J. Paleont., 75(3), 2001, pp. 743–751

0022-3360/01/0075-743$03.00

THE NEOGENE MARINE BIOTA OF TROPICAL AMERICA (''NMITA'') DATABASE: ACCOUNTING FOR BIODIVERSITY IN PALEONTOLOGY

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ABSTRACT—The reliability of any survey of biodiversity through geologic time depends on the rigor and consistency by which taxa are recognized and samples are identified. The main goal of the *N*eogene *M*arine B*i*ota of *T*ropical *A*merica ('NMITA') project is to create an online biotic database (http://nmita.geology.uiowa.edu) containing images and synoptic taxonomic information that are essential to collecting and disseminating high-quality taxic data. The database consists of an inventory of taxa collected as part of several large multi-taxa fossil sampling programs designed to assess marine biodiversity in tropical America over the past 25 m.y. In the first phase of the project, data for ~1,300 taxa and ~3,800 images are currently being entered into a relational database management system on an IBM RS6000 at the University of Iowa. Eleven taxonomic groups are represented: bivalves, gastropods (muricids, marginellids, strombinids), bryozoans (cheilostome, cyclostome), corals (azooxanthellate, zooxanthellate), benthic foraminifers, ostracodes, fish. The lowest taxonomic rank is species (genera/subgenera in mollusks) and the highest is family. Data that are collected and displayed on taxon pages include: (1) taxonomic authorship, synonyms, type specimens, and diagnostic morphologic characters; (2) images of representative specimens and associated museum catalog and measurement data; (3) distributional information including geologic ages, stratigraphic units, and spatial locations; and (4) higher level classification (genera and families) and bibliographic information. Illustrated glossaries of morphologic terms, character matrices, and identification tools are being developed for corals and mollusks. Interactive geographic maps and stratigraphic columns have been designed to provide information about taxa collected at different locations.

INTRODUCTION

OVER THE past decade, quantitative analyses of origination and extinction have become mainstream in paleontology, branching out from the original global assessments of Phanerozoic marine diversity (Raup, 1976; Bambach, 1977; Sepkoski 1978, 1984, 1988; Sepkoski et al., 1981; Sepkoski and Miller, 1985) to include focussed studies of selected taxonomic groups within limited geographic areas and intervals of geologic time (e.g., Alroy, 1996; Behrensmeyer et al., 1997; Budd and Johnson, 1999; Jackson and Johnson, 2000; Rosenberg, 1993; Roy et al., 1995, 1996; Wing et al., 1995). These latter, more refined studies provide the resolution essential for assessing biases, and thus for correlating biotic and environmental signals and ultimately interpreting the causes of biotic events, both small and large in scale. As methods of assessing biases in fossil biodiversity estimates have become more complex, so have the databases on which the analyses are based. Some databases are specifically designed to examine sampling questions [e.g., C. Marshall and J. Alroy's National Center for Ecological Analysis and Synthesis (''NCEAS'') Paleobiology Database at http://www.nceas.ucsb.edu/public/pmpd/], whereas others focus on the concepts used to distinguish taxa. Here, as part of the current special issue on the evolution of the Late Cenozoic marine biota of tropical America, we take the opportunity to describe an online biotic database designed to do the latter; i.e., to summarize the taxa used in ongoing analyses of fossil biodiversity, the criteria used in their identification, and their occurrences in space and time. This database, named the ''*N*eogene *M*arine B*i*ota of *T*ropical *A*merica'' (NMITA), contains high-quality images and synoptic information on taxa collected as part of several associated multidisciplinary fossil-collecting projects in the Caribbean, Central America, and northern South America (Fig. 1). Many of the contributors to the current special issue are also contributors to the NMITA database.

As databases have increased in complexity, so has the need for collaboration and sharing of high quality primary data among researchers. The NMITA database accomplishes this goal by obtaining data and images from an international group of researchers at various institutions, and making these data and images available on the World-Wide Web (''WWW'', http://nmita.geology.uiowa.edu). It focuses on morphology and recognition of taxa (systematics), and information is derived from specimens collected using standardized sampling procedures. The NMITA database provides a modern electronic alternative to more conventional systematic monographic treatments (e.g., the *Paleontological Society Memoir* series), and serves as a model for the future dissemination of taxonomic data in paleontology.

Specifically, the NMITA database contains high-quality images and synoptic taxonomic information that are essential to the consistent identification of taxa in collections of tropical American marine fossils. The database focuses on material collected as part of two large team projects (see below) that are unique in their rigorous sampling and age-determination protocols. In combination with the high-quality taxic data provided by NMITA, these collections permit unprecedented opportunities for quantitatively assessing patterns of biodiversity through geologic time. The NMITA database provides an illustrated inventory of taxa in the collections made by these team projects, and it documents taxonomic concepts used in their identification and classification. At minimum, NMITA contains annotated lists of all names that have been used in the identifications, images of representative specimens of each taxon, and a taxonomic bibliography. Wherever possible, it provides illustrated summaries of morphologic characters used in identifying the material, common synonyms, and summary information on the stratigraphic and geographic distribution of each taxon. Distributional data can also be obtained using interactive maps and stratigraphic charts. Online search tools including identification keys and character matrices are available for selected taxonomic groups.

The NMITA database was developed for use by professional paleontologists, students (graduate, undergraduate, K-12), and amateurs. For professional paleontologists, it summarizes the diversity of taxonomic groups at various levels, and the taxonomic concepts used in determining that diversity. For graduate students, it offers a starting point for reconstructing the phylogenies of selected clades, and is important in pointing out diverse and influential clades in need of future systematic study. For all users, it provides tools that can be used to identify specimens in new collections, and familiarizes them with the biota.

