An Annotated Bibliography of Sirenian Hearing

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Introduction

The following summaries of references on sirenian hearing and communication were compiled in conjunction with the development and execution of a study to determine the Florida manatee's hearing range based on behavioral testing. Included are two additional sections: one identifying some significant works on related acoustic studies on non-sirenian aquatic mammals and, the other a general interest section on marine mammal biology and basic methodology in the field of underwater sound.

To assist the reader and insure maximal continuity in any future editions of this bibliography, a **reference code** has been provided **for each citation. Keywords** for the publications are shown for each abstract and are **listed** on page 66. These keywords are provided to assist finding most of the dealings on the respective topic **as it relates to hearing and communication.** The order of information for each citations is: a sequential number, the reference code, year, author(s), title, citation reference, the abstract/unique contribution of the work, and keywords.

The original author's abstracts (where available) are presented for those works that focused on manatee communication. To the degree possible, abstracts are presented in the briefest* form possible (to indicate the topics covered in the work). Of particular focus was new contribution of information not previously described. In fields of study such as manatees where concrete new information may be hard to come by for extended periods of time, much information is repeated in various forms and, whether true or false, becomes part of the legend or conventional wisdom regarding a somewhat cryptic species.

This document is intended for students, environmentalists, and researchers who wish to better understand these unique animals. We hope that this small contribution makes learning about manatee communication biology a little easier and stimulates further interest in these secretive sirens of our coastal seas.

"A large amount of space is provided for one abstract (Steel, 1982) due to the substantial content and relevance of this doctoral thesis. This work is highly recommended as additional reading and as a springboard for future research.

ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the following individuals for their respective contributions to this effort: Jean Maguire, Lynn Lefebrve, Bob Hoffman, Darlene Ketten, Joe Blue, Susie Tapia, Daniel K. Odell, and Julie Patton.

Section I. Annotated Sirenian Communication Citations

	Ref. code	Year
1.	52524	1976.

Allen, J.F., M.M. Lepes, I.T. Budiarso, Dr. Sumitro and D. Hammond.

Some observations on the biology of the dugong (Dugong dugon) from the waters of South Sulawesi.

Aquatic Mammals. Vol. 4(1-2):66.

Abstract/UniqueContribution

0 Two captive dugongs described as noise-sensitive, spooking in response to someone entering the water or when weights dropped into the water and hit the pool bottom.

Keywords: acoustic sensitivity, anecdote, behavior, dugong, hearing, response (sound reaction), startle response

	Ref. code	Year
2.	5262	1979.

Anderson, P.K.

Dugong behavior: On being a marine mammal grazer.

The Biologist 61(4):113-144.

Abstract/UniqueContribution

0 Cites only others' work, in one case without reference.

Keywords: anatomy, behavior, calls (vocalizations), dugong

	Ref. code	Year
3.	5263	1981.

Anderson, P.K.

Dugong behavior: observations, extrapolations, and speculations.

In: The Dugong, H. Marsh (ed.), Proceedings of a seminar/workshop held May 8-13, 1979 at James Cook University of North Queensland, Townsville, Australia.

Abstract/Unique Contribution

0 Primarily cites other work,

0 Observed that sounds (chirps) were correlated with skin movements in the frontal area.

Keywords: anecdote, calls, chirpsdugong

	Ref. code	Year
4.	5266	1982.

Anderson, P.K.

Studies of dugongs at Shark Bay, Western Australia.

Australian Wildlife Research 9:69-84.

Abstract/UniqueContribution

0 3 bird-like calls and 2 grunts as dugongs circled a vessel.

0 8 faint grunts from an intentionally frightened animal.

0 Little or no vocalization during feeding.

0 Responses to divers and boats at moderate speed implies ability to detect, locate and identify disturbances up to 150 m in 5 m visibility.

0 Sound in the usual sense did not account for response. Divers making little or no sound elicited a response.

0 May use echolocation or a means of detecting-non-sonic vibrations possibly using body hairs (see: Reynolds, 1979).

0 Concerted avoidance of moderate-speed boat. Fast-speed boat resulted in aggregation and vertical surfacing by a distinguishable component of the group. These suggest communication and/or social coordination and division of labor.

0 Tradition suggests dugongs will flee in response to faint unfamiliar sounds. Researchers could not induce flight, suggesting that reactions are learned where dugongs are hunted.

Keywords: acoustic sensitivity, calls (vocalizations), dugong, hearing, mechanoreception, startle response, response (sound reaction), social behavior

	Ref. code	Year
5.	5264	1937.

