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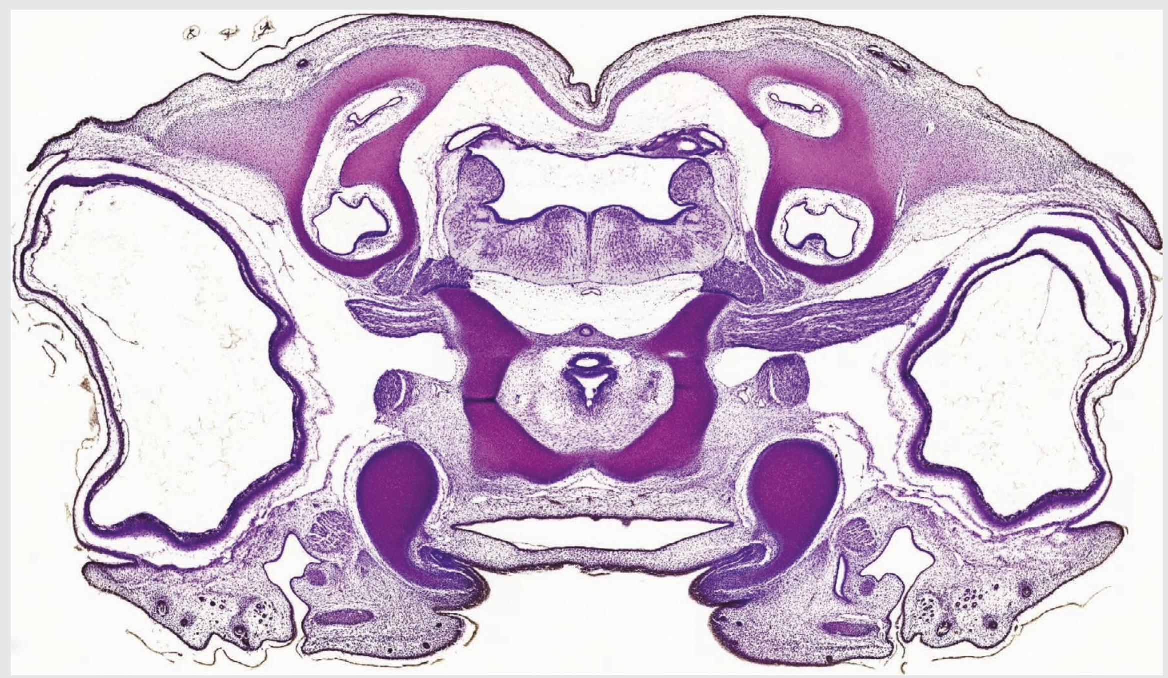

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Photo on the front cover:

Transverse section through the hindbrain region of a spiny dogfish embryo (*Squalus acanthias*). Northcutt Collection slide series MCZ SC-3780, slide 11, stained with Bodian and cresyl violet.

THE R. GLENN NORTHCUTT COLLECTION OF COMPARATIVE VERTEBRATE NEUROANATOMY AND EMBRYOLOGY: A NOVEL MUSEUM-BASED RESOURCE FOR NEUROSCIENCE AND EVOLUTIONARY BIOLOGY

JAMES HANKEN,[1] WILLIAM E. BEMIS,[2] PAUL CERVANTES,[1] MATT GAGE,[1] STEPHEN TURNEY,[3] AND JONATHAN WOODWARD[1]

CONTENTS

Abstract. In 2019, the Harvard Museum of Comparative Zoology acquired The R. Glenn Northcutt Collection of Comparative Vertebrate Neuroanatomy and Embryology, which comprises an estimated 500,000 histologic sections and whole mounts prepared and mounted on glass slides. Assembled by Professor Northcutt between 1963 and 2014 to reveal the microscopic anatomy of the nervous system and related tissues, the collection additionally includes valuable slide series prepared by other neuroanatomists, including John Black Johnston, Othmar Solnitzky, and David Senn. Most included specimens are serially sectioned whole or partial brains for comparative cytoarchitectonic studies. There also are series of entire heads and hundreds of serially sectioned embryos representing 22 genera for studies of the development of sensory systems and cranial nerves. The collection is scientifically unique in its taxonomic breadth: the more than 240 genera and 270 species included represent all major groups of living vertebrates as well as two key outgroups, acorn worms and cephalochordates. Particular strengths include hagfishes, lampreys, chondrichthyans, basal actinopterygians, basal sarcopterygians (including all genera of lungfishes and the coelacanth, *Latimeria*), amphibians, and tuatara (*Sphenodon*), and many families of squamates, turtles, crocodilians, marsupials, and primates. Ongoing curatorial activities are generating digital whole-slide images of most of the collection, which are accessible via the Internet. Here we briefly describe the history of the collection and its scientific importance, methods used to prepare slides, ancillary materials, doctoral and postdoctoral students and visiting scientists who utilized it in their studies, a partial list of publications based on the slides and, finally, a taxonomic inventory of the collection and related information that will facilitate its use in research and education.

Key words: Histology, Brain, Anatomy, Natural History Museum, Neurobiology, Developmental Biology, Zoology, Collections

INTRODUCTION

Historical slide collections prepared from biological specimens are unique and irreplaceable resources for the study of life on Earth; they are highly prized by researchers and

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educators (Richardson and Narraway, 1999; Zilles et al., 2011). Although representing essential vouchers for studies conducted over the last 1.5 centuries or more (Williston, 2016), they also provide valuable substrates for contemporary research (Sanger et al., 2015; Brocklehurst et al., 2016; Miyashita, 2016; Yaryhin and Werneburg, 2019). Yet, such collections are extremely fragile and may degrade with time, especially if they do not receive proper care and conservation (Di Giacomo, 2017; Decker et al., 2018). Natural history museums, which are committed to preserving biological specimens in perpetuity, are logical repositories for such materials. In some instances, they may be the only institutions willing to accept slide collections that are "orphaned" after an investigator's retirement or when a university or other host institution is no longer willing to retain them. At the same time, the capacity for such institutions to share these materials with the broader scientific community is being enhanced by the ongoing development of specialized yet cost-effective whole-slide imaging systems and web-based data management platforms, by which high-resolution images of entire slides may be viewed and analyzed remotely via the Internet (Dietrich et al., 2012; Heerlien et al., 2015; Musson et al., 2015; Decker et al., 2018; Allan et al., 2019; Giere et al., 2019).

The Harvard Museum of Comparative Zoology (MCZ) has embarked on a long-term project to acquire, curate, and digitalize historical slide collections and share these data worldwide. One of the largest collections acquired to date is The R. Glenn Northcutt Collection of Comparative Vertebrate Neuroanatomy and Embryology, a unique resource that comprises an estimated 500,000 histologic sections and whole mounts prepared and mounted on glass slides to reveal the microscopic anatomy of the nervous system and related tissues. Assembled by Professor Northcutt between 1963 and 2014 as the substrate for his renowned studies of the evolution and development of the vertebrate nervous system, the approximately 33,000 slides comprise a main neuroanatomical collection, an embryological collection, and a histochemical collection. In total, these materials were prepared from 270 species representing more than 240 genera. Before their relocation to Harvard, these materials were contained in 439 slide boxes that occupied about 90 linear feet of shelving. Most specimens in the Northcutt Collection comprise serial sections mounted on glass microscope slides. The resulting slide series are unique in the array of staining methods used to prepare them, including many beautiful series stained with technically challenging silver-staining methods such as the Bodian method (Bodian, 1936) and the Golgi–Cox method (Humason, 1979; Vints et al., 2019). Other valuable and interesting specimens include stained whole-mounts of skin that were prepared to show the distribution of neuromasts and electroreceptors in the axolotl, *Ambystoma mexicanum* (see Northcutt, 1990, 1992) and the channel catfish, *Ictalurus punctatus* (see Northcutt et al., 1994).

Here we provide an overview of the Northcutt Collection, including a comprehensive taxonomic list of its contents. For several slide series we indicate the taxon, specimen type (e.g., whole embryo), developmental stage, histologic preparation (plane of section, section thickness, staining method, etc.), and other features that may be of interest and assistance to potential users. Our goals are to announce the existence and availability of the Northcutt Collection, demonstrate its importance to dozens of published comparative studies of the vertebrate nervous system, and promote its future use in research and education. We contend that it will be especially useful to the current generation of neuroscientists who are using molecular and genetic approaches to elucidate mechanisms underlying evolutionary innovations. We also outline ongoing efforts to digitize the entire Northcutt Collection and serve the resulting high-resolution whole-slide images online.

