as natural laboratories for studying marine biodiversity and as commercially-fished habitats requiring careful management. SeamountsOnline (http://seamounts.sdsc.edu) is a web resource through which researchers and managers can access global information on species recorded from seamounts. Users of the system can access species lists from seamounts of interest, distribution information on species of interest, sampling effort and method data, and a searchable bibliography of seamount literature. The system is based on a relational database that holds information in the following main tables: taxonomic names, seamounts, sampling events, and observations (the recording of a particular species from a particular sampling event). Features of the system include mechanisms for crediting data providers, versioning with archival of previous versions, referencing of sources at the data-element level, open source schema and scripts, and participation in the Ocean Biogeographic Information System (www.iobis.org). A brief example shows how the system has been applied to describing spatial patterns in fish endemism on the Hawaiian and Emperor seamount chains. The article is aimed at both potential users of the system interested in seamount data and researchers interested in database and online information system development for ecological data.

Keywords: Seamount; Ecological information system; Endemism; Island biogeography theory; Database design, Hawaiian seamounts.

Introduction

SeamountsOnline (http://seamounts.sdsc.edu) is a project aggregating existing data on seamount biota and making them freely available through an integrated online interface for research, management, education, and other non-commercial uses. This article describes the data content, functionality, and system design of SeamountsOnline.

Seamounts are undersea peaks in the ocean's floor – submerged mountains created by volcanism or tectonic uplift. Though seamounts are strictly defined as rising at least 1000m above the surrounding seafloor (International Hydrographic Organization, 2001), this definition is not particularly meaningful biologically, and SeamountsOnline includes data from smaller peaks. While the true number of seamounts is unknown, they have been found in every ocean basin and it is estimated that at least several tens of thousands exist (Smith, 1985).

Seamounts are of interest to ecology and biogeography because many support unique biological communities and high numbers of endemics (species found on only one seamount or restricted seamount chain and nowhere else in the oceans to date). Recent large studies have found rates of endemism of 30 to 40% and more on seamounts off Tasmania, New Caledonia, and Chile (Parin *et al.*, 1997; de Forges *et al.*, 2000; Koslow *et al.*, 2001), though other seamounts have lower rates (*e.g.* Fock *et al.*, 2002). It has long been proposed that seamounts may act as centers of speciation, refugia for relict populations, and/or stepping-stones for trans-oceanic dispersal (Hubbs, 1959). Because they vary in their community structure and levels of biodiversity, and also in physical factors thought to be important to biological communities (depth, latitude, distance from like habitat, primary productivity, dissolved oxygen, etc.), seamounts represent case studies for understanding some of the fundamental processes that create and promote biological diversity in the oceans. Synthesizing data across many seamounts is necessary to approach these questions. But while over 200 seamounts have been sampled biologically, rarely have data from more than one seamount chain been compared. SeamountsOnline is designed to provide integrated access to this heterogeneous and distributed body of information to facilitate synthetic studies.

At the applied level, seamount resource management is a pressing concern. Many seamounts can support high concentrations of commercial fish, particularly orange roughy (*Hoplosthesus atlanticus*), hoki (*Macruronus novaezelandiae*), oreos (Oreosomatidae), amourhead (*Pseudopentaceros wheeleri*) and rockfish (*Sebastes*) (Probert *et al.*, 1997; WWF/IUCN/WCPA, 2001; Dower and Perry, 2001). Many of these have not been managed sustainably (Koslow *et al.*, 2000, Stone *et al.*, 2003). Furthermore, bottom trawling has been demonstrated to be highly destructive to the epifaunal communities of deep corals, sponges, crinoids, hydroids, etc. found on seamounts (Koslow *et al.*, 2001). In some cases, corals may be over 100 years old (Rogers, 1999), indicating that the recovery time from disturbance may be extremely long. Countries including the United States, Australia, and New Zealand have begun siting marine protected areas on seamounts, and the United Nations Informal Consultative Process on the Ocean and the Law of the Sea is considering several proposals to create a policy mechanism for protecting seamounts in high-seas waters. Decisions about managing and protecting seamounts can be improved by access to the best available scientific information on seamounts.

SeamountsOnline (http://seamounts.sdsc.edu) began in 2000 with funding from the US National Science Foundation as a way to meet the information needs of seamount researchers and managers. It is a work in progress and it is continually expanding. While it was created specifically for seamount information, the overall system design could be applied to a variety of habitat-specific, species-level distribution datasets. Today, the number of groups seeking to share ecological information through the web is increasing, as is the time spent designing and implementing new systems. A description of the SeamountsOnline system is given here, along with a discussion of some of the main design decisions, in the hopes that it may prove useful to others setting up similar projects.

System description and funtionality

Data content

SeamountsOnline is designed to hold species-level observations from seamounts. The core data within the system consists of a record that a particular species was observed or collected on a particular seamount. This will be called an 'observation' throughout this paper. The database can hold observations where only a genus- or family- level identification is given, but does not hold information for observations identified to higher taxonomic levels or to other biological categories (*e.g.* 'zooplankton'). All metazoan taxa are being included. Supporting each observation are data on how, where, and when the observation was made. Both presence/absence data and quantitative data can be accommodated.

