Database Development for Ocean Impacts:  
Imaging, Outreach, and Rapid Response

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LONG-TERM GOALS

The overall goal for this project is to provide a web-accessible database on the anatomy and physiology of marine mammals, their prey species, and other endangered marine species for which there are concerns for underwater acoustic impacts.

OBJECTIVES

A principal objective of this project is to provide a resource for the research community to improve accuracy of models and representations of marine mammal anatomy and standardization of measures taken during strandings which will as improve our broader understanding and response efficacy for stranding events. This multi-year effort will provide to the scientific community, stranding network, and public a research resource, educational tutorials at the lay and professional research level, professional clinical case histories, and interpretative manuals on imaging procedures, related research, and determination of normal vs abnormal findings for in vivo and post-mortem exams of marine mammals and sea turtles.

APPROACH

Available case material currently comprises over 1100 image sets from 170 species of marine and land mammals, including approximately 400 data sets for cetaceans alone. Making this database available to the scientific community is critical for several research fronts attempting to solve acoustic impact issues; e.g., finite element and finite difference models (FEM/FDM) of acoustic propagation characteristics of different species, modeling tissue responses to over exposure, understanding differences amongst species for specific sound sources, and the education of stranding responders and pathologists in the recognition and interpretation of normal variants vs. pathologies in different post-mortem stages for marine mammals.

The following developments are underway to transition the image files and related case metadata to a web database: design and testing of a large capacity database server to store images, case histories, and sound files; a secure network for transfer of data both locally (WHOI networks) and remotely.
(World Wide Web); a secure database allowing content to be continuously updated; and a website for information with registered user and public access to appropriate subsets of the data.

WORK COMPLETED

Database Development
A working public version of the website is accessible at www.whoi.edu/csi. This provides preliminary image sets and annotations at the lay level for a limited range of taxa and pathologies. The projected final database is undergoing beta testing with registered user accessibility only and is hosted on a local WHOI web server (cetus.whoi.edu). When public, the site traffic will be analyzed using Google Analytics to improve internet visibility and all web content will be optimized for multiple search engines.

We have integrated about ninety percent of all content on the current CSI website into the new website. Base configuration of a dynamic MySQL database structure that will serve the website content is complete with the exception of security configuration, annotations of images, and final metadata links.

Website design and CSS styling for individual web pages have been themed but not reviewed for final layout by laboratory staff and students. The current beta testing phase of website development is estimated to take one or two months to complete.

Current features of the new image database website include but are not limited to:

- User Login and Registration - (This option allows website administrators to control access rights to website content based on user profile criteria.)
- User Profiles - (This option allows users and website administrators to access and edit usernames, passwords and user information.)
- Full Boolean search capabilities for all content including images, multimedia and text files.
- Complete bibliography database of laboratory literature and specimen case files with multiple sorting options including publication type, year, author, title, keyword, etc.; export/import of citations in multiple formats; abstract and full text viewing; downloadable full text or abstract PDF files and upload of citations by users in multiple formats including EndNote, Tagged, XML and BibTex.
- Multiple image and video galleries containing sample images and videos obtained from CT scans, 3D reconstructions and field and laboratory dissections as well as links to specific case images and data for individual specimens.
- Audio galleries of sample recordings from representative species of whales and dolphins.
- Embedded PDF documents viewable without third party software (such as Adobe Reader)
- A service request form for all CT services for users requesting scan operations for new data acquisition or image processing for specific applications
- Web form reports to allow import and export of spreadsheets and tables in multiple formats including xcl, dba, acc and mysql.
• RSS feed aggregators for related stranding popular media news sites; e.g., WHOI News, CNN, and BBC News
• Categorized interdisciplinary discussion forums
• Content commenting for website user feedback and questions.
• Event Calendars - (This option will provide users with a list of upcoming interdisciplinary events for groups both within and outside WHOI. It also integrates iCal for use with thunderbird, outlook, apple mail, iPod, and entourage)
• Multiple embedded flash components for viewing web pages and search pages
• Categorized FAQ (frequently asked questions) section
• Create Content - (This option gives website administrators the ability to allow content creation by website users such as for events, publications, comments, forums, images and videos based on user profile criteria)
• Integrated links to multiple WHOI related websites and funding organizations