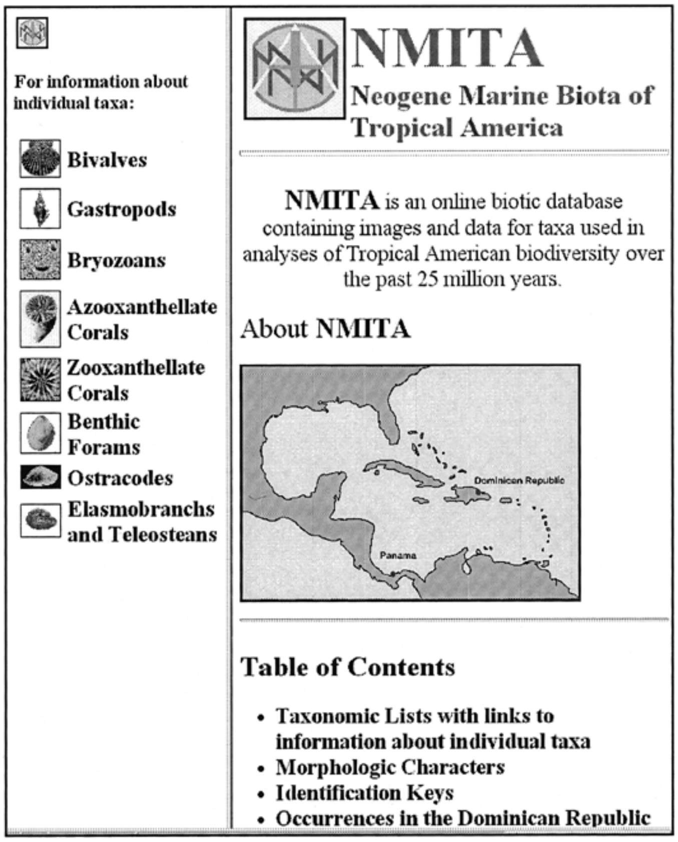


FIGURE *1*—Homepage for the NMITA database (http://nmita.geology.uiowa.edu), showing the statement of purpose, geographic scope, and primary taxonomic groups used for the project.

SCOPE OF THE NMITA PROJECT

The NMITA database currently focuses on the last 25 m.y. of geologic time, especially the Neogene Period, and is restricted geographically to tropical America (i.e., the Caribbean, Central America, and northern South America). The taxa consist of species and of genera and subgenera collected as part of two large team projects: 1) the Panama Paleontology Project (''PPP'') of the Smithsonian Tropical Research Institute (''STRI'') in Panama (Coates et al., 1992; Collins and Coates, 1999); and 2) the Neogene Paleontology of the Northern Dominican Republic Project (''DR'') of the Natural History Museum (''NMB'') in Basel, Switzerland (Saunders et al., 1986). Also included are taxa collected by PPP or DR team members as part of several other smaller collecting projects, which use equally rigorous sampling and age-dating protocols.

The Panama Paleontology Project.—The PPP was begun in 1986 by J. B. C. Jackson and A. G. Coates of STRI as a multidisciplinary project investigating the nature, timing, and magnitude of evolutionary events associated with closure of the Central American isthmus. Since the project began, its aims have expanded to encompass the general biotic history of tropical America and how it has been influenced by environmental change. The project entails several collecting trips per year to key Miocene to Recent sequences in tropical America, especially Panama and Costa Rica. Sampling has involved a unique team effort, in which: 1) detailed stratigraphic columns are constructed for each sequence (A. G. Coates); 2) microfossils (L. S. Collins) and macrofossils (P. Jung, J. B. C. Jackson, and A. F. Budd) are sampled within the context of these columns using standardized protocols that minimize bias; and 3) geologic age dates are obtained for the samples by integrating data on planktonic foraminifera (W. A. Berggren), nannofossils (M. P. Aubry), paleomagnetics (D. F. McNeill), and strontium isotopes. The resulting sampling and locality data have been entered into the PPP database, which is managed by L. S. Collins at Florida International University. At present, these data include >500 bulk samples and >500 bags of individual specimens, containing over a million specimens. After collection, samples have been sent from STRI to designated PPP systematists and research teams for preparation and identification (Table 1). More detailed studies of the systematics and evolution are currently in progress for selected taxa. After study, all micro- and macrofossils, except mollusks and fish, are deposited at the U.S. National Museum of Natural History (''NMNH''); mollusks and most fish specimens are deposited at the NMB. Further details concerning the current status of collections and specimens are provided on the NMITA homepage for each taxonomic group. The PPP collections have served as the basis for two volumes: 1) Jackson et al. (1996); and 2) Collins and Coates (1999). Other references are listed on the PPP web site (http://www.fiu.edu/~collinsl/).

The Dominican Republic Project.—The DR project was one of the first large multidisciplinary projects collecting fossils through a continuous 5–10 m.y. Neogene Caribbean sequence ranging from early Miocene to early Pliocene in age. During three field seasons in 1978–1980, a small field party, led by J. B. Saunders and P. Jung of the NMB, measured sections and collected large samples of micro- and macrofossils at closely spaced intervals along nine river sections in the Cibao Valley of the northern Dominican Republic. Geologic age dates were determined using planktonic foraminifera and nannofossils. The collections were accessioned by the NMB, and distributed to specialists for identification and preparation of systematic monographs. To date, 17 monographs have been published in the *Bulletins of American Paleontology* series ''Neogene Paleontology of the Northern Dominican Republic.'' The DR collections have served as the basis for classic empirical studies in evolutionary paleontology, including Cheetham's (1986) demonstration of punctuated equilibrium in bryozoans and Jung's (1989) revision of the *Strombina* group. Collecting in the DR project has been recently resumed by C. M. Tang and R. H. Nehm as part of an ongoing study assessing community stability within the Río Gurabo section.

Other related field sampling projects.—Taxa collected as part of associated projects using equally rigorous sampling and age dating protocols [e.g., collections made in Jamaica, Curaçao, and Bahamas by A. F. Budd (Budd et al., 1998; Budd and McNeill, 1998), and in Venezuela and Trinidad by J. B. C. Jackson] have also been included.