SeamountsOnline is a continually-growing system, and the data content is by no means complete. At the time of writing (5/2003) the database held ~8500 observations on ~2000 species and ~110 seamounts (Fig. 1). Coverage is most comprehensive for fishes and crustacea on the Hawaiian/Emperor/Mid-Pacific seamounts, fishes and invertebrates from the Nasca/Sala-y-Gomez chain and the Norfolk Ridge seamounts, and fishes from the Great Meteor Seamount.

The majority of the data in the system have come from literature publications that have been hand-entered by the SeamountsOnline staff. For quality control, only data that have been published in peer-reviewed literature or by recognized government or research organizations are used. Additional valuable holdings have been provided as electronic datasets by seamount researchers and institutions. SeamountsOnline thanks those who have already stepped forward to contribute their electronic datasets: Bertrand Richer de Forges and collaborators for the ORSTOM data from the Norfolk Ridge (summarized in de Forges *et al.*, 2000), Heino Fock and collaborators for the Great Meteor Seamount fish data (Fock *et al.*, 2002), George Boehlert for ichthyoplankton data from Hancock Seamount (Boehlert and Mundy, 1992), and the Scripps Institution of Oceanography's Vertebrate and Benthic Invertebrate Collections (http://collections.ucsd.edu).

Functionality – using the system

The SeamountsOnline web site has three avenues through which users can retrieve data, as described below.

Search for species. Through this avenue, the user can specify 1) a species or genus of interest and/or 2) either a particular seamount by name or a geographic area by latitude and longitude bounds. By searching on a species or genus name the user will retrieve all seamount locations where that taxon has been found. By searching on a seamount name or region, the user will retrieve all species that have been recorded from that place. The default returned data table contains the taxonomic name (genus, species, subspecies [where applicable], and authority), seamount name, latitude and longitude with precision estimate, and the author(s) and publication year of the original data source. Optional fields that can be included are family and phylum name, depth of capture, date collected, number collected, and the full bibliographic citation for the source data. Each observation includes a sample number that is live-linked to the full sample information (see below). The results from a search can be downloaded either as a tab-separated text table or as an Excel file. Users can choose to download the default core of information, or can select additional optional fields to include. They can also choose to download the full sample information associated with each observation, either as one merged table or as separate species-observation and sample tables.

Search for samples. This avenue is designed to give information about how thoroughly a particular seamount has been sampled. This information is important for evaluating whether species lists are complete and representative, and whether data are comparable between seamounts. For example, if a seamount of interest has only been sampled with a bottom trawl, then the absence of a particular pelagic species from the observations does not necessarily mean that the species is not present there. To search for samples, the user selects a seamount of interest and retrieves a list of all the samples known from that seamount. The returned data for each sample includes, where available, the date(s) taken, the latitude and longitude location with precision, the depth, the depth zone (*i.e.* benthic or midwater), whether the sample was quantitative, the station or sample name/number given in the original data source, the gear used, the taxonomic groups recorded (*e.g.* 'only fish were counted'), the cruise and vessel, and the individual or institution taking the sample (Fig. 2). The full set of results from a given seamount can be downloaded as either a tab-separated text file or as an Excel file.

Search References. In the process of building SeamountsOnline, over 1000 bibliographic citations relating to seamounts have been collected and entered into a commercial reference manager database. Users can search this bibliographic database for authors, seamount names, or other terms of interest. The result of a search is a text list of references with the author, year, title and source given for each reference. This can be downloaded by copying from the screen and pasting to a local application. There is also a feature for downloading the entire bibliography as a text file in the same format as the screen return. The coverage is strongest for biological aspects of seamounts but also includes some references about seamount geology, hydrology, etc.

System design

SeamountsOnline is based on a relational database designed for this project. Two versions of the database exist: data are initially entered into a desktop version in Microsoft Access and then periodically ported over to an Oracle version for serving. The Access and Oracle versions differ in that the Access version is designed for maximum ease and quality control of data entry and the Oracle version (in which no data entries or edits are done) is designed to maximize query speed and performance. The query interface was programmed in Perl/CGI. All scripts are available upon request to the author (for non-commercial uses); the database schema can be viewed from the 'Database Design' menu button on the SeamountsOnline home page.

The primary tables of the relational database are described below. In addition, each table contains the following fields for use in data management: the source of the data (as a reference number that links to the bibliographic database), the person who entered the data, the date of entry, the person who checked the data for correctness, the date of checking, the date of last edit, in-house comments about data entry, and a field for general notes.