Datasets Added
592 specimens scanned as follows:

• Coral cores for climate change research (A. Cohen, WHOI, PI)
• Stromatolites for climate change research (J. Bernard, A. McIntyre-Wressnig, WHOI, PI)
• Chondrichthyes (Rays and Shark) for fin design and hydrodynamics (F. Fish in association with Robert Russo, University of Virginia Department of Mechanical & Aerospace Engineering, PI)
• Narwhal flippers and flukes (F. Fish in association with Natalia Rybczynski, Canadian Museum of Nature-Research/ Paleobiology)
• Seals and pigs in pressure chamber (A. Fahlman, M. Moore, WHOI, PI)
• Odontocetes and seals for IFAW/NOAA NMFS for stranding diagnostics
• Turtle ear 3D reconstructions and fat volumes for hearing study (C. Carr, U. MD, PI)
• Terrapin diagnoses, in vivo, for National Marine Life Center (S. Rogers Williams, DVM)
• Blue whale ears for stranding evaluation (J. Jacobsen, Humboldt State)
• Shipworm infestation experiments (S. Gallagher, WHOI, PI)
• Minke whale head tissues (D. Ketten, WHOI, PI)
• Ziphius cavirostris ears, stranding evaluations (N. Hauser, Cook Islands, PI)
• Tiger ears for LF hearing studies (E. Walsh, Boystown, PI)
• Neophocoena phocaenoides stranding evaluations (W. Ding and D. Ketten, China, PI)
• Sand lances for summer student project on cetacean prey species (S. Strobel, WHOI)
• Bat head scans (J Simmons, Brown Univ., PI)
• Rubber stretch hose to evaluate defects in deep water buoys (L. l O’Hara, D. Peters, WHOI, PI)
• Micro-circuit boards to evaluate crystal defects (E. Gallimore, WHOI, PI)
• Tissue segmentations of whole cetaceans (K. Foote, WHOI, PI)
RESULTS

Unlike most research contracts and proposals, the principal output of this project is not a set of incremental discoveries but rather to categorize and annotate existing data sets acquired for individual projects and as part of diagnostic procedures for stranded animals. The first year of this project was devoted largely to completion of the design and to testing accuracy and efficiency of each component in an operational website. The majority of the second year has been devoted to transitioning existing data to a web-accessible database and increasing the sophistication of the website as well as testing security of proprietary data for individual researchers. In this process and to increase the value of the data, manuals on the scanning procedures used and interpretations of the data sets were submitted for publication. The second year was focused on the transitioning of major filesets for a full range of species, exploration of new protocols for challenging imaging subjects; e.g., high density, multi-meter coral cores, oarfish, and live invertebrates.

Specific progress on the transitioning of datasets consists of the following:

Storage:
A large capacity (10 terabyte) database server (CETUS.whoi.edu) was configured by WHOI Computer Information Systems staff (CIS) to store images in multiple formats and particularly for DICOM data obtained from the WHOI Computerized Scanning and Imaging Facility (WHOI CSI) CT scanner. A DICOM Server application (“Conquest”) was installed on CETUS to view and maintain these images. Conquest is a free open source application that allows modifications and redistribution of the code, providing flexibility and compatibility with similar efforts in linked veterinary and medical radiology sites. DICOM directories were created on CETUS to store CT images.

Networking:
Communication between CETUS, the CT scanner, and laboratory computers was established to move metadata, images, and case files between computers or by remote access using File Transfer Protocol (FTP), Mapped Network Drives (direct connection from one computer drive to another), or HTTP (local access via a web browser). Movement of DICOM images is currently restricted to one way transfer from the CT scanner to the CETUS storage server. Proprietary software limitations on the CT scanner currently prevent two way transfers with the CETUS server. The scanner manufacturer is reviewing a request to remove this block.

IMPACT/APPLICATIONS

The potential for scan data is illustrated by the examples below taken from recent studies within this laboratory. As indicated by the datasets listed above an by the publications list below, scan data is assisting a wide range of ONR researchers and ranges from climate change studies to in vivo diagnostics for determination of rehabilitation potentials and outcomes.