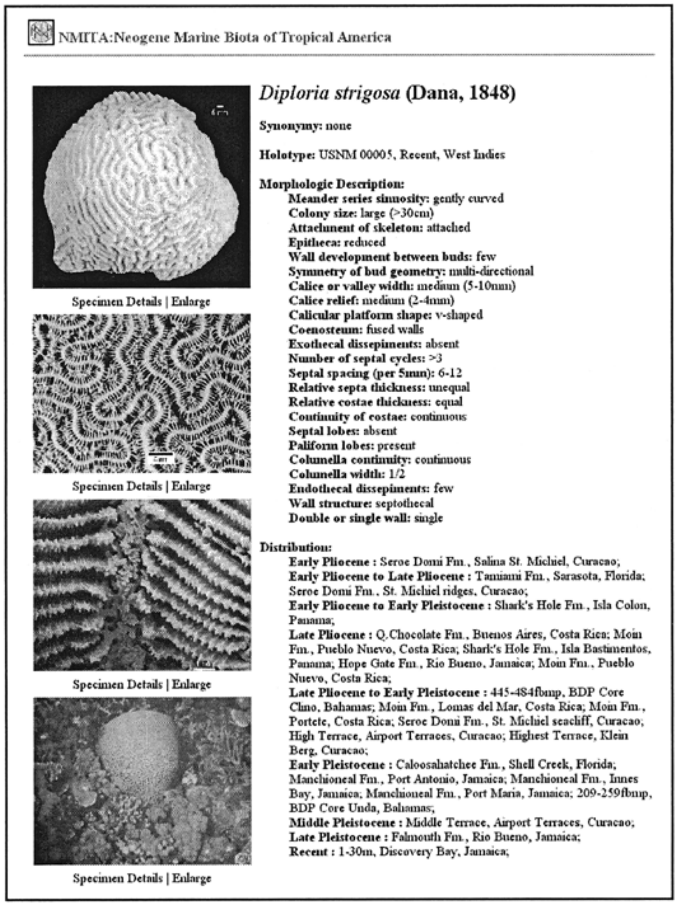
Overview of the six main taxonomic groups.—During the first stage of the project (through January 2001), data are being entered for ~1,300 taxa (~3,800 images) within a total of six major taxonomic groups: scleractinian coral species (zooxanthellate and azooxanthellate), bryozoans species (cheilostome and cyclostome), mollusks (bivalve genera and subgenera; columbellid, muricid, marginellid gastropod species), benthic foraminifera species, ostracode species, and teleost and elasmobranch fish species (Table 1). These taxonomic groups include two kingdoms (Protista, Animalia), one of which (Animalia) contains five phyla. They represent all abundant phyla in the collections, except calcareous nannoplankton.

STRUCTURE OF THE NMITA PROJECT

The NMITA database currently runs on an integrated WWW and enterprise (=UNIX-based) relational database management system (''RDBMS'') server at the University of Iowa. The main hardware consists of IBM RS6000 43P-140 computer; the web

TABLE 1—Taxa in the NMITA database. ''Dynamic'' web pages are created interactively by queries of the database; ''static'' web pages have been previously created and saved. Abbreviations not defined in the text: BMNH, British Museum of Natural History; SEM, scanning electron microscopy; UNEFM, Universidad Nacional Experimental Francisco de Miranda, Coro, Venezuela; USGS, U.S. Geological Survey.

Taxonomic group	Primary contributors	Estimated number of neogene and quaternary tropical American taxa	Estimated number of images	Collecting projects	Institution housing the collections	Dynamic search [http://nmita.geology.uiowa.edu:8001/ows-bin/owa/. . .]
Benthic foraminiferans	L.S. Collins, Florida International Univ.	100 species	250 (all SEM)	PPP	NMNH (Paleobiology)	foram_species
Cheilostome bryozoans	A. H. Cheetham, J. Sanner, NMNH	300 species	900 (all SEM)	DR, PPP; Venezuela & Trinidad	NMNH (Paleobiology); NMB	currently static pages only
Cyclostome bryozoans	P.D. Taylor, BMNH	30 species	150 (all SEM)	PPP	NMNH (Paleobiology)	cyclo_species
Corals (zooxanthellate)	A.F. Budd, Univ. Iowa	175 species	600 (400 light, 200 SEM)	DR, PPP; Jamaica, Curacao, Bahamas	NMNH (Inv. Zoology); NMB	type_genus; coral_species
Corals (azooxanthellate)	S.D. Cairns, NMNH	50 species	200 (100 light, 100 SEM	DR, PPP: Jamaica, Carriacou	NMNH (Inv. Zoology); NMB	currently static pages only
Fish (elasmobranch teeth; teleostean otoliths & teeth)	O. Aguilera, UNEFM	230 species	405 (369 light, 36 SEM)	DR, PPP: Venezuela & Trinidad	NMB, UNEFM	otolith_family; otolith_species
Bivalve mollusks	J. Todd, BMNH	299 genera & subgenera	900 (600 light, 300 SEM)	PPP & STRI Reference collections	NMB	biv_idform
Gastropod mollusks (marginellids)	R. Nehm, NMB	120 species	480 (360 light, 120 SEM)	DR, PPP	NMB	marg_genera
Gastropod mollusks (muricids)	D. Miller, NMB	120 species	480 (360 light, 120 SEM)	DR, PPP	NMB	muricid_genera
Gastropod mollusks (columbellids)	H. Fortunato STRI; P. Jung, NMB	120 species	480 (360 light, 120 SEM)	DR, PPP	NMB	hstrombinids
Ostracodes	T.M. Cronin, USGS; P. Borne, Louisiana State Univ.	300 species	600 (all SEM)	DR, PPP	NMNH (Paleobiology); NMB	currently static pages only



NMITA:Neogene Marine Biota of Tropical America

Diploria strigosa **(Dana, 1848)**

Synonymy: none

Holotype: USNM 00005, Recent, West Indies

Morphologic Description:
Meander series sinuosity: gently curved
Colony size: large (>30cm)
Attachment of skeleton: attached
Epitheca: reduced
Wall development between buds: few
Symmetry of bud geometry: multi-directional
Calice or valley width: medium (5-10mm)
Calice relief: medium (2-4mm)
Calicular platform shape: v-shaped
Coenosteum: fused walls
Exothecal dissepiments: absent
Number of septal cycles: >3
Septal spacing (per 5mm): 6-12
Relative septa thickness: unequal
Relative costae thickness: equal
Continuity of costae: continuous
Septal lobes: absent
Paliform lobes: present
Columella continuity: continuous
Columella width: 1/2
Endothecal dissepiments: few
Wall structure: septothecal
Double or single wall: single