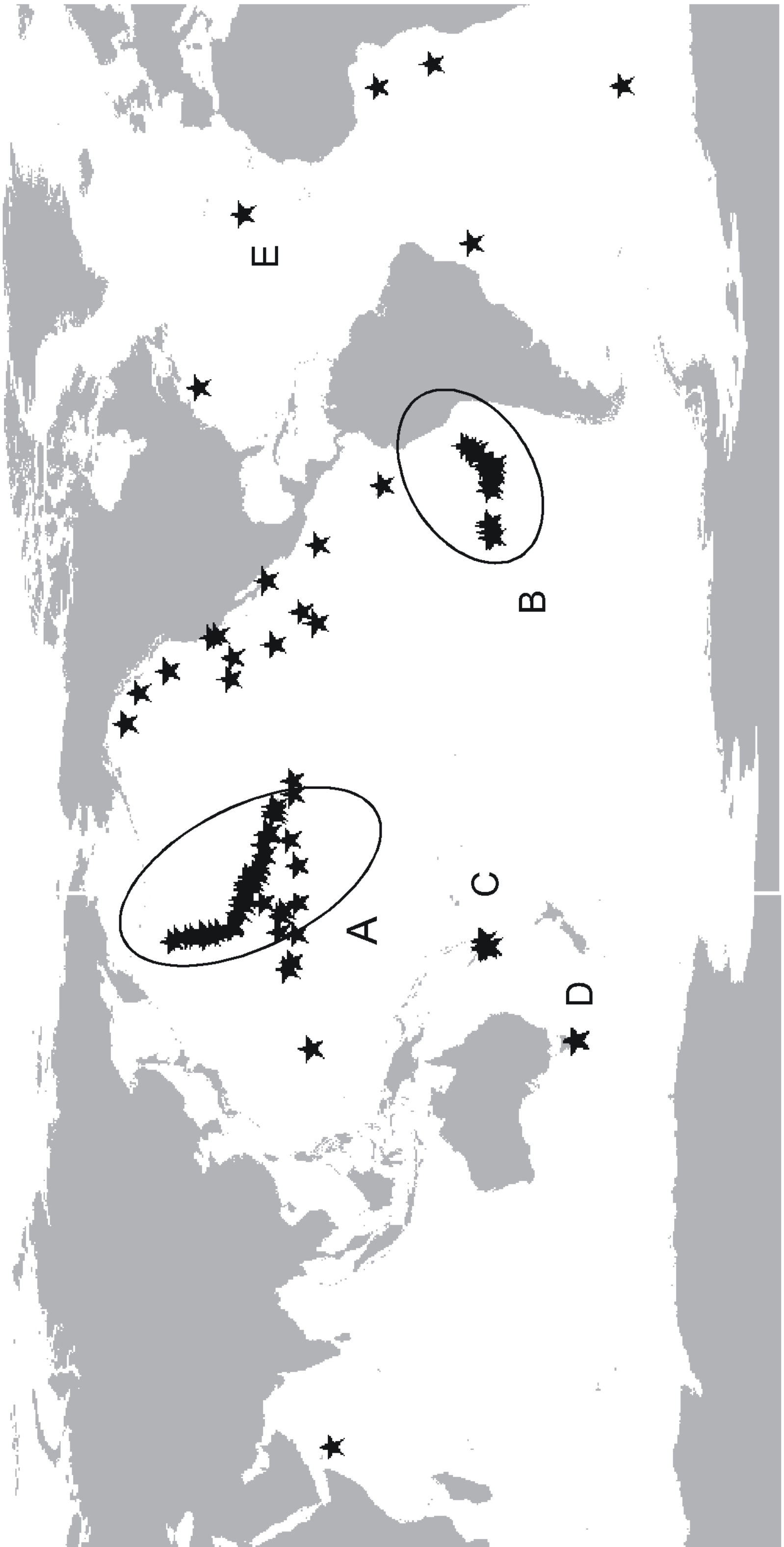


Fig. 1. Seamounts for which SeamountsOnline contains data. Seamount areas mentioned in the text: A = Hawaiian/Emperor chains, B = Nasca/Sala-y-Gomez chains, C = Norfolk Ridge seamounts, D = Tasmanian seamounts. E = Great Meteor Seamount.