BRIEF HISTORY OF THE NORTHCUTT COLLECTION

Most slides in the Northcutt Collection are derived from neuroanatomical studies conducted by Prof. Northcutt and his many students, postdoctoral fellows, and professional collaborators. The oldest of these materials, prepared in the early 1960s when Prof. Northcutt was an undergraduate at Millikin University, include sections of brains of a salamander (*Ambystoma*), lizards (*Iguana*, *Sceloporus*), and several mammals (*Oryctolagus*, *Rattus*, and *Lasiurus*). The Collection was further developed during Prof. Northcutt's initial faculty appointment at Case Western Reserve University beginning in 1968. Several series of the living coelacanth (*Latimeria chalumnae*) and the Australian lungfish (*Neoceratodus forsteri*) as well as other lungfishes and basal actinopterygians were made at the University of Michigan, where Prof. Northcutt held a faculty position between 1972 and 1986. The numerous histochemical preparations also were made at Michigan. These series include key taxa from across the vertebrate tree such as skates (*Raja* and related genera), rays (e.g., *Potamotrygon*), and sharks (e.g., *Triakis*), as well as marbled bichir (*Polypterus palmas*), longnose gar (*Lepisosteus osseus*), tuatara (*Sphenodon punctatus*), yellow-spotted Amazon River turtle (*Podocnemis unifilis*), and Virginia opossum (*Didelphis virginiana*). These series are of exceptional value because of the quality of the histology, the inherent difficulties of preparing histochemical series, and the rarity of some of the taxa included.

A large number of embryological series are most closely associated with Prof. Northcutt's research at Scripps Institution of Oceanography at the University of California San Diego, where he held a faculty appointment from 1986 until his retirement in 2014, when he transitioned to emeritus professor (Fig. 1). Particularly during the late 1980s and 1990s, one of his major research goals was to understand the role of embryonic placodes in the development of the lateral line and electroreceptive systems, taste buds, and cranial nerves. Only a few of the many hundreds of experimental manipulations of placodal development are included in the Northcutt Collection. Among these are the results of lateral line placodal extirpations and homotopic and heterotopic transplantations in the Mexican axolotl (*A. mexicanum*). By transplanting placodes from wild-type (pigmented) embryos into albino embryos, the migration and fates of placodally derived cells could be assessed by the distribution of dark pigment in skin mounts of the chimeric salamander later in development.

Finally, the collection also includes slide series prepared by other American and European neuroanatomists, including John Black Johnston (1868–1939), Othmar Solnitzky (1897–1980), and David G. Senn (1940—). Despite their age—some of J. B. Johnston's series were prepared no later than 1910—these slides are still in excellent condition and remain useful for neuroanatomic studies.

In 2014, the entire Northcutt Collection at Scripps was inventoried and then moved to Prof. William E. Bemis's laboratory at Cornell University in Ithaca, New York (Bemis and Northcutt, 2019). In 2019, ownership was transferred to Harvard University and the collection relocated to the MCZ in Cambridge, Massachusetts, where the slides are housed in a secure collections facility and maintained at constant temperature and humidity in lightproof cabinets (Fig. 2). Once at MCZ, slides were transferred from their original boxes onto stainless steel trays, accessioned into the museum's permanent Special Collections department, given unique identifying numbers, and individually barcoded. Whole-slide imaging of

Figure 1. Prof. R. Glenn Northcutt at the University of California San Diego, November 2014. On the shelves to his left are rows of slide boxes containing a small portion of the Northcutt Collection. Several additional slide boxes are open on the table in front of him. Photo by William E. Bemis.

Figure 2. (A) Slide cabinets in the Museum of Comparative Zoology; (B) each cabinet holds 600 trays; (C) each tray holds 36 or 72 slides, depending on slide size.

the entire collection began in 2021 with support from the U.S. National Science Foundation and the Faculty of Arts & Sciences, Harvard University. Corresponding digital images are accessible online directly via MCZbase, the museum's shared database, and indirectly via MorphoSource, a repository for digital image data hosted by Duke University, Durham, North Carolina.

No slides were culled from the Northcutt Collection before its move from Scripps, first to Cornell and then to Harvard. However, a small number of slide series was already on loan to investigators before the initial move. Some of these loans have since been returned and attempts by MCZ curatorial staff to recover the remaining outstanding loans are ongoing. As slides are returned, they are processed as described above. In general, very few slides in the Northcutt Collection are cracked or broken, and those that are damaged remain accessible—and are being digitalized—along with the rest of their series.

SLIDE PREPARATION AND ANNOTATION

Several different specimen fixatives and histological embedding methods were used to prepare slides in the Northcutt Collection. Typically, specimens were perfused with formol–alcohol (alcohol–formalin–glacial acetic acid fixative) or immersed in buffered formalin (Humason, 1979; Presnell and Schreibman, 1997). Most specimens were sectioned with a rotary microtome after being paraffin embedded because of the ease of mounting "ribbons" of paraffin sections and the wide array of methods that can be used to stain them. Some specimens, however, particularly intact embryos or embryonic tissues, were embedded in LKB Historesin (LKB-Produkter AB, Bromma, Sweden) or JB-4® polymer and the sections mounted individually. Such "plastic" sections present outstanding cellular detail but cannot be processed with many of the most important stains used for conventional neuroanatomy. Specimens for the histochemical series and some in the main collection were embedded in Tissue-Tek® O.C.T. Compound (Sakura Finetek USA, Inc., Torrance, California), frozen, and sectioned using a cryostat or an American Optical 860 sliding microtome equipped with a freezing stage; sections were mounted individually. Typically, paraffin sections were cut at a thickness of 10–15 μm, plastic sections at 5 μm, and frozen sections at 40 μm. The number of slides per series is a function of the size of the original specimen, section thickness, plane of section, and other factors. Many individual slide series in the Northcutt Collection include more than 100 slides each. Depending on specimen size, from 1 to 50 or more sections may be mounted on a single slide. The Northcutt Collection does not include uncut blocks containing embedded specimens or partially cut blocks used to prepare existing slides.

Most slides were identified originally by an alphanumeric code etched with a diamond scribe into the slide's label region (Fig. 3). Typically, but not always, the code begins with two letters that indicate the Latin name (binomial) of the species. "PM," for example, is the code for the sea lamprey, *Petromyzon marinus*. Additional characters indicate the number of the slide series of a given species (e.g., "PM-2" for the second series of *P. marinus*); multiple slides within a given series are numbered sequentially (1, 2, 3, etc.). When the Northcutt Collection came to the MCZ, each slide series was in addition given a Special Collections (SC) number, and a unique barcode sticker was affixed to each slide to aid tracking its physical location in storage cabinets (Fig. 3). Each SC number corresponds to a unique specimen record in MCZbase that contains all metadata associated with a given slide

Figure 3. Northcutt Collection slide of spiny dogfish, *Squalus acanthias* (Special Collections 3780, slide 32). A barcode sticker has been affixed to the label region at left, which also has the original Northcutt number, SA-62, etched with a diamond scribe. See also Figure 4.

series, such as specimen preservative, section thickness, staining procedure, developmental stage, specimen size and age, handwritten notes by Prof. Northcutt or other investigators, and, as they are generated, links to slide scan files on Faculty of Arts & Sciences Research Computing-managed network storage (Fig. 4). The name of the preparator is known for several series, and this information too is declared on the corresponding MCZbase record. For example, two whole-embryo series of spiny dogfish, *Squalus acanthias*, were cut by James DuPrie (Fig. 5), and at least 38 histochemical series of numerous species were cut by Ron Nichols. Finally, many slides are annotated with marks and notations made during original surveys and highlighting sections selected for use in publications. Typically, these annotations were made on the coverslip in alcohol-soluble ink, and every effort has been made to retain these annotations as slides are unpacked, cleaned, imaged, etc.

ARRANGEMENT OF SECTIONS

Sections prepared in paraffin embedding media, including Bodian-stained series in the Northcutt Collection, are typically arranged in one or more horizontal rows, each with successive sections in a "left-to-right" numerical sequence that parallels the long axis of the slide (Fig. 6). Sections cut from tissue blocks embedded in plastic are organized instead in a series of vertical columns, each with an "up–down" sequence of sections. For both paraffin and plastic sections, the series begins in the top left corner of the slide, adjacent to the label region, and it ends in the lower right corner. When each successive section is mounted, the "offset distance" (α)