Distribution:
Early Pliocene : Seroe Domi Fm., Salina St. Michiel, Curacao;
Early Pliocene to Late Pliocene : Tamiami Fm., Sarasota, Florida; Seroe Domi Fm., St. Michiel ridges, Curacao;
Early Pliocene to Early Pleistocene : Shark's Hole Fm., Isla Colon, Panama;
Late Pliocene : Q.Chocolate Fm., Buenos Aires, Costa Rica; Moin Fm., Pueblo Nuevo, Costa Rica; Shark's Hole Fm., Isla Bastimentos, Panama; Hope Gate Fm., Rio Bueno, Jamaica; Moin Fm., Pueblo Nuevo, Costa Rica;
Late Pliocene to Early Pleistocene : 445-484fbmp, BDP Core Clino, Bahamas; Moin Fm., Lomas del Mar, Costa Rica; Moin Fm., Portete, Costa Rica; Seroe Domi Fm., St. Michiel seacliff, Curacao; High Terrace, Airport Terraces, Curacao; Highest Terrace, Klein Berg, Curacao;
Early Pleistocene : Caloosahatchee Fm., Shell Creek, Florida; Manchioneal Fm., Port Antonio, Jamaica; Manchioneal Fm., Innes Bay, Jamaica; Manchioneal Fm., Port Maria, Jamaica; 209-259fbmp, BDP Core Unda, Bahamas;
Middle Pleistocene : Middle Terrace, Airport Terraces, Curacao;
Late Pleistocene : Falmouth Fm., Rio Bueno, Jamaica;
Recent : 1-30m, Discovery Bay, Jamaica;

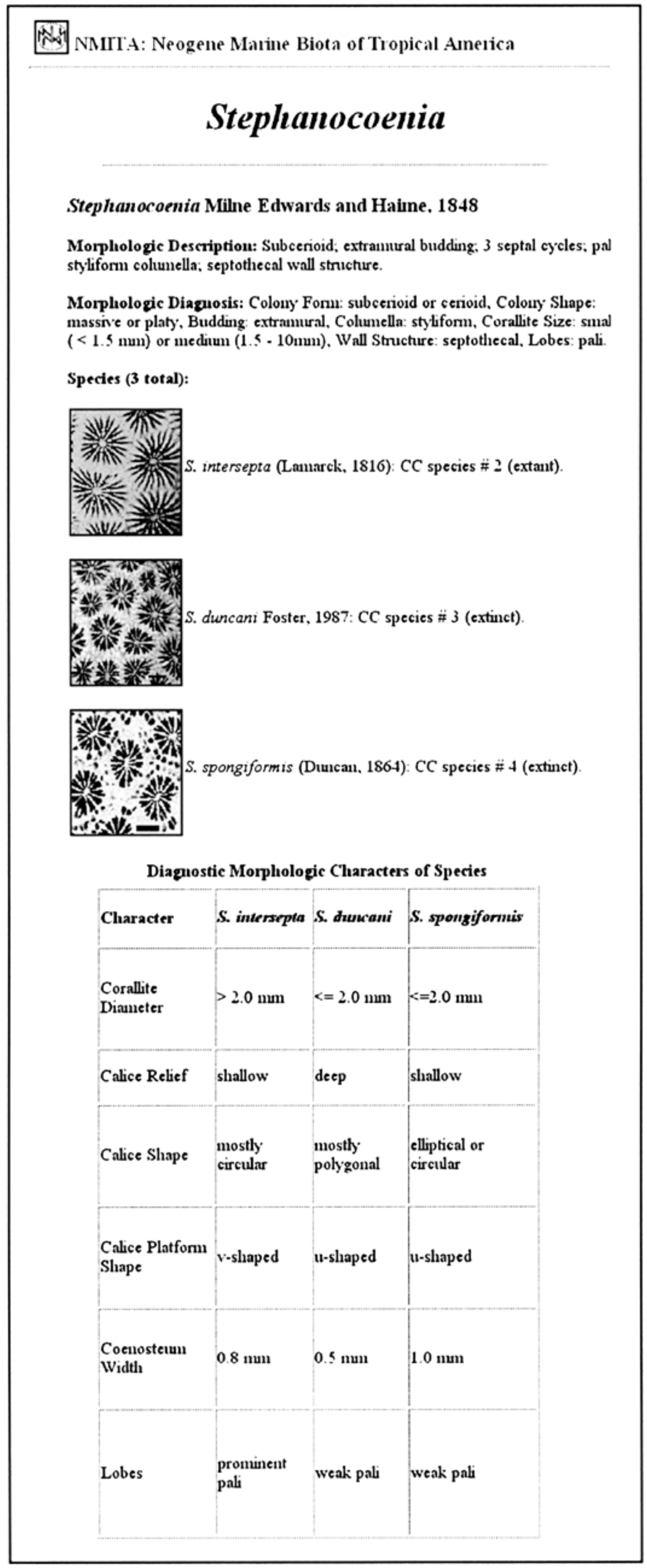
Specimen Details | Enlarge
Specimen Details | Enlarge
Specimen Details | Enlarge
Specimen Details | Enlarge

FIGURE 2—Example of a species page summarizing nomenclatural, morphologic, and distributional information.

server is Oracle Web Application Server 2.1. and the database software is Oracle 7.3. A team of students at the University of Iowa is responsible for designing web pages and the database, processing images, and creating Procedural Language/Standard Query Language (''PL/SQL'') code to query the Oracle database.