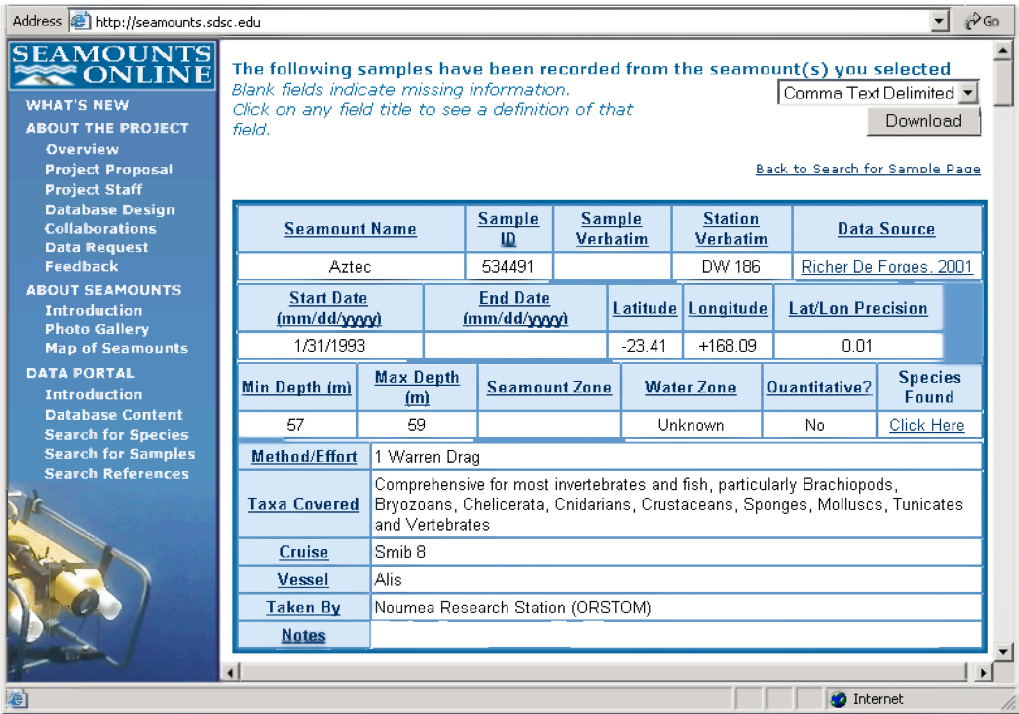


Fig. 2. Example of the data returned from a 'Search for Samples' (information from just one of multiple samples is shown).

Name. This table holds information about a taxonomic name including genus, species, subspecies (if applicable), and authority with year. In the Access version, the name is linked hierarchically to Family, Order, and Phylum tables. In the Oracle version, the higher taxonomic levels are incorporated into the Name table. All taxonomic names are entered as given in the original data source. The author is currently working on linking names to current valid names using the Catalog of Life (www.sp2000.org) and the taxonomic literature. Information on the geographic range of each species and whether it is a seamount endemic is also under development.

Seamount. This holds information about a particular seamount including name(s), seamount chain and region it is in, the central latitude and longitude with precision estimates, and the minimum depth. In development are fields for substrate type, geological age, seamount shape (*i.e.* plateau, pinnacle, etc.), surface area of the summit, and number of summits.

Sample. Information about each sampling event is held in this table. Sampling events can include both physical collections (net hauls, trap deployments, benthic cores, fisheries records, etc.) and visual observations (direct observation, video, and still photography). The data elements from this table are the same as those described in the 'Search for Samples' part of the Functionality section, above. This table has the flexibility to hold both point samples and line samples (*i.e.* net hauls with a start and end latitude and longitude). In development is a 'seamount zone' feature that characterizes whether the sample was taken from the top, sides, or base of a seamount. Each sample is linked to a seamount in the Seamount table.

Observation. This is the core of the database. It links a species from the Name table to a sample in the Sample table to record when and where a particular species was found. Supporting this are data, when available, on the person who made the identification, the identification guide/key used, the museum and accession number of any specimens that were preserved, the number found, and whether adults, juveniles, larvae, gravid females and/or eggs were recorded.

Supporting these tables are a few smaller tables including Expedition, which records information on major cruises; Institution, which gives the location and contact information for places where specimens are held; and Person, which gives the institution and address of people acting as identifiers of specimens or as chief scientists on cruises.

Design considerations

With recent improvements in internet connectivity and database technologies, efforts to integrate, organize, and distribute digital scientific data are increasing greatly. These efforts include large-scale projects like the Global Biodiversity Information Facility, but also many small-scale systems developed by individual researchers and small groups who may not have formal training in information system development. How these systems are structured and handled may greatly impact their utility and the support they receive from the research and management communities. Below are listed some of the system decisions that the SeamountsOnline team felt were critical to creating a robust system, and the rationale behind each decision. They are offered in the hope that they may assist others in developing their systems.

Credit for data providers. For large-scale or multi-taxa datasets it is rare that all the pertinent data are collected by a single research effort. By nature, therefore, database compilation often requires the integration of data from multiple sources. The data providers often have little incentive to share their data. While SeamountsOnline cannot compensate data providers, it does seek to give visible credit to the original providers of data. All data served through SeamountsOnline have a tag citing the original data source. Users of SeamountsOnline must agree to cite the original data source before they can search the system. While SeamountsOnline has no means to enforce this agreement, it at least assures data providers that the system is not seeking to take credit for their work.

Versioning. One of the primary purposes of SeamountsOnline is to act as a data resource for scientific research on seamount ecology. It is important for publishing researchers to be able to cite the data from which they drew their results, and for later researchers, perhaps trying to reproduce results, to be able to retrieve exactly those data. For this reason, data updates in SeamountsOnline are done periodically, each update is given a version number, and all previous versions are permanently archived at the San Diego Supercomputer Center and are available on request. Operationally, this is done by having a desktop version of the database which is continually updated with new data entries, and a separate version on the server that is updated intermittently from the desktop version.