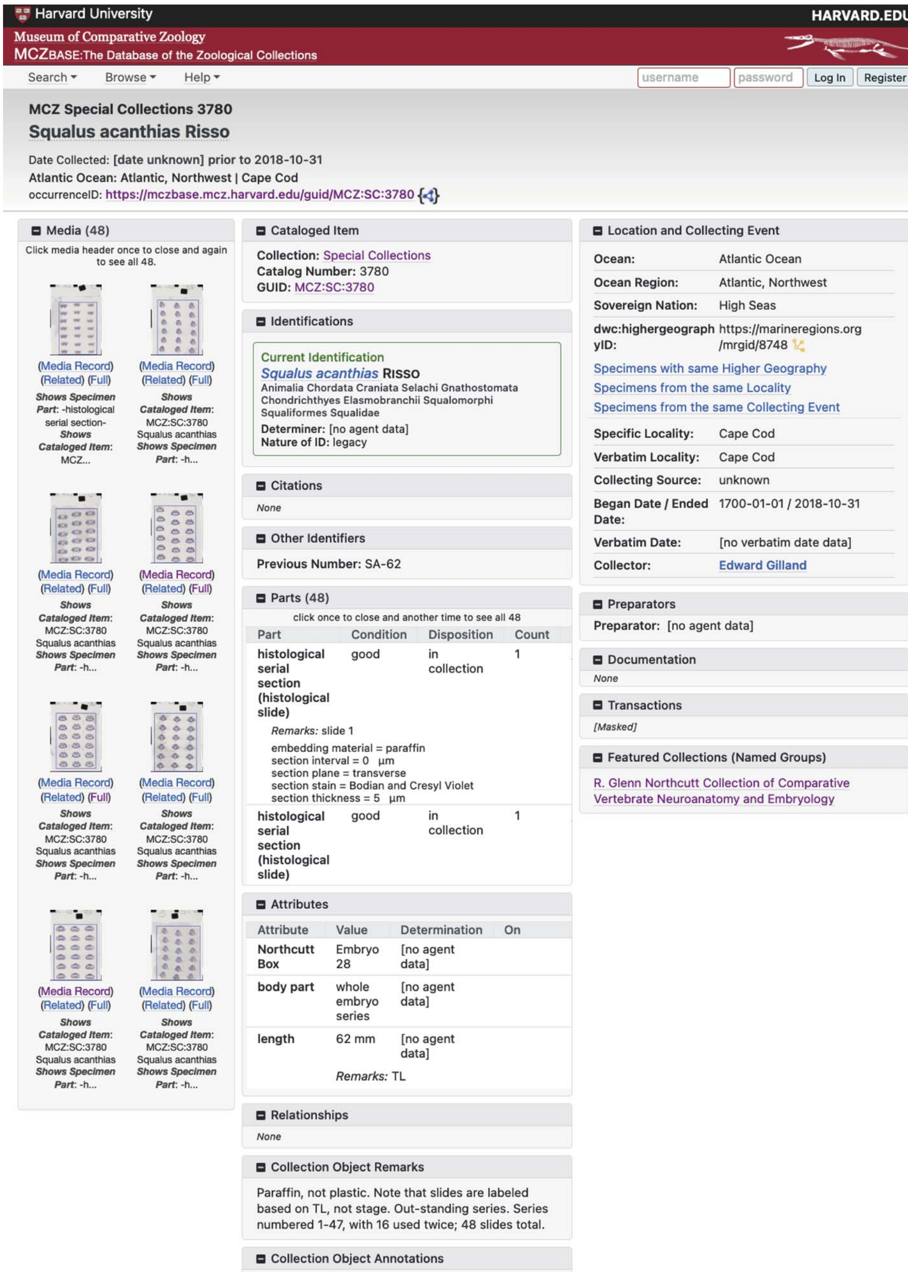

Figure 4. MCZbase specimen record of one Northcutt Collection slide series. Special Collections 3780 comprises 48 slides prepared from a 62-mm-long embryo of spiny dogfish, *Squalus acanthias* (Northcutt number SA-62). When digital whole-slide images are available, as here, thumbnail images are displayed in the media field (left column). Clicking on (Full) below a given thumbnail image opens the full image. See also Figure 3.

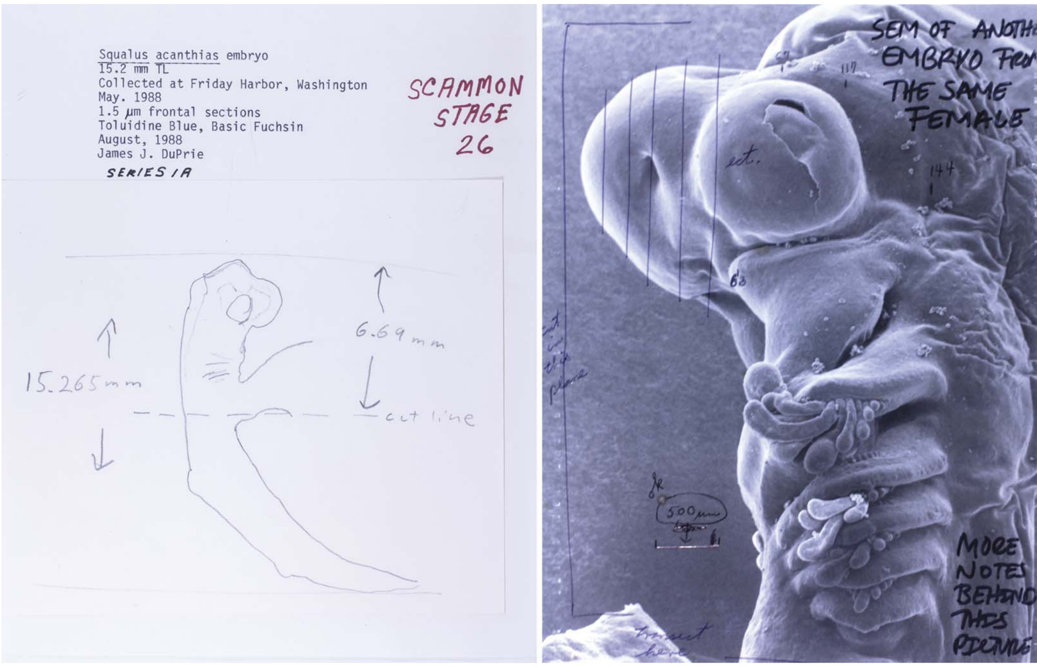

Figure 5. Preparation notes and scanning electron micrograph (SEM) accompanying Special Collections 3762, a series of 99 Northcutt Collection slides of an embryo of spiny dogfish, *Squalus acanthias*. The notes identify the person who prepared the sections, James J. DuPrie, and provide other important information. SEM by William E. Bemis.

between sections is 0 µm. Nonzero values of α apply to situations in which sections to be mounted were saved at regular intervals, e.g., every fifth section.

PUBLICATIONS BASED ON THE NORTHCUTT COLLECTION

Publications by Prof. Northcutt and his many students, postdocs, and professional collaborators are listed in Appendix 1. Nearly all of these publications report studies that were based on examination of slides in the Northcutt Collection. Publications by additional workers who utilized the slides in their research are not included, but as we learn of such works their citations will be added to an online, up-to-date version of this list that will be maintained by the MCZ and linked to Northcutt Collection metadata: https://mcz.harvard.edu/r-glenn-northcutt-collection. Please send information regarding such publications to MCZ_collections_operations@oeb.harvard.edu. When a given slide series can be associated with a particular publication based on it, we will upload a Portable Document Format (PDF) version of the publication to the corresponding MCZbase specimen record for use by students and researchers.

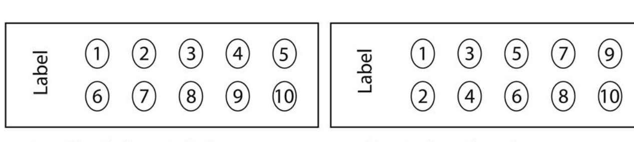

Figure 6. Numerical order of serial sections on Northcutt slides differs according to embedding medium: paraffin vs. plastic.

ANCILLARY MATERIALS

Developmental Series Preserved in Fluid

Associated with the slide collection are several important developmental series preserved in fluid. These include specimens of African knifefish (*Gymnarchus niloticus*), Australian lungfish (*Neoceratodus forsteri*), and aquatic and terrestrial caecilians (*Typhlonectes compressicauda* and *Ichthyophis kohtaoensis*). Some of these developmental series have already been embedded in plastic and sectioned (e.g., embryos of *Neoceratodus* and *Ichthyophis*).

Unpublished Notes and Drawings

Unpublished scanning electron micrographs, labeled camera lucida drawings of sections, notes, and schematic diagrams of embryonic materials are associated with several specimens in the Northcutt Collection (Fig. 5). These materials will be digitized and linked with the corresponding online (MCZbase) specimen records for ready access.

NORTHCUTT TAXONOMIC INVENTORY

Slide series in the Northcutt Collection, organized taxonomically by higher taxon, genus, and species, are listed in Table 1. Some species names originally used to identify the slide series ("Northcutt Taxonomy") are no longer in use; "Current Taxonomy" lists the corresponding valid names obtained from the following sources: *World Register of Marine Species* (WoRMS Editorial Board, 2024); *Eschmeyer's Catalog of Fishes* (Fricke et al., 2024); *Amphibian Species of the World 6.2* (Frost, 2024); *eBird/Clements Checklist v2023b* (Clements et al., 2023); *Mammal Diversity Database, v. 1.12.1* (Mammal Diversity Database, 2023); *ITIS* (Integrated Taxonomic Information System on-line database); *National Center for Biotechnology Information (NCBI) Taxonomy* (Schoch et al., 2020); and *The Reptile Database* (Uetz et al., 2023). For a few series identified originally only to genus (or family), the species cannot be determined. A few additional slide series and individual slides not listed in Table 1 include sections of domestic chicken, unidentified mammals and frogs, and human spinal cord and fetal brain. The latter materials will be transferred to an appropriate repository that is authorized to maintain human remains.

Examples of slide series in the Northcutt Collection, with associated metadata regarding specimen type, slide preparation, etc., are listed in Table 2. Additional notes regarding specimen source and preservation, section quality, associated publications, and other features are available for many series. They can be obtained from the corresponding online specimen records in MCZbase or by direct communication with curatorial staff.