As described above, data are contributed to NMITA by specialists at different institutions, who are experts in the systematics of a given taxonomic group (Table 1). Contributors submit data and images in a print-oriented format (usually Tagged Image File format or ''TIFF'' format) to NMITA staff in Iowa, who process the images and import the data into Oracle. Contributors typically submit images in 8-bit grayscale mode (black and white photos) or in 24-bit true color mode (color photos). The resolution depends on the features that are illustrated in the image, but are usually ~2,000 × 2,000 pixels. After final processing, all images are converted into an on-screen graphics format (usually Graphics Interchange Format or ''GIF'') at three different sizes: 1) regular size or 450 × 450 pixels (file size ~100–300 K); 2) large size or 900 × 900 pixels (file size ~1 MB); and 3) thumbnail size or 150 × 150 pixels (file size <20 KB). The original TIFF files are saved as an archive on CD-ROM.

Contributors also provide at least the following textual information: 1) a hierarchical list of taxa (including at least the following ranks: Class, Order, Family, Genus); 2) a bibliography including all systematics citations (in *Journal of Paleontology* format); 3) spreadsheet tables containing information about the image and the specimen in the image, type specimens and authorship



NMITA: Neogene Marine Biota of Tropical America

Stephanocoenia

***Stephanocoenia* Milne Edwards and Haime, 1848**

Morphologic Description: Subcerioid; extramural budding; 3 septal cycles; pal styliform columella; septothecal wall structure.

Morphologic Diagnosis: Colony Form: subcerioid or cerioid, Colony Shape: massive or platy, Budding: extramural, Columella: styliform, Corallite Size: smal (< 1.5 mm) or medium (1.5 - 10mm), Wall Structure: septothecal, Lobes: pali.

Species (3 total):

S. intersepta (Lamarck, 1816): CC species # 2 (extant).

S. duncani Foster, 1987: CC species # 3 (extinct).

S. spongiformis (Duncan, 1864): CC species # 4 (extinct).

Diagnostic Morphologic Characters of Species

Character	*S. intersepta*	*S. duncani*	*S. spongiformis*
Corallite Diameter	> 2.0 mm	<= 2.0 mm	<=2.0 mm
Calice Relief	shallow	deep	shallow
Calice Shape	mostly circular	mostly polygonal	elliptical or circular
Calice Platform Shape	v-shaped	u-shaped	u-shaped
Coenosteum Width	0.8 mm	0.5 mm	1.0 mm
Lobes	prominent pali	weak pali	weak pali

FIGURE 3—Genus page listing species and comparing morphologic characters among species.

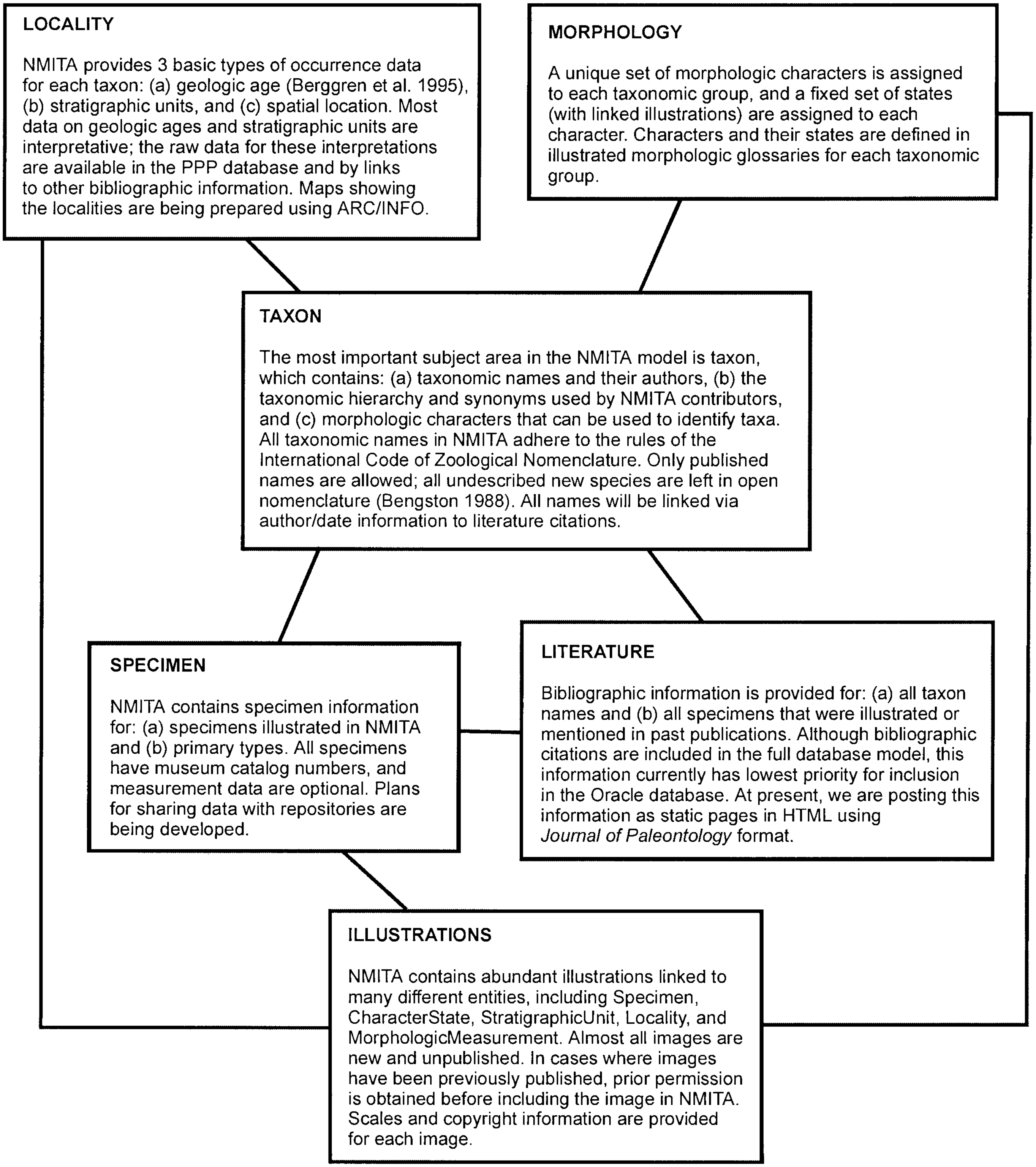


FIGURE 4—Summary of the six main subject areas in the full NMITA database model.

of each lowest-level taxon, and localities at which each lowest-level taxon occurs.