Sampling effort information. In order to understand the distribution of a species it is important to know not just where it is found but also where it is not found. By tying observations to information, where available, on how the sample was taken and what groups were recorded (*e.g.* 'all cephalopods' or 'commercial fish only') SeamountsOnline assists users in determining whether the absence of a particular species is due to a lack of sampling or to a potentially true biological absence. In addition, it allows the users to re-create the species lists from particular samples to look at, for example, the rate of new species accumulation with increased sampling.

Habitat focus. SeamountsOnline is organized along the theme of a particular habitat type. By linking observations to an identified feature in the Seamount table, it allows information to be held about that feature, such as geological age, bottom type, etc. This same approach may be useful for other databases that focus on spatially-discrete geographical locations, such as islands, hydrothermal vents, trenches, seagrass beds, etc.

Data source referencing. All data items within SeamountsOnline are supported by a reference for the data source. This gives the flexibility to link multiple elements within one record of a table to different references (*i.e.* the source for the minimum depth of a seamount may be different from the source of the latitude and longitude of that seamount). References of many kinds, including unpublished datasets and web pages, can be recorded in the system.

Open data/Open source. SeamountsOnline has made a commitment to be an open-source system. All code and system designs are freely shared (for non-commercial uses only), and can be requested from the author. Most people developing ecological or biogeographic datasets are interested in ecology and not in information science and programming. While documenting scripts and database schema appropriately for an outside person to use takes time, the discipline overall will be best served by leveraging from past work.

Compatibility. As the ability and inclination of small groups to post their data on the internet grow, organizing elements will be necessary to create pathways through the large and heterogeneous volumes of data that emerge. The world of biological information is quickly organizing itself through new data warehouses and large 'umbrella' projects. Groups like the Ocean Biogeographic Information System (www.iobis.org), the Global Biodiversity Information Facility (www.gbif.org), and the US National Oceanographic Data Center (www.nodc.noaa.gov) are working to facilitate access to biogeographic data. Linking in or registering with these umbrella sites allows smaller datasets to be found and used more easily. To this end, SeamountsOnline has become a participant in the Ocean Biogeographic Information System, a globally-distributed network of marine systematic and ecological data resources (Zhang and Grassle, 2002). All data within SeamountsOnline can be searched and viewed through the main OBIS data portal at www.iobis.org. For information on taking part in OBIS, please visit the OBIS web site.

Example application: Hawaiian fish endemism

The data within SeamountsOnline are currently being used to look at patterns of endemism on the Hawaiian and Emperor Seamount chains (Fig. 1). Data from 17 published studies on these seamounts and one online data resource were entered into SeamountsOnline (Barsukov, 1973; JAMARC, 1973; Katayama, 1975; Chen, 1980; Gooding, 1980; Nakaya *et al.*, 1980; Kanayama, 1981; Dolganov, 1982; Nakabo *et al.*, 1983; Parin and Mikhailin, 1983; Yabe, 1983; Humphreys *et al.*, 1984; Uchida and Tagami, 1984; Randall and Chen, 1985; Borets, 1986; Uchida and Uchiyama, 1986; Chave and Mundy, 1994; Froese and Pauly, 2002). Then, the 'search for species' option was used to sequentially select seamounts of this chain and return all species observations associated with that seamount. For each seamount for which more than 10 fish species were recorded, the table of observations was downloaded and imported into Excel. From this a species list was created for each seamount.

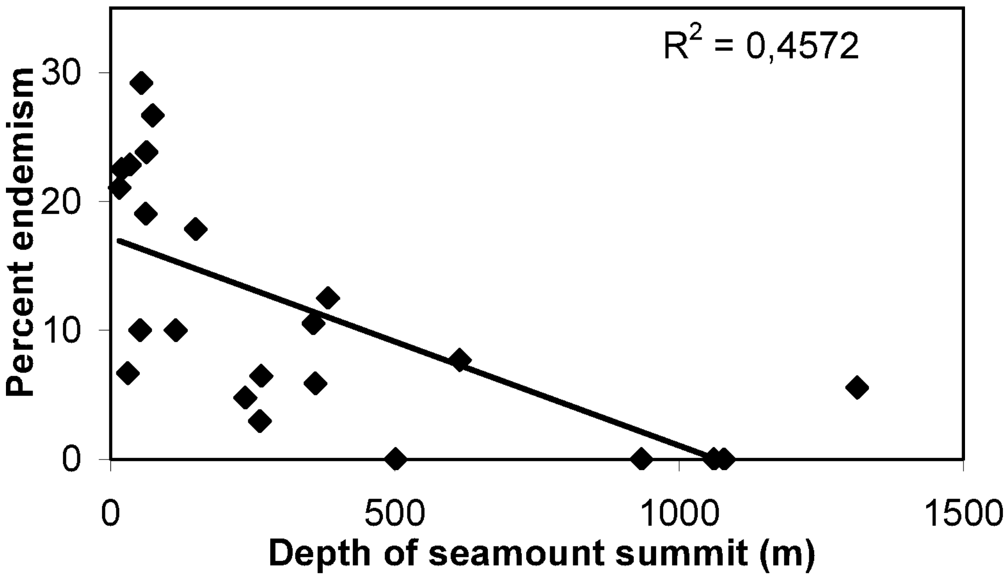
Then, each of the 213 fish species found was designated as a potential endemic or not based on the known distribution as found in the above sources plus: Jordan and Evermann (1973), Tinker (1978), Boehlert and Sasaki (1988), Blum (1989), Masuda *et al.* (1992), Pequeño (1997), Randall (1998), Castle and Smith (1999), Randall (1999), Randall and Lim (2000), Shinohara *et al.* (2001). Endemics were separated into two categories: those found only on seamounts of the Hawaiian/Emperor chains, and those found on these seamounts and also around the Hawaiian Islands. (Endemicity information is currently being added to the SeamountsOnline database, but is not yet available through the web site.) From these data, the total percent endemic species was calculated for each seamount. Absolute numbers of endemics were not evaluated because the sampling effort varied greatly across seamounts and in some cases was not well documented. Percent endemic species was regressed against both the depth of the seamount summit and the distance from the main island of Hawaii as measured in degrees of latitude/longitude. Regressions were run using Statistix 7 analytical software (www.statistix.com).