DISCUSSION

The Northcutt Collection is an irreplaceable resource for studies of the evolution and development of the vertebrate brain and nervous system, especially for the current generation of neuroscientists using molecular and genetic approaches to elucidate mechanisms underlying evolutionary innovations. It complements other existing brain collections whose potential contributions to comparative neuroanatomy are largely unrealized (Iwaniuk, 2010, 2011; Kaas and van Eden 2011; Zilles et al., 2011). It is the product of a unique period in human and scientific history, when the dedication and resources needed to assemble such a collection matched global access to the specimens that are its basis. Changing patterns of science funding, changing national regulations regarding access to diverse biological materials, and, most important, changing and degraded natural environments make it unlikely that such a collection will be replicated in the future. Many of the most important studies based on the Northcutt Collection were made at

TABLE 1. SLIDE SERIES IN THE NORTHCUTT COLLECTION, ORGANIZED TAXONOMICALLY BY HIGHER TAXON, GENUS, AND SPECIES. "NUMBER OF SLIDE SERIES" INDICATES THE TOTAL NUMBER OF SERIES AND, WITHIN PARENTHESES, THE CORRESPONDING NUMBERS OF NEUROANATOMICAL SERIES/EMBRYOLOGICAL SERIES/HISTOCHEMICAL SERIES/FLAT MOUNTS.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
Acorn worms (Hemichordata: Enteropneusta)	*Balanoglossus aurantiaca*	*Balanoglossus aurantiacus*	golden acorn worm	1 (1/-/-/-)
Lancelets (Cephalochordata: Leptocardii)	*Branchiostoma floridae*	*Branchiostoma floridae*	Florida lancelet	1 (1/-/-/-)
Hagfishes (Agnatha: Myxini)	*Eptatretus stoutii*	*Eptatretus stoutii*	Pacific hagfish	7 (7/-/-/-)
	Myxine glutinosa	*Myxine glutinosa*	Atlantic hagfish	1 (1/-/-/-)
Lampreys (Agnatha: Cyclostomi)	*lchthyomyzon unicuspis*	*lchthyomyzon unicuspis*	silver lamprey	2 (2/-/-/-)
	Mordacia mordax	*Mordacia morax*	short-headed lamprey	8 (-/-/-/8)
	Petromyzon marinus	*Petromyzon marinus*	sea lamprey	24 (8/14/-/2)
Chimaeras (Chondrichthyes: Holocephali)	*Hydrolagus colliei*	*Hydrolagus colliei*	spotted ratfish	6 (6/-/-/-)
Skates and rays (Chondrichthyes: Elasmobranchii: Batoidea)	*Dasyatis*	*Dasyatis*[1]	rays	1 (1/-/-/-)
	Gymnura marmorata	*Gymnura marmorata*	California butterfly ray	1 (1/-/-/-)
	Leucoraja erinacea	*Raja erinacea*	little skate	2 (2/-/-/-)
	Leucoraja ocellata	*Raja ocellata*	winter skate	1 (1/-/-/-)
	Could be any of several valid genera	*Raja* sp.[1]	skate	1 (1/-/-/-)
	Could be any of several valid genera	*Raja*[1]	skate	1 (-/-/1/-)
	Platyrhinoidis triseriata	*Platyrhinoidis triseriata*	thornback guitarfish	11 (8/3/-/-)
	Potamotrygon	*Potamotrygon*[1]	stingray	4 (-/-/4/-)
	Rostroraja eglanteria	*Raja eglanteria*	clearnose skate	20 (3/17/-/-)
	Urobatis halleri	*Urolophus halleri*	Haller's round ray	1 (1/-/-/-)
Sharks (Chondrichthyes: Elasmobranchii: Selachii)	*Ginglymostoma cirratum*	*Ginglymostoma cirratum*	nurse shark	5 (5/-/-/-)
	Heterodontus francisci	*Heterodontus francisci*	horn shark	3 (3/-/-/-)
	Isistius brasiliensis	*Isistius brasiliensis*	cookie cutter shark	1 (1/-/-/-)
	Mustelus canis	*Mustelus canis*	smooth dogfish	2 (2/-/-/-)
	Notorynchus cepedianus	*Notorynchus maculatus*	broadnose sevengill shark	1 (1/-/-/-)
	Scyliorhinus canicula	*Scyliorhinus canicula*	smaller spotted catshark	1 (1/-/-/-)
	Squalus acanthias	*Squalus acanthias*	spiny dogfish	56 (35/21/-/-)[2]
	Squatina dumeril	*Squatina dumeril*	sand devil	1 (1/-/-/-)
	Triakis semifasciata	*Triakis*	leopard shark	1 (-/-/1/-)
Coelacanth (Osteichthyes: Sarcopterygii: Coelacanthi)	*Latimeria chalumnae*	*Latimeria chalumnae*	West Indian Ocean coelacanth	8 (8/-/-/-)
Lungfish (Osteichthyes: Sarcopterygii: Dipneusti)	*Lepidosiren paradoxa*	*Lepidosiren paradoxa*	South American lungfish	3 (3/-/-/-)
	Neoceratodus forsteri	*Neoceratodus forsteri*	Australian lungfish	21 (2/17/-/2)
	Protopterus	*Protopterus*[1]	African lungfish	1 (1/-/-/-)
	Protopterus amphibius	*Protopterus amphibius*	East African lungfish	4 (4/-/-/-)
	Protopterus annectens	*Protopterus annectens*	West African lungfish	5 (2/-/-/3)[3]
Bichir and reedfish (Osteichthyes: Actinopterygii: Cladistii: Polypteriformes)	*Erpetoichthys calabaricus*	*Calamoichthys calabaricus*	reedfish	2 (2/-/-/-)
	Polypterus palmas	*Polypterus palmas*	marbled bichir	13 (9/-/4/-)
	Polypterus senegalus	*Polypterus senegalus*	gray bichir	11 (3/8/-/-)

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
Sturgeon and paddlefish (Osteichthyes: Actinopterygii: Actinopteri: Chondrostei)	*Acipenser oxyrinchus*	*Acipenser oxyrhynchus*	Atlantic sturgeon	2 (2/-/-/-)
	Acipenser transmontanus	*Acipenser transmontanus*	white sturgeon	8 (6/2/-/-)
	Polyodon spathula	*Polyodon spathula*	Mississippi paddlefish	4 (4/-/-/-)
	Scaphirhynchus platorynchus	*Scaphirhynchus platorynchus*	shovelnose sturgeon	27 (5/22/-/-)
Bowfin and gars (Osteichthyes: Actinopterygii: Actinopteri: Holostei)	*Amia calva*	*Amia calva*	bowfin	8 (8/-/-/-)
	Lepisosteus oculatus	*Lepisosteus productus*	spotted gar	3 (3/-/-/-)
	Lepisosteus osseus	*Lepisosteus osseus*	longnose gar	11 (6/-/5/-)
Teleost fish (Osteichthyes: Actinopterygii: Actinopteri: Teleostei)	*Ameiurus melas*	*Ictalurus melas*	black bullhead	1 (1/-/-/-)
	probably *Amphilophus labiatus*	*Cichlasoma erythraeum*	red devil cichlid	1 (1/-/-/-)
	Anabas testudineus	*Anabas testudineus*	climbing perch	1 (1/-/-/-)
	Anguilla rostrata	*Anguilla rostrata*	American eel	1 (1/-/-/-)
	Ariopsis felis	*Galeichthys felis*	hardheaded sea catfish	1 (1/-/-/-)
	Astronotus ocellatus	*Astronotus ocellatus*	oscar	5 (5/-/-/-)
	Astroscopus ygraecum	*Astroscopus ygraecum*	southern stargazer	1 (1/-/-/-)
	Astyanax jordani	*Anoptichtys jordani*	blind cave tetra	1 (1/-/-/-)
	Balistoides conspicillum	*Balistoides conspicillum*	clown triggerfish	3 (3/-/-/-)
	Brevoortia tyrannus	*Brevoortia tyrannus*	Atlantic menhaden	2 (2/-/-/-)
	Carassius auratus	*Carassius auratus*	goldfish	38 (38/-/-/-)
	Chirocentrus dorab	*Chirocentrus dorab*	Dorab wolf herring	1 (1/-/-/-)
	Cichlasoma portalegrense	*Aequidens portalegrensis*	port acara	4 (4/-/-/-)
	Could be any of several valid genera	*Clarius* sp.[1]	catfish	1 (1/-/-/-)
	Clupea harengus	*Clupea harengus*	Atlantic herring	3 (3/-/-/-)
	Crenuchus spilurus	*Crenuchus spilurus*	sailfin tetra	1 (1/-/-/-)
	Culaea inconstans	*Eucalia inconstans*	brook stickleback	1 (1/-/-/-)
	Cyema atrum	*Cyema atrum*	bobtail snipe eel	1 (1/-/-/-)
	Danio rerio	*Danio rerio*	zebrafish	13 (6/-/7/-)
	Devario aequipinnatus	*Devario aequipinnatus*	giant danio	1 (1/-/-/-)
	Diodon hystrix	*Diodon hystrix*	spot-fin porcupinefish	1 (1/-/-/-)
	Eigenmannia virescens	*Eigenmannia virescens*	glass knifefish	2 (2/-/-/-)
	Electrophorus electricus	*Electrophorus electricus*	electric eel	1 (1/-/-/-)
	Elops saurus	*Elops saurus*	ladyfish	1 (1/-/-/-)
	Embiotoca jacksoni	*Embiotoca jacksoni*	black perch	1 (1/-/-/-)
	Engraulis mordax	*Engraulis mordax*	northern anchovy	1 (1/-/-/-)
	Esox lucius	*Esox lucius*	northern pike	2 (2/-/-/-)
	Gillichthys mirabilis	*Gillichthys mirabilis*	long-jawed mudsucker	1 (1/-/-/-)
	Gnathonemus petersii	*Gnathonemus petersi*	elephantnose fish	1 (1/-/-/-)
	Gymnarchus niloticus	*Gymnarchus niloticus*	African knifefish	3 (3/-/-/-)
	Neither genus nor species specified	Gymnotidae sp.	naked-back knifefishes	1 (1/-/-/-)
	Gymnothorax moringa	*Gymnothorax moringa*	spotted moray	1 (1/-/-/-)