Barbour, T.

Birth of a manatee.

Journal of Mammalogy 18: 106-107.

Abstract/UniqueContribution

0 During the latter part of the period when the mother was carrying the calf, a number of times during the day when coming up for air she would let out a groan as if in more or less pain. (Original author's statement)

Keywords: anecdote, calls, Miami Seaquarium, mood-specific noises, pregnancy, social behavior

	Ref. code	Year
6.	5265	1935.

Barrett, O.W.

Notes concerning manatees and dugongs.

Journal of Mammalogy 16:217-218.

Abstract/Unique Contribution

0 "When the animals are frightened - as during the daytime, in the 'lair' - the slightest unusual noise, like rain falling on a tin pail in a cayuca (canoe), or the spitting of the hunter, is sufficient to keep the whole herd submerged from sight for hours; yet while they are grazing the hunter may go up and slap them on the back unnoticed."

0 "The noise made by the flapping of the huge upper lip and the crunching by the large teeth can be heard distinctly on a still night 200 yards or more away. The sound made by a dozen or more manatees grazing on the 'yerba Guinea' is much like that of horses grazing in a pasture."

0 "The 'blow', however, is usually a rather silent one." (Original author's statements)

Keywords: acoustic sensitivity, anatomy, anecdote, behavior, breathing, defense, dugong, hearing, resting

	Ref. code	Year
7.	5267	1985.

Bengston, J.L. and S.M. Fitzgerald.

Potential role of vocalizations in West Indian manatees (Trichechus ***manatus).***

Journal of Mammalogy 66(4):816-819.

Abstract/Unique Contribution

0 This is a study of why manatees make sounds. The context and function of vocalizations. Charts illustrate conclusions.

- The behavioral situations studied included:

  1. Natural feeding
  2. Swimming
  3. Resting
  4. Artificial feeding from a tray of various plants lowered into their vicinity
  5. Milling in groups but not cavorting
  6. Cavorting

- No attempt was made to differentiate between whistle-squeaks and chirps-all vocalizations were lumped together and counted as number of calls per time unit.

- Basic description of recording equipment and method of computing mean number of calls per manatee.

- Rates of vocalization were higher when manatees were cavorting, milling, or artificial feeding than when feeding naturally, swimming, or resting.

- No evidence calls used for echolocation.

- Call rates increase as level of excitement and social interaction increases.

- Calls may serve as means of identifying individuals. For example a quiet feeding group of six suddenly left their spot, started calling rapidly, swam 50 meters towards entrance of lagoon where lone manatee was approaching, cavorted with him, then all seven returned to their feeding ground.

- Manatees hear quite well: react to shuffling feet in boat 15 m distant, human voices at 5 m, aircraft engine 300 m.

Keywords: Call rates, cavorting, chirps, feeding, artificial feeding, resting

	Ref. code	Year
8.	5153	1964.

Bertram, G.C.L., and C.K.R. Bertram.

Manatees in the Guianas.

Zoologica 49: 115-120.

Abstract/Unique Contribution

0 Distribution in the Guianas.

0 Sizes.

0 Movements.

0 Identification of individuals.

0 Breathing, though normally quite silent, was audible when the animal was startled and was the only sound researchers heard them make in British Guiana. However, one Thomas Gann reported hearing a manatee "give a hoarse bellow not unlike a foghorn" in British Honduras (Ancient Cities and Modern Tribes. 1926. pp. 25-29).

Keywords: Breathing, bellow, startle response

	Ref. code	Year
9.	5268	1980.

Bullock, T.H., D.P. Domning and R.C. Best.

Evoked brain potentials demonstrate hearing in a manatee (Sirenia: ***Trichechus inunguis).***

Journal of Mammalogy 61(1):130-133.

Abstract/Unique Contribution

0 A simple physiological method, without conditioning the animal, is enough to manifest brain responses to arbitrary sounds.

0 Description of test animal.

- Description of test (transcranial-averaged evoked potential [aep] recordings over the cerebrum):
  - length of tests (2 hr each)
  - types of signals (3 kHz gave greatest response)
  - electrode placement
  - illustration of AEP.
- Sensitivity of various parts of head to sound stimuli.
- It is possible that the most sensitive area for hearing is zygomatic process of squamosal bone, an inflated area composed of cancellous bone saturated with oil just rostral to auditory meatus.
- Later acoustic AEP's from cerebral hemispheres should be used for simple and for complete natural sounds, instead of the early acoustic AEP's attributed to the first relays in the brain stem pathway.