Overall, 5% of the fish species found on these seamounts are known only from the seamounts of the Hawaiian/Emperor Chains and an additional 12% are known only from these seamounts or the Hawaiian Islands, for a total of ~17% endemic to the area. For those species endemic to both the islands and seamounts of Hawaii there is a significant relationship with distance away from the main island of Hawaii and with depth of the seamount (Fig. 3) ($P<0.01$ for both). Note that depth and distance are correlated on this seamount chain. The relationship with distance is what would be predicted from a simple application of Island Biogeography Theory (MacArthur and Wilson, 1967), assuming that the islands of Hawaii, which have much more habitat area than the small seamount peaks, represent the main pool of species. While a causative factor cannot be determined from this work, it is an example of how a clear spatial pattern can emerge from the compilation of datasets that are each too small to show any pattern alone.

The future of SeamountsOnline

SeamountsOnline is a continually-growing project designed as a permanent archive and distributor of data from seamounts. The San Diego Supercomputer Center has committed to providing permanent server access to this database, and the Ocean Biogeographic Information System will perpetuate data maintenance in the event the author no longer can.

However, the growth of the SeamountsOnline dataset, and thus its utility to the community, will rely greatly on the willingness of researchers to share their datasets. While data can be entered by hand from literature publications, literature data are often summarized and lose resolution. Furthermore, manual entry of data from the literature is extremely time consuming. If researchers are willing to provide electronic datasets (in any format) to SeamountsOnline, the system will be able to incorporate them efficiently and continue to grow in the coming years. SeamountsOnline is grateful to those researchers, named in the Data Contents section above, who have already given data to the system. *If you have species-level sampling data from seamounts and are interested in providing them to SeamountsOnline, please contact the author.*



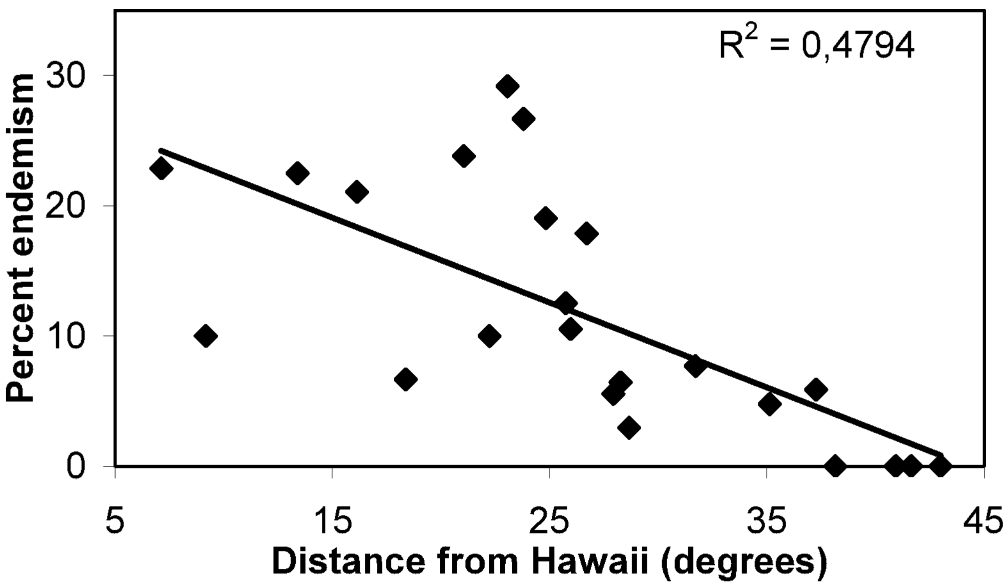


Fig. 3. Percent endemism in fish species from seamounts of the Hawaiian and Emperor chains compared to A) depth of the seamount summit and B) distance from mainland Hawaii in degrees. R^2 values are for linear regressions. P<0.01 for both regressions.