THE DATA

Taxon pages.—At the heart of NMITA are taxon pages representing the lowest taxonomic rank that is currently being used in analyzing biodiversity within a given taxonomic group. Also available are pages listing and comparing lowest-rank taxa within an appropriate higher rank. For most taxonomic groups, these pages are at the species and genus level. One exception is mollusks where the lowest rank is genera and subgenera, and the higher rank is families.

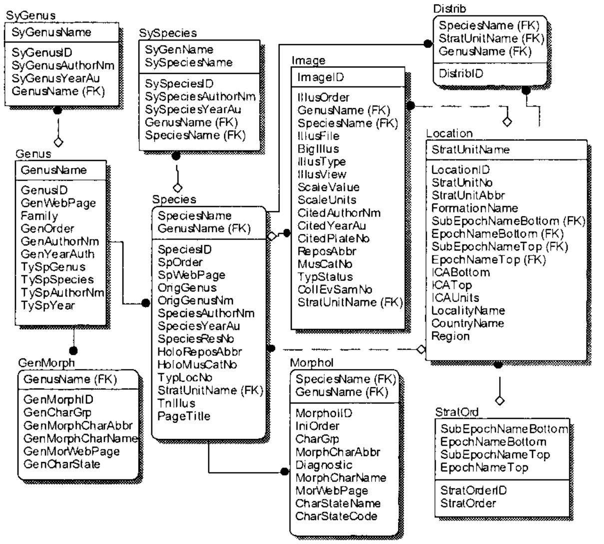


FIGURE 5—Reduced database model (10 tables, 80 fields) currently being used to generate web pages for the zooxanthellate coral family Faviidae.

Lowest-rank taxon or species pages (Fig. 2) summarize nomenclatural, descriptive, and distributional criteria that are useful in identification. They contain:

- Name—author—date information: As used in analyses of biodiversity based on the data.
- Images of representative specimens: In a range of standard orientations and prepared using various techniques. In zooxanthellate corals, for example, whole colony, calical surface, thin-sections, field photos are included. Each image is linked to information about the image and illustrated specimen (the museum catalog number, type, and locality information, scale and orientation).
- Synonyms: Different names applied by other authors, with an emphasis on the last 50 yr.
- Type specimen information: Museum catalog number, type locality information.
- Morphologic information: A list of characters and their states. The characters are linked to a glossary, which provides a complete list of possible states for each character.
- Distribution (Occurrences): Geologic Ages, Formations, and general geographic locations.

In many respects, the information provided on these lowest-rank pages is similar to that of a traditional species description in a printed monograph. The main difference is that information in NMITA is contained in a database, and queries of the database are used to generate static web pages and to perform dynamic online queries. Unlike a printed monograph, NMITA is regularly updated to include recent discoveries and developments as new material is identified. At present, NMITA is still in the initial stages of data entry, and has not yet been subjected to the peer-review process. In future years, we plan to overcome this problem by developing a system for regular peer review, which would be similar to those conducted by professional scientific journals.

In addition, in NMITA, three components of a traditional species description involve links to other databases:

1. Morphologic Description: In NMITA, character information is highly structured and formatted as a character matrix. The characters and their states are linked to a glossary, which provides a complete list of possible states for each character.
2. Material: Instead of a list of specimens, NMITA provides links to specimen databases, such as the "Cenozoic Coral Database" in Microsoft Access, which is available for downloading from NMITA. Future plans involve links to museum catalogs.
3. Individual occurrences and interpreted distributions: NMITA provides links to datasets with occurrence information that is used in larger-scale assessments of biodiversity through geologic time. One such dataset is Cenozoic coral compilation of species occurrences "cc97" (based on Budd et al., 1994, and used in Budd and Johnson, 1999), which is available for downloading from NMITA.

Higher-rank or genus taxon pages (Fig. 3) contain:

- Name—author—date information, synonyms, other nomenclatural information.
- Thumbnail photos of each lowest-rank taxon within the given higher-rank taxon.
- Character matrices summarizing morphologic differences among lowest-rank taxa.

Database model and organization.—Taxon pages are generated by a relational database linking tables containing taxon, morphologic, specimen, and occurrence data. The full database model consists of 71 tables and is patterned after the 1993 Association of Systematics Collections ("ASC") Information Model for Biological Collections (http://biodiversity.uno.edu/). Detailed information concerning the NMITA model, including table and field definitions, is available on the NMITA web site. The NMITA database model consists of six major subject areas: taxon, specimen, locality, morphology, illustrations, and literature (Fig. 4). It expands on the ASC model by adding fields for morphologic characters, measurements, and illustrations (e.g., photographs, drawings, and diagrams).

Reduced, denormalized versions (i.e., using fewer tables, which contain redundant fields) of the full model are currently being used for prototype development. Although their basic structure is similar, different models and databases are being developed and used for each taxonomic group, because different contributors have provided slightly different data fields for each group. Detailed lists of tables and fields are available on the NMITA web site. For example, in zooxanthellate corals, the database used to generate taxon pages consists of ten tables and 80 fields, including four tables within the taxon subject area and three within the locality subject area (Fig. 5). Information for the illustration and specimen subject areas are combined into one table, and two additional tables summarize morphologic data for species and for genera.

Data entry.—During the first stage of the project (through January 2001), we plan to enter data for ~1,300 lowest-rank taxa, including ~3,800 images (Table 1). Data are entered by entering the information into a spreadsheet, and using conversion routines to load the data into Oracle. Data for PPP localities are obtained by downloading the current version of the PPP database from the PPP web site, and importing relevant fields into the Oracle database.