Keywords: auditory evoked potential (aep), brain, cancellous bone, signal, zygomatic process

	Ref. code	Year
10.	52526	1981.

Bullock, T.H., D.P. Domning and R.C. Best.

Cerebral potentials through acoustic stimulation show hearing in the manatee (Sirenia: *Trichechus inunguis).*

Acta Amazonica 11(3):423-427.

Abstract/UniqueContribution

0 A young Amazonian manatee ***(Trichechus inunguis)*** showed peak auditory sensitivity at about 3 kHz and averaged evoked potentials (AEP) from 200 Hz to 35 kHz but not at 40 kHz as measured by transcranial evoked potentials. The maximum sensitivity was recorded about 20 mm rostral to the auditory meatus, possibly implicating the broad posterior part of the zygomatic process of the squamosal bone in the acoustic system of the manatee. The techniques used in this study are recommended for studies of acoustic sensitivity of animals to simple and complex natural sounds that have relatively abrupt onsets. (Original authors' abstract)

Keywords: acoustic sensitivity, auditory evoked potential (aep), auditory meatus, hearing, methods, squamosal bone, zygomatic process.

	Ref. code	Year
11.	5257	1982.

Bullock, T.H., T.J. O'Shea and MC. McClune.

Auditory evoked potentials in the West Indian Manatee (Sirenia: *Trichechus manatus).*

J. Comp. Physiology A. 148(4):547-554.

Abstract/Unique Contribution

- Auditory brain stem responses to sounds delivered through padded earphones were recorded by fine wires inserted extracranially in 4 manatees. Tests were conducted in open air with the animal lying on a foam rubber mat on a concrete apron adjoining the pool.

- Animals were lightly restrained during the test. The foam rubber mat was electrically insulated from the concrete pad. 3 wires were inserted under the animals' skin by means of a hypodermic needle through which wires were threaded. The animal was grounded to an aluminum foil sheet under its chest. Stimuli were delivered to either one or both ears.

- Findings indicate that this species can receive ultrasonic signals to 35 kHz, possibly to 40 kHz.

- West Indian manatees are known to produce sounds in the 35 kHz range. Thus it seems likely such vocalizations are heard and may serve as alarm signals, contact signals, or emotive signals.

- Manatees emit short (0.1-0.5 sec) calls with complex harmonic structure and harmonically unrelated overtones (Schevill and Watkins 1965). Frequencies vary from 600 Hz to 5 kHz (ibid). Diagrams. Additional detail on sound spectra from other studies.

- Manatees can hear boat engine and propeller noise (Urich 1975; Wenz 1962).

- Manatee ear is not much more sensitive to sound than the area in front of it.

Keywords: auditory evoked potential (aep), audiogram, auditory brain stem response (abr), brain, calls (vocalizations), mood-specific noises, signal, tone pips.

	Ref. code	Year
12.	5270	1874.

Conklin, W.A.

The manatee at Central Park.

Forest and Stream 1(11):166.

Abstract/UniqueContribution

0 "It manifests at times extreme playfulness, and will answer the call of the keeper by a peculiar noise somewhat resembling the squeak of a mouse." (Original author's statement)

Keywords: acoustic sensitivity, anecdote, artificial feeding, behavior, breathing, calls (vocalizations), cavorting, defense, feeding, hearing, response, social behavior, squeaks

	Ref. code	Year
13.	5269	1990.

Court, N.

Periotic anatomy of *Arsinoitherium* (Mammalia, Embrithopoda) and its Phylogenetic implications.

Journal of Vertebrate Paleontology 10(2):170-182.

Abstract/UniqueContribution

0 The description of two previously unknown petrosal specimens of *Arsinoitherium* highlights a number of derived ungulate characteristics. A Phylogenetic analysis based on ungulate periotic anatomy implies that perissodactyls, sirenians, proboscideans, and arsinoitheres are united by the absence of a subarcuate fossa, derived course of the facial nerve, and open stylomastoid foramen. Absence of a discrete cochlear aqueduct implies a sister-group relationship between arsinoitheres and proboscideans. Artiodactyls are primitive in all respects except for the complete enclosure of the epitympanic recess by the tegmen tympani. (Abbreviated original author's abstract)

Keywords: anatomy, elephants, hearing, ossicle (bulla, stapes, malleus, incus)

14. Ref. code 5271 Year 1977.

Domning, D.P.

Observations on the myology of *Dugong dugon* (Muller).

Smithsonian Contributions to Zoology 226:iii + 57.