Acknowledgements

SeamountsOnline was funded by National Science Foundation Division of Biological Infrastructure grant DBI-0074498 and server support and other infrastructure is provided by the San Diego Supercomputer Center. Lisa Levin and David Stockwell at the University of California at San Diego have given valuable assistance as have Phoebe Zhang and Fred Grassle from the OBIS secretariat. Daphne Fautin was kind enough to provide a schema of her 'Biogeoinformatics of Hexacorals' database (www.kgs.ukans.edu/Hexacoral/) to assist in the design of SeamountsOnline. John Lin lent his talents to both web design and Perl/CGI programming, and Megan Williams and Elisheba Spiller contributed to database content development.

The project also gratefully acknowledges the researchers who have freely provided their data to SeamountsOnline: Bertrand Richer de Forges and collaborators for the ORSTOM data from the Norfolk Ridge, Heino Fock and collaborators for Great Meteor Seamount fish data, George Boehlert for ichthyoplankton data from Hancock Seamount, and the Scripps Institution of Oceanography's Vertebrate and Benthic Invertebrate Collections.

References

Barsukov V.V. 1973. The species composition of the genus *Helicolenus* (Sebastinae, Scorpaenidae, Pisces) and a description of a new species. Journal of Ichthyology 13:161-167.

Blum S.D. 1989. Biogeography of the Chaetodontidae: an analysis of allopatry among closely related species. Environmental Biology of Fishes 25: 9-31.

Boehlert G.W. and B.C. Mundy. 1992. Distribution of ichthyoplankton around Southeast Hancock Seamount, central North Pacific, in summer 1984 and winter 1985: data report. NOAA Technical Memorandum NMFS-SWFSC-176. 109p.

Boehlert G.W. and T. Sasaki. 1988. Biogeography of the armorhead, *Pseudopentaceros wheeleri*, and recruitment to isolated seamounts in the North Pacific Ocean. Fishery Bulletin 86:453-465.

Borets L.A. 1986. Ichthyofauna of the Northwestern and Hawaiian ridges. Journal of Ichthyology 26:1-13.

Castle P.H.J. and D.G. Smith. 1999. A reassessment of the eels of the genus *Bathycongrus* in the Indo-west Pacific. Journal of Fish Biology 54: 973-995.

Chave E.H. and B.C. Mundy. 1994. Deep-sea benthic fish of the Hawaiian archipelago, Cross Seamount, and Johnston Atoll. Pacific Science 48:367-409.

Chen C.H. 1980. Primary studies of demersal fish resources investigations on trawl grounds at Kanmu Seamount. Bulletin of Taiwan Fisheries Research Institute 32: 317-338.

de Forges B., J.A. Koslow and G.C.B. Poore. 2000. Diversity and endemism of the benthic seamount macrofauna in the southwest Pacific. Nature 405:944-947.

Dolganov V.N. 1982. Discovery of a rare rabbitfish species, *Chimaera owstoni* (Holocephali, Chimaeridae), in the region of the Northwestern underwater ridge. Journal of Ichthyology 22:145-146.

Dower J.F. and R.I. Perry. 2001. High abundance of larval rockfish over Cobb Seamount, an isolated seamount in the Northeast Pacific. Fisheries Oceanography 10:268-374.

Fock H., F. Uiblein, F. Köster and H. von Westernhagen. 2002. Biodiversity and species-environment relationships of the demersal fish assemblage at the Great Meteor Seamount (subtropical NE Atlantic), sampled by different trawls. Marine Biology 141:185-199.

Froese R. and D. Pauly (Eds). 2002. FishBase. World Wide Web electronic publication. www.fishbase.org. 12 December 2002.

Gooding R.M. 1980. Exploratory fishing on the Hancock Seamounts by the Townsend Cromwell, 1976-79. p.241-250. In: Proceedings of the Symposium on Status of Resource Investigations in the Northwestern Hawaiian Islands, April 24-25, 1980. Grigg R.W. and R.T. Pfund (Eds). Honolulu, Hawaii.

Hubbs C.L. 1959. Initial discoveries of fish faunas on seamounts and offshore banks in the Eastern Pacific. Pacific Science 13:311-316.

Humphreys R.L. Jr., D.T. Tagami and M.P. Seki. 1984. Seamount fishery resources within the southern Emperor - northern Hawaiian Ridge. p.283-327. In: Second Symposium on Resources Investigations in the Northwestern Hawaiian Islands, 25-27 May 1983. Grigg R.W. and K.Y. Tanoue (Eds). Honolulu, Hawaii.

International Hydrographic Organization. 2001. Standardization of undersea feature names. Bathymetric Publication No. 6, 3rd Edition. International Hydrographic Bureau.

JAMARC (Japan Marine Fishery Resource Research Center). 1973. Surveys of trawling grounds in the north central Pacific, 1972 season. JAMARC Report No. 7.

Jordan D.S. and B.W. Evermann. 1973. The shore fishes of Hawaii. Charles E. Tuttle Company, Rutland, Vermont. 392p.