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
	Hemichromis bimaculatus	*Hemichromis bimaculatus*	jewelfish	7 (7/-/-/-)
	Hiodon tergisus	*Hiodon tergisus*	mooneye	1 (1/-/-/-)
	Hippocampus erectus	*Hippocampus hudsonius*	lined seahorse	1 (1/-/-/-)
	Hippocampus zosterae	*Hippocampus zosterae*	dwarf seahorse	3 (3/-/-/-)
	Holocentrus rufus	*Holocentrus rufus*	longspine squirrelfish	2 (2/-/-/-)
	Hoplias malabaricus	*Hoplias malabaricus*	trahira	1 (1/-/-/-)
	Hypopomus artedi	*Hypopomus artedii*	knifefish	1 (1/-/-/-)
	probably *Hypostomus plecostomus*	*Plecostomus cyanin*	suckermouth catfish	1 (1/-/-/-)
	Ictalurus punctatus	*Ictalurus punctatus*	channel catfish	90 (5/70/-/15)
	Lagodon rhomboides	*Lagodon rhomboides*	pinfish	1 (1/-/-/-)
	Lepomis cyanellus	*Lepomis cyanellus*	green sunfish	5 (5/-/-/-)
	Lepomis gibbosus	*Lepomis gibbosus*	pumpkinseed sunfish	1 (1/-/-/-)
	possibly *Anguilla rostrata*	Leptocephalus	eel larva	1 (1/-/-/-)
	Leuresthes tenuis	*Leuresthes tenuis*	California grunion	1 (1/-/-/-)
	Lipogramma klayi	*Lippogramma klaiji*	bicolor basslet	1 (1/-/-/-)
	Myrichthys breviceps	*Myrichthys accuminatus*	sharptail eel	1 (1/-/-/-)
	Oncorhynchus mykiss	*Salmo gairdneri*	rainbow trout	8 (5/-/3/-)
	Opistognathus maxillosus	*Opistognathus maxillosus*	mottled jawfish	1 (1/-/-/-)
	Oreochromis mossambicus	*Tilapia mossambica*	Mozambique tilapia	1 (1/-/-/-)
	Osteoglossum bicirrhosum	*Osteoglossum bicirrhosum*	silver arawana	2 (2/-/-/-)
	Pantodon buchholzi	*Pantodon buchholzi*	freshwater butterflyfish	1 (1/-/-/-)
	Parachanna africana	*Ophiocephalus africanus*	African snakehead	1 (1/-/-/-)
	Paralabrax clathratus	*Paralabrax clathratis*	kelp bass	1 (1/-/-/-)
	Rasbora caudimaculata	*Rasbora caudimaculata*	greater scissortail	2 (2/-/-/-)
	Rhabdolichops troscheli	*Rhabdolichops troscheli*	glass knifefish	1 (1/-/-/-)
	Rhinecanthus aculeatus	*Rhinecanthus aculeatus*	blackbar triggerfish	1 (1/-/-/-)
	Sorubim lima	*Sorubin lima*	shovel-nose catfish	1 (1/-/-/-)
	Sphyraena barracuda	*Sphyraena barracuda*	great barracuda	4 (4/-/-/-)
	Strongylura notata	*Strongylura notata*	redfin needlefish	1 (1/-/-/-)
	Thunnus alalunga	*Thunnus alalunga*	albacore	1 (1/-/-/-)
	Toxotes jaculatrix	*Toxotes jaculatrix*	banded archerfish	2 (2/-/-/-)
	Trachinotus blochii	*Trachinotus falcatus*	tropical pompano	1 (1/-/-/-)
	Umbra limi	*Umbra limi*	central mudminnow	1 (1/-/-/-)
	Xenomystus nigri	*Xenomystus nigri*	African knifefish	1 (1/-/-/-)
Amphibia	species unknown	species unknown	amphibian	1 (-/-/-/1)
Salamanders and newts (Amphibia: Caudata)	*Ambystoma maculatum*	*Ambystoma maculatum*	spotted salamander	65 (10/55/-/-)
	Ambystoma mexicanum	*Ambystoma mexicanum*	axolotl	238 (4/43/-/191)[4]
	Ambystoma tigrinum	*Ambystoma tigrinum*	tiger salamander	8 (8/-/-/-)
	Amphiuma means	*Amphiuma means*	two-toed amphiuma	1 (1/-/-/-)
	Cryptobranchus alleganiensis	*Cryptobranchus alleganiensis*	hellbender	3 (2/-/-/1)[3]

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
	Dicamptodon ensatus	*Dicamptodon ensatus*	California giant salamander	1 (-/-/-/1)
	Ichthyosaura alpestris	*Triturus alpestris*	Alpine newt	1 (-/-/-/1)
	Necturus maculosus	*Necturus maculosus*	common mudpuppy	6 (5/-/-/1)
	Notophthalmus viridescens	*Notophthalmus viridescens*	eastern newt	1 (1/-/-/-)
	Siren intermedia	*Siren intermedia*	lesser siren	1 (-/-/-/1)
Frogs and toads (Amphibia: Anura)	*Anaxyrus americanus*	*Bufo americanus*	American toad	1 (1/-/-/-)
	Anaxyrus boreas	*Bufo boreas*	boreal toad	1 (1/-/-/-)
	Aquarana catesbeiana	*Rana catesbeiana*	American bullfrog	10 (8/-/2/-)
	Ascaphus truei	*Ascaphus truei*	tailed frog	1 (1/-/-/-)
	Bombina orientalis	*Bombina orientalis*	Oriental fire-bellied toad	1 (-/-/-/1)
	Could be any of several valid genera	*Bufo* sp.[1]	toad	4 (4/-/-/-)
	Lithobates pipiens	*Rana pipiens*	northern leopard frog	11 (11/-/-/-)
	Pseudacris crucifer	*Hyla crucifer*	spring peeper	1 (1/-/-/-)
	Rhinella marina	*Bufo marinus*	marine toad	1 (1/-/-/-)[5]
	Spea hammondii	*Scaphiopus hammondi*	western spadefoot toad	1 (1/-/-/-)
	Xenopus laevis	*Xenopus laevis*	African clawed frog	16 (4/12/-/-)
Caecilians (Amphibia: Gymnophiona)	*Ichthyophis glutinosus*	*Ichthyophis glutinosus*	common yellowband caecilian	1 (1/-/-/-)
	Ichthyophis kohtaoensis	*Ichthyophis kohtaoensis*	Koa Tao Island caecilian	6 (-/6/-/-)
	Typhlonectes natans	*Typhlonectes natans*, *Nectocaecilia haydee*	Rio Cauca caecilian	5 (5/-/-/-)
Alligators, crocodiles, and caiman (Reptilia: Crocodylia)	*Alligator mississippiensis*	*Alligator mississippiensis*	American alligator	2 (2/-/-/-)
	Caiman crocodilus	*Caiman crocodilus*, *C. sclerops*	spectacled caiman	27 (23/-/4/-)
	Crocodylus niloticus	*Crocodylus niloticus*	Nile crocodile	4 (4/-/-/-)[5]
Turtles and tortoises (Reptilia: Testudines)	*Acanthochelys spixii*	*Platemys spixii*	black spine-necked swamp turtle	1 (1/-/-/-)
	Apalone spinifera	*Trionyx spinifer*	spiny softshell	1 (1/-/-/-)
	Caretta caretta	*Caretta caretta*	loggerhead turtle	4 (4/-/-/-)
	Carettochelys insculpta	*Carettochelys insculpta*	pitted-shelled turtle	1 (1/-/-/-)
	Chelonia mydas	*Chelonia mydas*	green sea turtle	5 (5/-/-/-)
	Chelonoidis carbonarius	*Geochelone carbonaria*	red-footed tortoise	2 (2/-/-/-)
	Chelydra serpentina	*Chelydra serpentina*	common snapping turtle	6 (6/-/-/-)
	Chelus fimbriata	*Chelys fimbriata*	mata mata	1 (1/-/-/-)
	Chrysemys picta	*Chrysemys picta*	painted turtle	5 (3/-/2/-)
	Chrysemys picta bellii	*Chrysemys picta bellii*	western painted turtle	28 (28/-/-/-)
	Dermatemys mawii	*Dermatemys mawii*	hickatee	1 (1/-/-/-)
	Emys orbicularis	*Emys orbicularis*	European pond turtle	1 (1/-/-/-)
	Gopherus agassizii	*Gopherus agassizi*	Agassiz's desert tortoise	2 (2/-/-/-)
	Kinosternon acutum	*Kinosternon actum*	Tabasco mud turtle	1 (1/-/-/-)
	Lissemys punctata	*Lissemys punctata*	Indian flap-shelled turtle	1 (1/-/-/-)
	Pelomedusa subrufa	*Pelomedusa subrufa*	helmeted turtle	1 (1/-/-/-)
	Pelusios sinuatus	*Pelusios sinuatus*	East African serrated mud turtle	1 (1/-/-/-)
	Platysternon megacephalum	*Platysternon megalocephalum*	big-headed turtle	1 (1/-/-/-)