Abstract/UniqueContribution

0 Remarks (pp. 26-27) on observations of the pair of auriculares. Suggests "they may, by pulling the auditory canal against the small auricular cartilage, close it against water pressure during dives" or they "...may alter the direction of the outer part of the canal to improve directionality of hearing".

0 Mentions Fraser and Purves (1960: 131-132) conclusion "that auricular muscles provide directional hearing by constricting the canals to equalize sound intensities at the cochleae, and may also protect the ears against high sound intensities."

Keywords: anatomy, auditory meatus, auriculares, auricular cartilage, directional hearing (localization), damage (injury), dugong, hearing

15. Ref. code 5272 Year 1978.

Domning, D.P.

Sirenian evolution in the North Pacific Ocean.

University of California Publications in Geological Sciences 118:xi + 176.

Abstract/UniqueContribution

0 "Striking differences are seen between the ear regions of *Dusisiren* and *Hydrodamalis gigas.* In the latter the pars temporalis is swollen, the shape of the tympanic altered, and the orbicular apophysis and processus muscularis of the malleus reduced, in addition to numerous lesser changes. The latter two features suggest reduction of the stiffness of the ossicular chain, and can be seen as compensations for the increased stiffness due to the greater absolute mass of the bones, in order to avoid changing the

'tuning' of the ears as the animals increased in size." (Original author's statement, p. 132)

Keywords: anatomy, *Dusisiren,* hearing, *Hydrodamalis gigas,* ossicle, pars temporalis

	Ref. code	Year
16.	5273	1884.

Doran, A.

On the auditory ossicles of *Rhytina stelleri.*

Journal of the Linnean Society of London (Zoology) 17:366-370.

Abstract/UniqueContribution

0 A detailed description and comparison of the ossicles of *Rhytina* with *Trichechus manatus, T. senegalensis,* and *Halicore (Dugong)* as well as elephants and baleen whales.

Keywords: anatomy, elephants, *Hydrodamalis gigas,* ossicle (bulla, stapes, malleus, incus), squamosal bone, West African manatee ***(** Trichechus senegalensis)*

	Ref. code	Year
17.	5274	1967.

Evans, W.E.

Vocalization among marine mammals.

In: Marine Bio-Acoustics, Vol. 2 (W.N. Tavolga ed.), pp. 159-186. Pergamon Press, Oxford.

Abstract/UniqueContribution

0 Restatement of Schevill & Watkins (1965)

Keywords: acoustic sensitivity, calls (vocalizations), harmonics, Miami Seaquarium

	Ref. code	Year
18.	5275	1967.

Evans, W.E. and J. Bastian.

Marine mammal communication: social and ecological factors.

In: The Biology of Marine Mammals (H.T. Andersen, ed.). pp. 425-475. Academic Press, New York.

Abstract/UniqueContribution

0 Animal communication such as making noise vocally or adopting a physical stance or body posture is precisely the same as animal social behavior.

0 Sirenia signaling systems include the apparent ability to hear (they startle in response to human voice, make sounds under water, have dense ossicles in inner ear, external auditory meatus is heavily muscled).

Keywords: hearing, ossicle, response, auditory meatus, signal, social behavior

	Ref. code	Year
19.	5252	1970.

Evans, W.E. and E.S. Herald.

Underwater calls of a captive Amazon manatee, Trichechus inunguis.

Journal of Mammalogy, 51(4):820-823.

Abstract/UniqueContribution

0 Underwater sounds produced by *T.* inunguis were louder than those of Florida manatee. Sounds as high as 22 dB above background noise, probably because animal so close to hydrophone (1 m or less). Sounds were similar to *T. manatus latirostris:* 0.15-0.22 sec in duration, fundamental less intense than second harmonic, equally complex first and final parts. The sounds differed thus:

	T. inunguis	*T. latirostris*
Frequency	6-8 KHz	2.5-5.0 KHz
Call pulses	Yes	no

0 Pulses occurred only when feeding and only when squeaking.

Keywords: Calls, harmonics, methods

	Ref. code	Year
20.	5276	1963.

Fenart, R.

Note sur l'etude du crane de *Halicore dugong* par la methode vestibulaire.

Mammalia 27(1):92-98.

Abstract/UniqueContribution

0 Etude du crane du Dugong d'apres la methode vestibulaire. Ce crane presente des caracteres de Mammiferes quadrupedes et des caracteres de Mammiferes marins, resultant de l'orientation du cou, en plus de particularites propres (surtout visibles dans la partie anterieure de la face et de la mandibule). (Original author's abstract)

0 Detailed morphological description of the skull, ossicles and semicircular canal system.

Keywords: anatomy, dugong, ossicle (bulla, stapes, malleus, incus)

	Ref. code	Year
21.	5279	1988.