Kanayama T. 1981. Scorpaenid fishes from the Emperor Seamount Chain. Research Institute of North Pacific Fisheries, Special Volume 56:119-129.

Katayama M. 1975. *Caprodon unicolor*, a New Anthiine Fish from the North Pacific Ocean. Japanese Journal of Ichthyology 22:13-15.

Koslow J.A., G.W. Boehlert, J.D.M. Gordon, R.L. Haedrich, P. Lorance, and N. Parin. 2000. Continental slope and deep-sea fisheries: implications for a fragile ecosystem. ICES Journal of Marine Science 57: 548-557.

Koslow J.A., K. Gowlett-Holmes, J.K. Lowry, G.C.B. Poore, and A. Williams. 2001. The seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. Marine Ecology Progress Series 213:111-125.

MacArthur R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, NJ. 203p.

Masuda H., K. Amaoka, C. Araga, T. Uyeno and T. Yoshino. 1992. The Fishes of the Japanese Archipelago, English Edition ed. Tokai University Press, Tokyo. 456p.

Nakabo T., T. Yamamoto and C.H. Chen. 1983. Two new species of the genus *Foetorepus* (Callionymidae) from the Emperor Seamounts, north-central Pacific. Japanese Journal of Ichthyology 29:349-354.

Nakaya K., K. Amakoa and K. Abe. 1980. A review of the genus *Lepidion* (Gadiformes, Moridae) from the Northwestern Pacific. Japanese Journal of Ichthyology 27:41-47.

Parin N.V. and S.V. Mikhailin. 1983. *Lepidopus calcar*, a new trichiurid fish from the Hawaiian Underwater Ridge. Japanese Journal of Ichthyology 29:27-30.

Parin N.V., A.N. Mironov and K.N. Nesis. 1997. Biology of the Nazca and Sala y Gomez submarine ridges, an outpost of the Indo-West Pacific fauna in the Eastern Pacific Ocean: composition and distribution of the fauna, its communities and history. Advances in Marine Biology 32:145-242.

Pequeño G. 1997. Peces de Chile. Lista sistemática revisada y comentada: addendum. Revista de Biologia Marina y Oceanografia 32:77-94.

Probert P.K., D.G. McKnight and S.L. Grove. 1997. Benthic invertebrate bycatch from a deep-water trawl fishery, Chatam Rise, New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems 7:27-40.

Randall J.E. 1998. Shore Fishes of Hawaii. University of Hawai'i Press, Honolulu, Hawaii. 216p.

Randall J.E. 1999. Review of the Dragonets (Pisces: Callionymidae) of the Hawaiian Islands, with descriptions of two new species. Pacific Science 53:185-207.

Randall J.E. and C.H. Chen. 1985. First record of the labrid fish *Bodianus cylindriatus* (Tanaka) from the Hawaiian Islands. Pacific Science 39:291-293.

Randall J.E. and K.K.P. Lim. 2000. A checklist of the fishes of the South China Sea. Raffles Bulletin of Zoology 8 Suppl.:569-667.

Rogers A.D. 1999. The biology of *Lophelia pertusa* and other deep-water reef-forming corals and impacts from human activities. International Review of Hydrobiology 84:315-406.

Shinohara G., H. Endo, K. Matsuura, Y. Machida and H. Honda. 2001. Annotated checklist of the deepwater fishes from Tosa Bay, Japan. p.283-343. In: Deep-sea fauna and pollutants in Tosa Bay. Fujita T., H. Saito and M. Takeda (Eds). National Science Museum, Tokyo. 380p.

Smith D.K. 1985. The statistics of seamount populations in the Pacific Ocean. PhD thesis, University of California San Diego, San Diego, California. 212p.

Stone G., L. Madin, K. Stocks, G. Hovermale, P. Hoagland, M. Schumacher, C. Steve and H. Tausig. 2003. Seamount biodiversity, exploitation and conservation. Presentation, proceedings. Defying Ocean's End Conference, Cabo San Lucas, Mexico, May 29 - June 3, 2003.

Tinker S.W. 1978. Fishes of Hawaii. Hawaiian Service, Inc., Honolulu, Hawaii. 532p.

Uchida R.N. and D.T. Tagami. 1984. Groundfish fisheries and research in the vicinity of seamounts in the North Pacific Ocean. Marine Fisheries Review 46:1-17.

Uchida R.N. and J.H. Uchiyama. 1986. Fishery atlas of the Northwestern Hawaiian Islands. NOAA Technical Report 38:1-142.

WWF/IUCN/WCPA. 2001. The status of natural resources on the high-seas. WWF/IUCN, Gland, Switzerland. 93p.

Yabe M. 1983. A new cottoid fish of the family Ereuniidae, *Marukawichthys pacificus*, from the central North Pacific. Japanese Journal of Ichthyology 30:18-26.

Zhang Y.Q. and J.F. Grassle. 2002. A portal for the ocean biogeographic information system. Oceanologica Acta 25:193-197.