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
	Podocnemis expansa	*Podocnemis expansa*	giant South American river turtle	1 (1/-/-/-)
	Podocnemis unifilis	*Podocnemis unifilis*	yellow-spotted Amazon River turtle	7 (3/-/4/-)
	Pseudemys or *Trachemys*	*Pseudemys*[1]	freshwater turtle	1 (1/-/-/-)
	Terrapene carolina	*Terrapene carolina*	common box turtle	1 (1/-/-/-)
	Trachemys scripta	*Pseudemys scripta*	red-eared slider	1 (1/-/-/-)
	Could be any of several valid genera	*Trionyx*[1]	softshell turtles	1 (1/-/-/-)
Tuatara (Reptilia: Lepidosauria: Sphenodontia)	*Sphenodon punctatus*	*Sphenodon punctatus*	tuatara	10 (6/-/4/-)
Amphisbaenians (Reptilia: Lepidosauria: Squamata: Amphisbaenia)	*Amphisbaena innocens*	*Amphisbaena innocens*	innocent worm lizard	2 (2/-/-/-)
	Amphisbaena kingii	*Anops kingi*	King's worm lizard	1 (1/-/-/-)
	Bipes biporus	*Bipes biporus*	five-toed worm lizard	1 (1/-/-/-)
	Cynisca leucura	*Cynisca leucura*	coast worm lizard	1 (1/-/-/-)
	Rhineura floridana	*Rhineura floridana*	Florida worm lizard	1 (1/-/-/-)
Lizards and snakes (Reptilia: Lepidosauria: Squamata)	*Acontias kgalagadi*	*Typhlosaurus lineatus*	Kalahari burrowing skink	1 (1/-/-/-)
	Afrotyphlops blanfordii	*Typhlops blanfordi*	Blanford's blind snake	1 (1/-/-/-)
	Ahaetulla nasuta	*Dryophis nasutus*	long-nosed tree snake	2 (2/-/-/-)
	Ameiva ameiva	*Ameiva ameiva*	Amazon racerunner	1 (1/-/-/-)
	Anelytropsis papillosus	*Anelytropsis papillosus*	Mexican blind lizard	1 (1/-/-/-)
	Anilios bituberculatus	*Ramphotyphlops bituberculatus*	prong-snouted blind snake	1 (1/-/-/-)
	Anniella pulchra	*Anniella pulchra*	California legless lizard	1 (1/-/-/-)
	Anolis carolinensis	*Anolis carolinensis*	green anole	4 (4/-/-/-)
	Aspidoscelis sexlineatus	*Cnemidophorus sexlineatus*	six-lined racerunner	1 (1/-/-/-)
	Basiliscus basiliscus	*Basiliscus basiliscus*	common basilisk	2 (2/-/-/-)
	Callisaurus draconoides	*Callisaurus draconoides*	zebra-tailed lizard	2 (2/-/-/-)
	Calotes versicolor	*Calotes versicolor*	eastern garden lizard	1 (1/-/-/-)
	Causus rhombeatus	*Causus rhombeatus*	rhombic night adder	1 (1/-/-/-)
	Cercosaura argulus	*Prionodactylus argulus*	white-lipped cercosaura	1 (1/-/-/-)
	Coleonyx variegatus	*Coleonyx variegatus*	western banded gecko	1 (1/-/-/-)
	Corallus cookii	*Boa cooki*	Cook's tree boa	1 (1/-/-/-)
	Coluber constrictor	*Coluber constrictor*	eastern racer	1 (1/-/-/-)
	Could be any of several valid genera	*Cordylus* sp.[1]	spiny lizard	1 (1/-/-/-)
	Crotalus helleri	*Crotalus viridis helleri*	southern Pacific rattlesnake	2 (2/-/-/-)
	Crotaphytus collaris	*Crotaphytus collaris*	collared lizard	1 (1/-/-/-)
	Ctenosaura quinquecarinata	*Enyaliosaurus quinquecarinatus*	five-keeled spiny-tailed iguana	1 (1/-/-/-)
	Ctenosaura hemilopha	*Ctenosaura hemilopha*	Baja California spiny-tailed iguana	2 (2/-/-/-)
	Dibamus novaeguinae	*Dibamus novaeguineae*	New Guinea blind earless skink	1 (1/-/-/-)
	Dipsosaurus dorsalis	*Dipsosaurus dorsalis*	desert iguana	5 (5/-/-/-)

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
	Dracaena guianensis	*Dracaena guianensis*	northern caiman lizard	1 (1/-/-/-)
	Draco sp.	*Draco* sp.[1]	flying dragon	1 (1/-/-/-)
	Elgaria multicarinata	*Gerrhonotus multicarinatus*	southern alligator lizard	1 (1/-/-/-)
	Epictia phenops	*Leptotyphlops phenoys*	slender threadsnake	1 (1/-/-/-)
	Eumeces algeriensis	*Eumeces algeriensis*	Algerian skink	1 (1/-/-/-)
	Gambelia wislizenii	*Crotaphytus wislizenii, Gambelia wislizeni*	longnose leopard lizard	2 (2/-/-/-)
	Gekko gecko	*Gekko gecko*	tokay	5 (3/-/2/-)
	Gymnophthalmus speciosus	*Gymnophthalmus speciosus*	golden spectacled tegu	1 (1/-/-/-)
	Heloderma horridum	*Heloderma horridum*	Mexican beaded lizard	1 (1/-/-/-)
	Heterodon nasicus	*Heterodon nasicus*	western hog-nosed snake	2 (2/-/-/-)
	Heterodon platirhinos	*Heterodon platyrhinos*	eastern hog-nosed snake	2 (2/-/-/-)
	Iguana iguana	*Gambelia iguana*	common green iguana	19 (19/-/-/-)[5]
	Intellagama lesueurii	*Physignathus lesueuri*	eastern water dragon	1 (1/-/-/-)
	Lacerta schreiberi	*Lacerta schreiberi*	Iberian emerald lizard	1 (1/-/-/-)
	Lacerta trilineata	*Lacerta trilineata*	Balkan emerald lizard	1 (1/-/-/-)
	Lacerta viridis	*Lacerta viridis*	green lizard	1 (1/-/-/-)
	Lampropeltis nigra	*Lampropeltis getulus niger*	black kingsnake	1 (1/-/-/-)
	Lanthanotus borneensis	*Lanthanotus borneensis*	Borneo earless monitor	1 (1/-/-/-)
	Laticauda semifasciata	*Laticauda semifasciatum*	broad-banded blue sea krait	1 (1/-/-/-)
	Leptophis ahaetulla	*Leptophis ahaetuilla*	parrot snake	1 (1/-/-/-)
	Lialis burtonis	*Lialis burtonis*	Burton's legless lizard	1 (1/-/-/-)
	Liotyphlops albirostris	*Liotyphlops albirostris*	whitenose blind snake	1 (1/-/-/-)
	Loxopholis parietalis	*Leposoma parietale*	common root lizard	1 (1/-/-/-)
	Malayopython reticulatus	*Python reticulata*	reticulated python	1 (1/-/-/-)
	Naja haje	*Naja haje*	Egyptian cobra	1 (1/-/-/-)
	Natrix natrix	*Natrix natrix*	common grass snake	1 (1/-/-/-)
	Nerodia sipedon	*Natrix sipedon*	common watersnake	8 (6/-/2/-)[5]
	Ophisaurus compressus	*Ophisaurus compressus*	island glass lizard	1 (1/-/-/-)
	Paralaudakia caucasia	*Agama caucasica*	Caucasian agama	1 (1/-/-/-)
	Pholidobolus montium	*Pholidobolus montium*	mountain pholidobolus	1 (1/-/-/-)
	Phrynosoma cornutum	*Phrynosoma cornutum*	Texas horned lizard	7 (7/-/-/-)
	Phrynosoma platyrhinos	*Phrynosoma platyrhinos*	desert horned lizard	7 (7/-/-/-)
	Pituophis catenifer annectens	*Pituophis catenifer annectens*	San Diego gopher snake	1 (1/-/-/-)
	Platysaurus sp.	*Platysaurus* sp.[1]	flat lizard	1 (1/-/-/-)
	Podarcis siculus	*Lacerta sicula*	Italian wall lizard	13 (13/-/-/-)
	Potamites ecpleopus	*Neusticurus ecpleopus*	common stream lizard	1 (1/-/-/-)
	Proctoporus bolivianus	*Proctoporus bolivianus*	Bolivian lightbulb lizard	1 (1/-/-/-)
	Proctoporus rahmi	*Euspondylus rahmi*	Rahm's sun tegu	1 (1/-/-/-)
	Rena dulcis	*Leptotyphlops dulcis*	Texas slender blind snake	1 (1/-/-/-)
	Rena humilis	*Leptotyphlops humilis*	western threadsnake	1 (1/-/-/-)