ACCESSING THE DATABASE

To navigate the database, users select the name of a taxon from dynamically generated lists of taxa that match specified taxonomic, morphologic, or occurrence criteria. These queries consist of PL/SQL programs designed and compiled using the Oracle Schema manager, and code for these programs is posted separately on the NMITA web site. One example using taxonomic data involves a query of zooxanthellate coral species, consisting of two procedures (http://nmita.geology.uiowa.edu/ds_zcoral.htm). The first

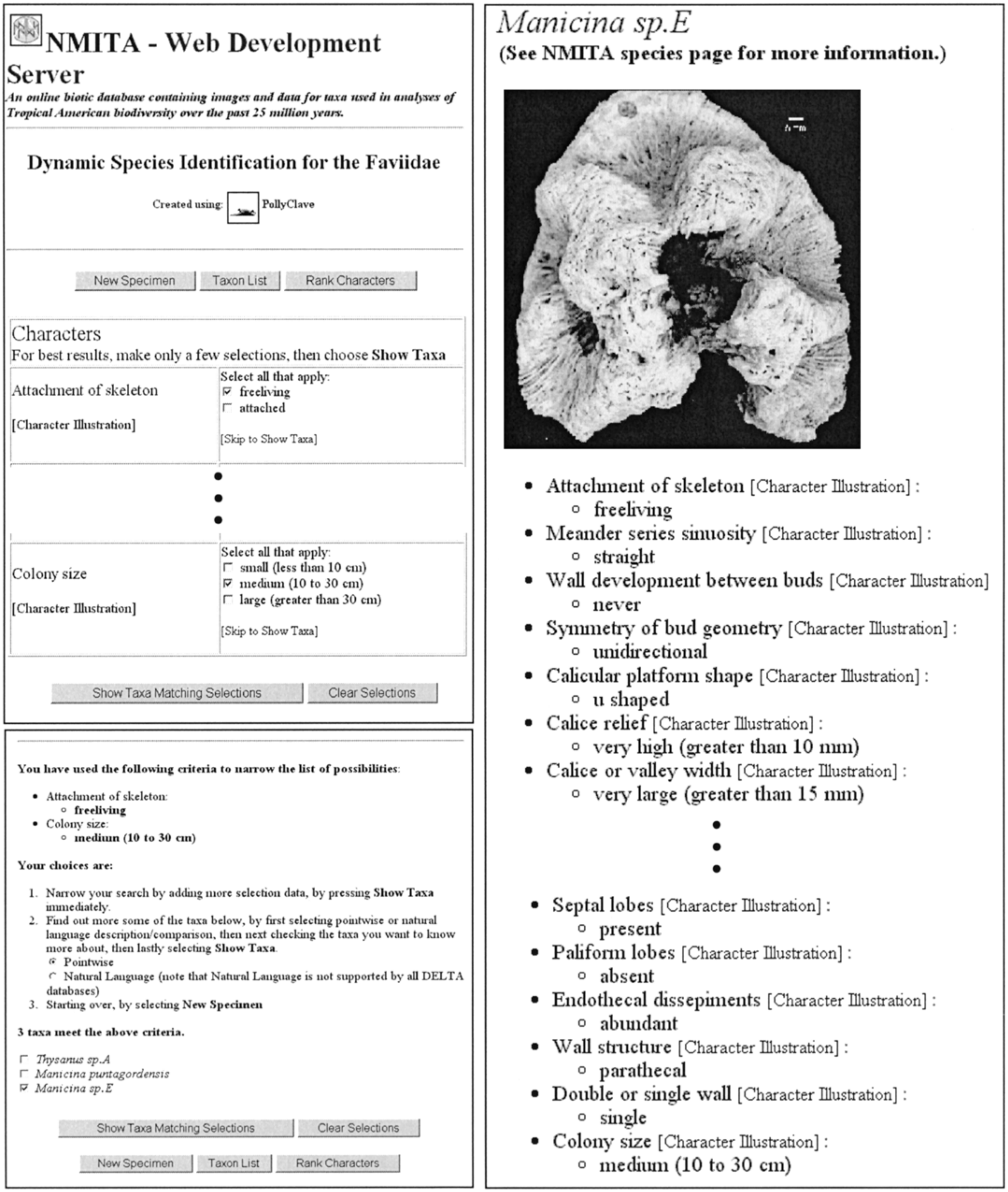
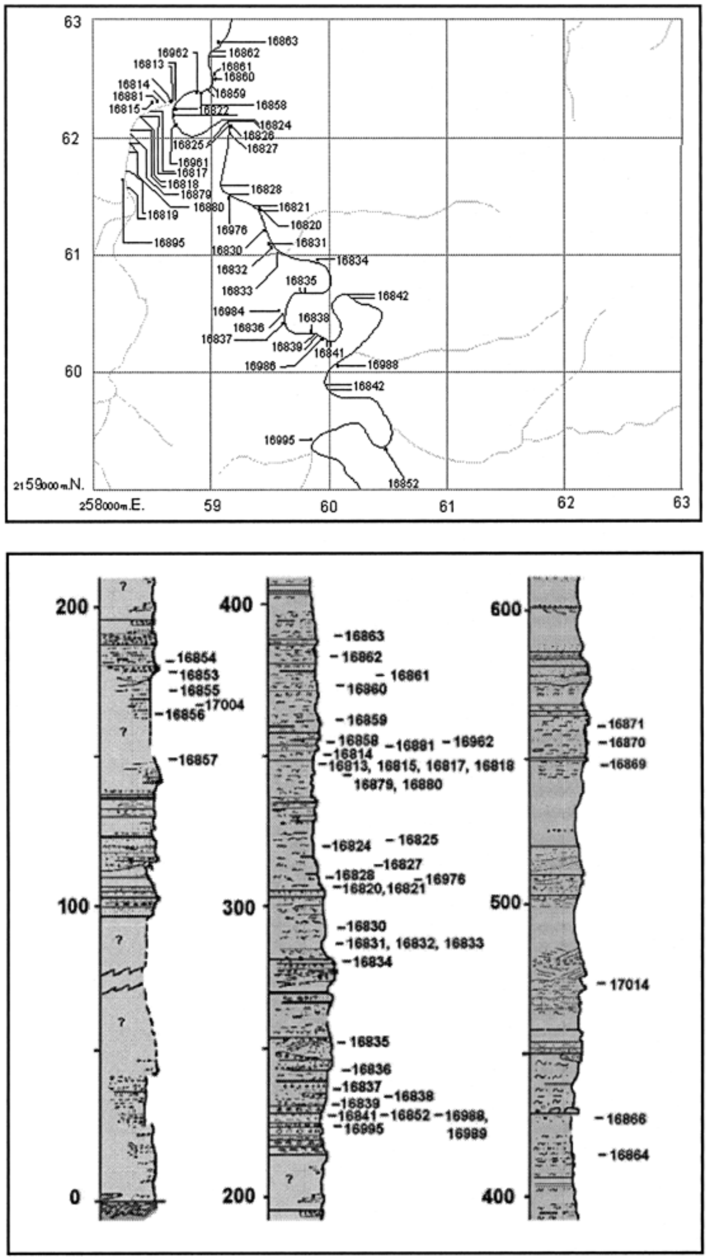


