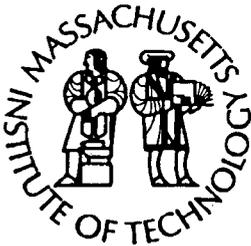


MIT/WHOI 2007-17

**Massachusetts Institute of Technology
Woods Hole Oceanographic Institution**



**Joint Program
in Oceanography/
Applied Ocean Science
and Engineering**



DOCTORAL DISSERTATION

**Biomechanics of North Atlantic Right Whale Bone:
Mandibular Fracture as a Fatal Endpoint for Blunt
Vessel-Whale Collision Modeling**

by

Regina P. Campbell-Malone

September 2007

MIT/WHOI

2007-17

**Biomechanics of North Atlantic Right Whale Bone: Mandibular Fracture as a Fatal
Endpoint for Blunt Vessel-Whale Collision Modeling**

by

Regina P. Campbell-Malone

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

and

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

September 2007

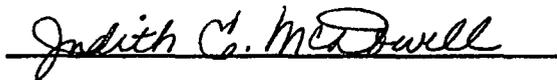
DOCTORAL DISSERTATION

Funding was provided by the National Science Foundation, the National Oceanic and Atmospheric Administration (Award number NA04NMF4720402), the Ocean Life Institute, the Quebec Labrador Foundation, WHOI SeaGrant NA16RG2273, and an MIT Presidential Fellowship. All right whale samples were collected under National Marine Fisheries Service no. 932-1489-05.

Reproduction in whole or in part is permitted for any purpose of the United States Government. This thesis should be cited as: Regina P. Campbell-Malone, 2007. Biomechanics of North Atlantic Right Whale Bone: Mandibular Fracture as a Fatal Endpoint for Blunt Vessel-Whale Collision Modeling. Ph.D. Thesis. MIT/WHOI, 2007-17.

Approved for publication; distribution unlimited.

Approved for Distribution:

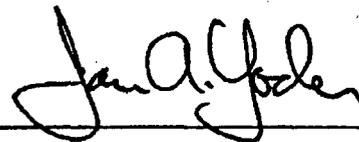


Judith E. McDowell, Chair

Department of Biology



Paola Malanotte-Rizzoli
MIT Director of Joint Program



James A. Yoder
WHOI Dean of Graduate Studies

Biomechanics of North Atlantic Right Whale Bone: Mandibular Fracture as a Fatal Endpoint for Blunt Vessel-Whale Collision Modeling

by

Regina Campbell-Malone

Submitted to the MIT Department of Biology and the WHOI Biology Department in
partial fulfillment of the requirements for the degree of
Doctor of Philosophy

ABSTRACT

The North Atlantic right whale, *Eubalaena glacialis*, one of the most critically endangered whales in the world, is subject to high anthropogenic mortality. Vessel-whale collisions and entanglement in fishing gear were indicated in 27 (67.5%) of the 40 right whales necropsied between 1970 and December 2006. Of those, at least 9 deaths (22.5%) resulted from blunt contact with a vessel. To reduce the likelihood of fatal collisions, speed restrictions are being considered for vessels traversing critical habitat, although the effects of speed on collision outcomes have not been specifically evaluated from a biomechanics perspective.

The ultimate goal of a larger collaborative project is to evaluate the efficacy of speed restrictions for reducing blunt collision mortality using a multi-scale finite element model. Complete, transverse fracture of the right whale mandible, an injury seen only in right whales killed by vessels, is used as a proxy for mortality in the model. Vital for that model are the material properties and biomechanical behavior of the right whale mandible.

Here, the internal structure and physical properties of right whale jawbone tissue are reported. The average apparent densities, $0.4258 \text{ g/cc} \pm 0.0970$ and $1.2370 \text{ g/cc} \pm 0.0535$ for trabecular and cortical bone respectively, indicate that the bone is of relatively low density. Average ash content for trabecular bone ($64.38\% \pm 1.1330$) is comparable with values from other species, indicating that low density results from a reduction of bone mass, not mineralization.

Mechanical properties of right whale bone (Young's modulus of elasticity and Poisson's ratio) were determined via uniaxial compression testing. These data are incorporated into the finite element model simulating different loading conditions (e.g. vessel speeds) that likely lead to mandibular failure and thereby mortality from blunt vessel collisions. Model results (e.g. risk of fracture) are used to determine the effect of speed restrictions on collision outcomes.