Macro to Micro: Whole Body Imaging to Inner Ear and Hearing Loss of Cetaceans
In Figure 1, 3D reconstructions of two species of odontocetes demonstrate significant differences in the structure, volume, and content of tissues that are critical to sound reception. By segmenting tissues in the heads of each species, based on their X-ray attenuations, which correspond to tissue sound transmission, it is possible to determine geometries fundamental to the frequency and acoustic attenuation characteristics. In both cases, fatty tissues are found to be pinnal analogues but also that these fatty “pinnae” are species specific. This implies that, like the pinnae and outer ear canals of
land mammals, the fatty tissues are critical determinants of peak resonances and thus sensitivities of each species.

**Figure 1.** In each figure, a reconstruction of scans of the head of an intact specimen reveals the skull anatomy (transparent white), two components of the melon (outer layer green and inner core purple), and the multi-lobed fats aligning with and surrounding the mandible (gold) (see also: Ketten, D.R. 2008 Underwater ears and the physiology of impacts: Comparative liability for hearing loss in sea turtles, birds, and mammals. Bioacoustics, vol. 17, no. 1-3, pp. 312-315).

**Fig. 1A.** Dorsal view of head and fats, Common Dolphin, *Delphinus delphis*

**Fig. 1B.** Lateral view of head and dorsal view of fats, Cuvier’s Beaked Whale, *Ziphius cavirostris*

In Figure 2, CT images and 3D reconstructions of the inner ear of bottle nose dolphins are used to calculate sites of absence of auditory nerve fibers and thus corresponding frequencies of hearing loss in older animals. Comparisons of the predicted loss maps with the hearing curves of these animals show perfect correspondance for the maps with hearing abilities measured behaviourally. This exercise demonstrates the accuracy and potential for CT exams to determine the presence or absence of hearing deficits in stranded animals, pre or post mortem.

**Figure 2.** Tursiops truncatus inner ear imaged with CT to obtain frequency of hearing loss. Figure 1A shows the basilar membrane (green) auditory nerve (orange), and ganglion cells and fiber (purple)
distributions. Estimates of frequency calculated for this ear are listed by position on the membrane. The lack of fibers beyond ~57 kHz suggests that this was the high frequency functional cutoff for this animal in its later life. A graph (Fig. 2B) shows the curve calculated for this ear for the frequency distributions. Celloidin histology of the ear confirmed the loss. Comparisons with the actual hearing responses show that this form of diagnosis with CT accurately predicts sensorineural hearing loss from aging and noise in this animal. (see also Ketten, D. R., Arruda, J., S. Cramer, Dunn, M., and Ridgway, S. 2010 Mature Mammal Hearing Loss: A Natural Experiment in Presbycusis. Association for Research in Otolaryngology, Anaheim Calif.).

Figure 2A. 3D reconstruction of inner ear of bottlenose dolphin with superimposed frequency map.

Figure 2B. Calculation of inner ear of bottlenose dolphin frequency map and position of ganglion cell losses related to hearing loss.
RELATED PROJECTS

The methods developed (and personnel employed in the design and implementation) in this database project have been employed to assist in the formation of a second website for the WHOI Marine Mammal Center which will host a website for the dissemination of marine mammal sound data (P. Tyack, PI, N000140710988).

Segmentation data from scan datasets and their analyses for tissue volumes and densities have also been employed in the following ONR projects: lung tissues analyses, Fahlman N000141010791; multi-tissue segmentations, Foote N000140910482; imaging of tissue morphometry under pressure, Moore N000140811220. Other PIs with ONR affiliated projects include hydrodynamics of marine fishes and mammals (F. Fish) and swim bladder morphology (J. Webb).

Publications during the last year related to these projects employing website data are listed below.

PUBLICATIONS (downloadable pdfs http://www.whoi.edu/csi/research/publications.html)

Refereed Journals


In Press


2010 Mooney, TA, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, Nachtigall, PE, Ketten, DR. 2010. Sound detection by the longfin squid (*Loligo pealeii*) studied with auditory evoked potentials:
sensitivity to low-frequency particle motion and not pressure. (accepted, *Journal of Experimental Biology*, in press.)

**Refereed Short Communications**


2010  Tubelli, A., A. Zosuls, D. R. Ketten and D. C. Mountain. Prediction of a Mysticete Audiogram via Finite Element Analysis of the Middle Ear. 2nd International Conference of the Effects of Noise on Aquatic Life, Cork, Ireland