FIGURE 6—Pollyclave identification key for the zooxanthellate coral family Faviidae. The user selects states for one or more characters from a list of 23 characters (top left panel), and obtains a list of faviid coral species meeting the criteria (bottom left panel). From this list of taxa, the user may select one or more taxa, and obtain images and a complete list of characters for that taxon (right panel).



Locality = NMB16881 Cana, 352 m, Gurabo Formation, nn12, e.Pliocene

Locality Group = C5, Cana5, 330 - 375 m, Rio Cana, fig.15&16, Saunders et al. 1986, 5.6 - 4.5 Ma

Faunal List:

Agaricia lamarcki
Dichocoenia tuberosa
Diploria zambensis
Leptoseris gardineri
Leptoseris glabra
Leptoseris sp.A
Leptoseris sp.B
Madracis cf.herricki
Madracis decactis
Meandrina braziliensis
Montastraea-I brevis
Montastraea-I limbata-2
Montastraea-I limbata-3
Montastraea-II canalis
Mussa angulosa
Mussismilia aff.hartti
Pavona sp.A
Pavona sp.B
Porites-I macdonaldi
Porites-I portoricensis
Porites-II baracoaensis
Scolymia cubensis
Stephanocoenia duncani
Stylophora monticulosa
Trachyphyllia bilobata
Undaria agaricites
Undaria crassa
Undaria sp.A

FIGURE 7—Links from localities shown on maps and stratigraphic columns allow users to obtain faunal lists for those localities, which are in turn linked to species pages.

procedure queries the Oracle database for all coral species and generates a web page with a pull-down list from which the user selects the name of a species. This name is submitted to the second procedure, which queries the database and creates an actual species Hypertext Markup Language or ''HTML'' page.

Three types of identification keys using morphologic data are available for zooxanthellate corals: a) polychotomous keys using hypertext links, b) online searches of morphologic data in the Oracle database, and c) online searches using morphologic data in DELTA format (Dallwitz, 1980; Dallwitz et al., 1993–1999). All three involve highly-structured morphologic data with links to glossaries containing morphologic character and character state definitions. In the Oracle search, users select one character state for each of a pre-defined set of morphologic characters, and obtain a list of genera having the selected states. Each genus is linked to its corresponding genus page. Online searches of morphologic data in DELTA format (Fig. 6) are implemented using a computer program named ''Pollyclave'' (http://prod.library.utoronto.ca/polyclave/). The Pollyclave searches are more flexible than the Oracle searches, and offer numerous additional advantages, including the ability to: a) weight characters and specify character reliabilities; b) handle numeric values (including overlapping sets of numeric values), variable characters, and missing values; and c) list similarities and differences among taxa.

Users may also obtain interactive lists of taxa occurring within a selected geographic region or stratigraphic horizon (Fig. 7). Such lists can be generated by clicking on geographic maps or associated stratigraphic columns. These procedures have been developed for three river sections in the DR project by downloading road, river, railroad and city data contained in ESRI's

(Environmental Science Research Institute, Inc.) Digital Chart of the World available on the Penn State University Libraries Digital Chart of the World Server (http://www.maproom.psu.edu/dcw/). The data are in ARC/INFO® (a Geographic Information System software package from ESRI) Export format. These data are merged with scanned 1:50,000 locality maps, which have been imported into ARC/INFO® and registered to the same coordinate system. The merged data sets are then exported and interactive maps are created using web editing tools, linking the image maps to the Oracle database, and writing the PL/SQL code to query the database for information about the age of the formation (s) and coral taxa collected at each locality.

FUTURE PLANS

In addition to adding more high quality data to NMITA, we plan to: 1) share data with projects developing tools for analyzing biodiversity data in paleontology; 2) share data with online museum catalogs (e.g., the NMB and the Type Catalog of Stony Corals at the NMNH) and other specimen databases, and 3) develop new and improved laboratory exercises for use in undergraduate courses in paleontology. Our biggest challenge involves the first objective, in which the NMITA database will be shared with two projects: a) the NCEAS Paleobiology database (see above), and b) the Statistical Analysis of Palaeontological Occurrence Data (''STATPOD'') of Johnson and McCormick (1999). To share data, we will implement online queries of the NMITA database from web sites for the NCEAS Paleobiology Database and STATPOD, thereby allowing users to analyze NMITA data using tools on these other two web sites. The STATPOD programs will allow users to calculate stratigraphic ranges for individual taxa and determine their collective evolutionary rates through geologic time. They will also provide confidence intervals and randomization tests for evaluating the resulting evolutionary patterns.

ACKNOWLEDGMENTS

We thank D. B. Blake and A. I. Miller (two former Paleontological Society journal editors), N. MacLeod, and C. M. Tang for reviewing the manuscript. In addition to the many contributors listed in Table 1, we are grateful to S. P. Jones and J. S. Klaus for writing programs that query the NMITA database, and T. Adrain and V. Baeder-Helmke for image processing and data entry. S. Dahint, A. Heitz, and R. Panchaud helped with preparing, curating, and photographing specimens for NMITA at the Natural History Museum in Basel, Switzerland. The project is funded by a grant from the Biotic Surveys and Inventories Program at the National Science Foundation (DEB-9705199) and by the University of Iowa.

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ACCEPTED 29 DECEMBER 2000