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
	Sceloporus magister	*Sceloporus magister*	desert spiny lizard	3 (3/-/-/-)
	Sceloporus undulatus	*Sceloporus undulatus*	fence lizard	1 (1/-/-/-)
	Scincella lateralis	*Scincella laterale*	ground skink	1 (1/-/-/-)
	Sphaerodactylus cinereus	*Sphaerodactylus cinereus*	gray gecko	1 (1/-/-/-)
	Thamnophis sirtalis	*Thamnophis sirtalis*	common garter snake	4 (4/-/-/-)
	Thelotornis kirtlandii	*Thelotornis kirtlandii*	forest vine snake	1 (1/-/-/-)
	Trioceros bitaeniatus	*Chamaeleo bitaeniatus*	side-striped chameleon	1 (1/-/-/-)
	Trioceros jacksonii	*Chamaeleo jacksoni*	Jackson's chameleon	6 (5/-/1/-)
	Tupinambis teguixin	*Tupinambus teguixin*	common tegu	1 (1/-/-/-)
	Typhlops pusillus	*Typhlops pusillus*	Hispaniola worm snake	1 (1/-/-/-)
	Varanus bengalensis	*Varanus bengalensis*	Bengal monitor	1 (1/-/-/-)
	Varanus niloticus	*Varanus niloticus*	Nile monitor	2 (2/-/-/-)
	Xantusia vigilis	*Xantusia vigilis*	desert night lizard	1 (1/-/-/-)
	Xenosaurus agrenon	*Xenosaurus grandis agrenon*	mountain knob-scaled lizard	1 (1/-/-/-)
Birds (Aves)	*Anas platyrhynchos*	*Anas platyrhynchos*	mallard	1 (1/-/-/-)
	Columba livia	*Columba livia*	rock pigeon	1 (1/-/-/-)
	Corvus brachyrhynchos	*Corvus brachyrhynchos*	American crow	3 (3/-/-/-)
	Gallus gallus	*Gallus gallus*	red junglefowl	4 (4/-/-/-)
	Meleagris gallopavo	*Meleagris gallapavo*	wild turkey	1 (1/-/-/-)
	Melopsittacus undulatus	*Melopsittacus undulatus*	budgerigar	8 (8/-/-/-)
	Opisthocomus hoazin	*Opisthocomus hoazin*	hoatzin	3 (3/-/-/-)
	Ortalis poliocephala	*Ortalis poliocephala*	west Mexican chachalaca	1 (1/-/-/-)
	Passer domesticus	*Passer domesticus*	house sparrow	5 (5/-/-/-)
	Pygoscelis adeliae	*Pygoscelis adeliae*	Adelie penguin	1 (1/-/-/-)
	Serinus canaria	*Serinus canarius*	island canary	3 (3/-/-/-)
	Struthio camelus	*Struthio camelus*	common ostrich	1 (1/-/-/-)
	Sturnus vulgaris	*Sturnus vulgaris*	European starling	4 (4/-/-/-)
	Taeniopygia guttata	*Poephila guttata*	zebra finch	1 (1/-/-/-)
	Tyto alba	*Tyto alba*	barn owl	1 (1/-/-/-)
Mammals (Mammalia)	*Canis familiaris*	*Canis familiaris*	domestic dog	1 (1/-/-/-)[6]
	Chlorocebus sabaeus	*Cercopithecus aethiops sabaeus*	grivet	1 (1/-/-/-)[6]
	Didelphis marsupialis	*Didelphis marsupialis*	southern opossum	3 (3/-/-/-)
	Didelphis virginiana	*Didelphis virginiana*	Virginia opossum	3 (-/-/3/-)
	Felis catus	*Felis domestica*	domestic cat	1 (1/-/-/-)
	Heterohyrax brucei	*Heterohyrax* sp.[1]	yellow-spotted rock hyrax	1 (1/-/-/-)
	Lasiurus borealis	*Lasiurus borealis*	eastern red bat	1 (1/-/-/-)
	Macaca mulatta	*Macaca rhesus, M. mulatta*	rhesus macaque	3 (3/-/-/-)[6]
	Macaca sp.	*Macaca* sp.[1]	macaque	3 (3/-/-/-)[6]
	Meriones	*Meriones*[1]	jird (several species possible)	1 (1/-/-/-)
	Mus musculus	*Mus musculus*	house mouse	2 (2/-/-/-)
	Oryctolagus cuniculus	*Oryctolagus cuniculus*	European rabbit	3 (3/-/-/-)
	Ovis aries	*Ovis aries*	mouflon	1 (1/-/-/-)[6]

Table 1. Continued.

Higher Taxon	Current Taxonomy	Northcutt Taxonomy	Common Name	Number of Slide Series
	Perodicticus potto	*Perodicticus potto*	potto	2 (2/-/-)[6]
	Rattus norvegicus	*Rattus norvegicus*	Norway rat	6 (6/-/-)
	Sapajus apella	*Cebus fatuellus*	tufted capuchin	2 (2/-/-)[6]
	Scalopus aquaticus	*Scalopus aquaticus*	eastern mole	1 (1/-/-)
	Suncus murinus	*Suncus murinus*	house shrew	2 (2/-/-)
	Tupaia glis	*Tupaia glis*	common tree shrew	3 (3/-/-)

[1] Identified only to genus—species unspecified.
[2] Includes at least 22 neuroanatomical series from the J. B. Johnston Collection ("Squalus 1 & 2").
[3] Species identification of one skin mount is tentative.
[4] There are additional skin mounts of axolotl from lateral-line extirpation and transplantation experiments.
[5] One or more series are listed in the original Northcutt Collection inventory (Bemis and Northcutt, 2019) as being on loan or otherwise were not transmitted to the Museum of Comparative Zoology.
[6] O. Solnitzky Collection.

Scripps Institution of Oceanography, where Prof. Northcutt was a member of the five-faculty Neurobiology Unit. Led by Theodore Bullock, the other members were Walter Heiligenberg, Ad Kalmijn, and James Enright. The Neurobiology Unit became an attractive destination for students, colleagues and visitors from around the world, many of whom contributed to the scientific study of the Northcutt Collection (Appendix 2).

The Northcutt Collection can serve as the basis for many future research projects, ranging from comparative cytoarchitectonic studies to the comparative embryology of placodally derived sense organs and cranial nerves. Cytoarchitectonics was a primary rationale for the main (neuroanatomical) collection, but the full potential of this data set has never been realized because it was assembled sequentially over many years as individual species became available. Now, however, many of the most important vertebrate taxa are well represented, so, at last, they may be compared directly. There are, for example, exquisite but unstudied series of kelp bass (*Paralabrax clathratus*), Picasso triggerfish (*Rhinecanthus aculeatus*), and Nile crocodile (*Crocodylus niloticus*). In addition, several slide series in the histochemical collection include beautiful sections stained with cresyl violet. The thickness of these sections (40 μm) makes them especially useful as reference material for studies of cytoarchitectonics. Similarly, the embryonic collection contains excellent thin plastic sections prepared to examine lateral line and cranial nerve development in shovelnose sturgeon (*Scaphirhynchus platorynchus*), Australian lungfish (*N. forsteri*), and the Koa Tao Island caecilian (*I. kohtaoensis*), but these studies remain to be pursued. The availability of additional fluid-preserved, intact embryos for some of these series will facilitate complementary studies using methods such as scanning electron microscopy and diffusible iodine-based contrast-enhanced computed tomography to visualize sense organs and nerves, respectively.

Table 2. Examples of slide series in the Northcutt Collection. Abbreviations: CL, carapace length; SVL, snout–vent length; TL, total length. Slides of rhesus macaque are derived from the O. Solnitzky collection.

Species	Common Name	Specimen Type, Age, Stage, etc.	SC #	Northcutt #	Embedding Medium	Plane of Section	Section Thickness and Interval	Stain/Method	Number of Slides
Petromyzon marinus	sea lamprey	whole embryo, Piavis stage 16, gill clefts	3731	PM-16	plastic	transverse	5 μm α 0 μm	cresyl violet	50
Platyrhinoidis triseriata	thornback guitarfish	neonatal, 48 h	3318	Pt-1	paraffin	transverse	15 μm α 0 μm	Bodian, cresyl violet and hematoxylin	71
Rostroraja eglanteria	clearnose skate	whole embryo, 5 wk	3789	RE-5B	plastic	transverse	5 μm α 0 μm	cresyl violet	32
Squalus acanthias	spiny dogfish	whole embryo, Scammon stage 26, 15.2 mm TL	3762	—	paraffin	frontal	15 μm α 0 μm	toluidine blue and basic fuchsin	100
Scaphirhynchus platorynchus	shovelnose sturgeon	whole embryo, stage 33	3814	Sp33	plastic	transverse	5 μm α 0 μm	cresyl violet	42
Polypterus senegalus	gray bichir	whole embryo, 5 d	3798	PS-1	plastic	transverse	5 μm α 0 μm	cresyl violet	91
Gymnarchus niloticus	African knifefish	5.7 cm TL	3665	Gn-3	paraffin	transverse	15 μm α 0 μm	Bodian	20
Ictalurus punctatus	channel catfish	whole embryo, Armstrong (1962) stage 53	3889	IP-53A	plastic	transverse	5 μm α 0 μm	neutral red	76
Ictalurus punctatus	channel catfish	whole-skin flat mount, stage 43	3911	—	—	—	—	methylene green	1
Neoceratodus forsteri	Australian lungfish	whole embryo, Kemp (1982) stage 30	3932	NF-30	plastic	transverse	5 μm α 0 μm	cresyl violet	30
Ambystoma mexicanum	axolotl	whole embryo, Bordzilovskaya et al. (1989) stage 33	3975	AMx-S33, set 1	plastic	horizontal	5 μm α 0 μm	cresyl violet	36
Ichthyophis kohtaoensis	Koa Tao Island caecilian	whole embryo, 34 mm TL	4006	IK-34	plastic	transverse	5 μm α 0 μm	cresyl violet	74
Sphenodon punctatus	tuatara	brain	3142	SP1	paraffin	transverse	15 μm α 0 μm	Klüver	12
Heloderma horridum	lizard	brain	3256	H-1	frozen	transverse	40 μm α 0 μm	cresyl violet	23
Podarcis siculus	Italian wall lizard	embryo, 4 d	3590	Ls-4B	paraffin	horizontal	10 μm, α 0 μm	cresyl violet	4
Iguana iguana	iguana	brain	3118	I-12	paraffin	transverse	15 μm α 0 μm	Cajal method I	36
Nerodia sipedon	common watersnake	stage 36	3102	Ns-36	paraffin	transverse	15 μm α 0 μm	Klüver	20
Chelydra serpentina	common snapping turtle	31.2 g, 4.0 cm CL	3373	Cs-4	paraffin	transverse	15 μm α 0 μm	cresyl violet	20
Chrysemys picta bellii	turtle	olfactory bulb	3251	Cp-12	paraffin	horizontal	15 μm α 0 μm	Nauta, 7 d	8

Table 2. Continued.

Species	Common Name	Specimen Type, Age, Stage, etc.	SC #	Northcutt #	Embedding Medium	Plane of Section	Section Thickness and Interval	Stain/Method	Number of Slides
Gopherus agassizii	desert tortoise	brain	3120	Ga	paraffin	transverse	15 µm ∝ 45 µm	cresyl violet	8
Opisthocomus hoazin	hoatzin	late embryo	—[1]	Op-1	paraffin	transverse	15 µm ∝ 0 µm	cresyl violet	1–18
Macaca mulatta	rhesus macaque	brain	—[1]	—	paraffin	horizontal	60 µm ∝ 180 µm	Morgan hematoxylin	10

[1] Special Collections accession number is not yet assigned.

Now that the Northcutt Collection is accessioned and properly housed in MCZ facilities, attention has shifted to making these valuable materials readily accessible to a variety of audiences. Digital imaging of the slides will undoubtedly facilitate their use in research and education and complement novel technologies for studying brain structure, development, and function (Motta et al., 2019; Kalra et al., 2020; Shapson-Coe et al., 2024). It will foster fruitful collaborations between the neuroscience and biodiversity communities and, together with related projects that seek the mass digitization and sharing of other biological collections, will enhance the ability of natural history institutions to more fully serve both science and society and thus move beyond their traditional constituencies (Suarez and Tsutsui, 2004; Lendemer et al., 2020; Heberling et al., 2021; Blackburn et al., 2024). Two recent grant awards, one from the U.S. National Science Foundation and another from the Harvard Faculty of Arts & Sciences, are making this goal a reality. High-resolution whole-slide images prepared by using high-throughput, automated slide scanners (Fig. 7) are being served online in two ways: directly via individual records in MCZ's museum-wide specimen database, MCZbase; and indirectly via the digital image repository MorphoSource. (All of the whole-slide images are maintained on storage servers at Harvard.) As of 11 December 2024, 8,255 whole-slide images of the Northcutt Collection have been prepared and are available for viewing, analysis, and downloading from both sites. Details regarding the whole-slide imaging workflow and other aspects of image sharing will be presented in a subsequent publication.

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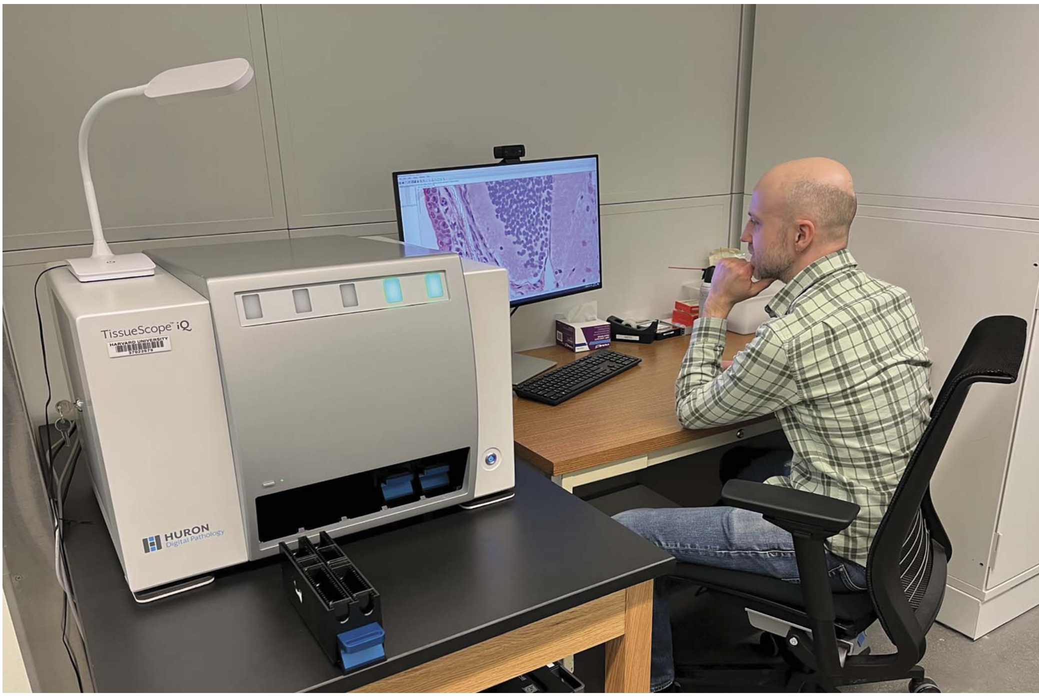

Figure 7. Scanning station used to digitize the Northcutt Collection. The automated slide scanner on table at left (TissueScope™ iQ Intelligent Slide Scanner; Huron Digital Pathology, Ontario, Canada) is operated from an adjacent computer workstation. Photo by James Hanken.

unpacking, cleaning, accessioning, and barcoding the Northcutt Collection. The Tontogany Creek Fund and R. Glenn Northcutt defrayed costs associated with moving the collection from University of California San Diego to Cornell. Digitization of the Northcutt Collection is supported by the National Science Foundation (DBI-2122620, to J.H. and Josh Sanes) and by the Harvard University Faculty of Arts & Sciences Dean's Competitive Fund for Promising Scholarship (2020 cycle, to J.H.). Andrew Bass, Michael Pritz, and an anonymous reviewer provided valuable suggestions regarding earlier drafts. Finally, we thank Glenn and Mary Sue Northcutt for the decades they spent preparing, curating, and sharing the R. Glenn Northcutt Collection of Comparative Vertebrate Neuroanatomy and Embryology. By facilitating ready access to the Collection, they enabled students and researchers from all over the world to study these materials, thus transforming the study of comparative vertebrate neurobiology.

APPENDIX 1

Publications by Prof. Northcutt and collaborators; nearly all are based on slides in the Northcutt Collection. Additional publications by other workers who used the slides in their research are not included.

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APPENDIX 2

Doctoral students, postdoctoral trainees, and visiting scientists whose research utilized the Northcutt Collection or who contributed to the acquisition, preparation and study of materials contained within it

Doctoral students	
Jose Alves-Gomes (1994–96)	Michael B. Pritz (1969–75)
Andrew H. Bass (1975–79)	Richard L. Puzdrowski (1981–88)
Christopher B. Braun (1992–97)	Mark C. Ronan (1978–83)
Ann B. Butler (1968–71)	Jiakun Song (1982–89)
Kenneth C. Catania (1991–94)	Georg F. Striedter (1985–90)
Preston Holmes (1993–2001)	Walter Wilczynski (1973–78)
Catherine A. McCormick (1973–78)	Calvin Wong (1994–97)
Postdoctoral Trainees	
Michael L. Andry (1975–78)	Stuart Matz (1995–99)
Linda A. Barlow (1992–97)	Timothy J. Neary (1974–77)
Diana H. Bauer (1976–78)	Carmen Piñeula (1993–96)
Mark R. Braford, Jr. (1972–75)	Barbara Rupp (1995–96)
Shaun P. Collin (1989–91)	Gerhard Schlosser (1996–98)
Heather Eisthen (1992–93)	Jacqueline F. Webb (1987–89)
Melissa Gibbs (1997–98)	Helmut Wicht (1989–91)
Michael Hofmann (1993–95)	Mario F. Wullimann (1985–88)
Visiting Scientists	
James Albert	Leo S. Demski
F. Amemiya	E. Fiebig
William E. Bemis	Bernd Fritzsch
David A. Bodznick	H. M. Mueller
Jeffery T. Corwin	Wolf Plassman
D. Crapon de Caprona	Tatjana Piotrowski
Bruce Criley	Thomas F. Schilling
William L. R. Cruce	W. J. A. J. Smeets

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