Fischer, M.S.

Contributions to the anatomy of the hearing organ of the seacow *Trichechus manatus* L. (Mammalia; Sirenia)

Z. Saeugetierkd. 53(6):365-379.

Abstract/UniqueContribution

0 The anatomy of the soft parts of the hearing organ of *Trichechus manatus* L. is described. Two specimens have been dissected and in both cases the external auditory meatus ends in a blind pouch, which has no contact to the tympanic membrane. The latter is pushed outwards by the Manubrium mallei. The tympanic membrane consists of unusual dense connective tissue. A major peculiarity of the middle ear of *Trichechus* is the tympanic sac. Ventrally the tympanic cavity is bordered by a membranous sac. It encloses the space between the basioccipital, basisphenoid, the pterygoid process and the tympanic ring. The tympanic sac is part of the tympanic

cavity and covered on the inner side with a respiratory epithelium. The Eustachian tube is highly divergent from the condition found in other mammals. A comparison of the tympanic sac with the Eustachian sac of Procaviidae, Equidae and Tapiridae reveals no homology between these two structures. Cautious reflexions on the function of the tympanic sacs suggest that they could be a kind of air-cushion which isolate the ear against the sirenian's own vocalization. The problem of directional hearing under water and sound conduction is briefly discussed and applied to the morphology of the manatee. (Original author's English abstract)

Keywords: anatomy, auditory meatus, directional hearing (localization), eustachian tube, hearing, tubular sacs, tympanic membrane

	Ref. code	Year
22.	5278	1990.

Fischer, M.S.

The unique ear of elephants and manatees (Mammalia) - a Phylogenetic paradox.

Comptes Rendus de L 'Academic Des Sciences, Serie III-Sciences de La Vie 311(4): 157-162.

Abstract/UniqueContribution

0 Morphogenetic studies of the ear region on fetal elephant heads and the anatomy of this region in manatees show that these two groups neither possess a fenestra rotunda nor a cochlear canaliculus but just one opening. (see: Court, N., 1990) It is the perilymphatic foramen which usually persists into the adult. This unique character gives strong support to the hypothesis of a sister-group relationship of Proboscidea and Sirenia. (Original author's English abstract)

Keywords: anatomy, elephants, hearing, low frequency (infrasound), ossicle (bulla, stapes, malleus, incus), tympanic membrane

	Ref. code	Year
23.	5277	1956.

Fish, C.J. and M.P. Fish. (Anon. article citing Dr. and Mrs. Fish)

Hear manatee sounds for first time.

Science News Letter 70:37 (July 21, 1956).

Abstract/UniqueContribution

0 Claimed first recording of manatee noises.

0 Recorded sounds and took colored movies in Puerto Rico.

0 Sounds like pieces of wet leather rubbing together.

0 Both investigators agreed the noises sounded involuntary.

Keywords: calls, mood-specific noises, recording.

	Ref. code	Year
24.	5280	1973.

Fleischer, G.

Studien am Skelett des Gehörorgans der Säugetiere, einschließlich des Menschen.

Säugetierkundliche Mitteilungen (München) 21:131-239.

Abstract/UniqueContribution

0 A detailed comparison of ossicles and tympanic cavities of a broad spectrum of species including *Manatus* **(=** *Trichechus).*

Keywords: anatomy, ossicle (bulla, stapes, malleus, incus), tympanic membrane

	Ref. code	Year
25.	5281	1976.

Fleischer, G.

On the anchoring system of the stapes in the ear of cetaceans and sirenians.

Z. Saeugetierkd. 41(5):304-317.

(German)

Abstract/UniqueContribution

0 A total of 18 species has been examined. Studies with the scanning electron microscope revealed that there is a large increase in the surface of bone where the annular ligament is attached to the stapes, as well as to the oval window. The area of insertion of the annular ligament to the stapes increases negatively allometrically, relative to the weight of the stapes. These ratios show different patterns for Odontoceti, Mysticeti, and Sirenia. There are relatively large areas of attachment of the annular ligament. Low-frequency animals, on the other hand (baleen whales and sirenians), have heavy stapes and relatively small attachments... (Original author’s English abstract)

Keywords: anatomy, dugong, hearing, low frequency, methods, ossicle

	Ref. code	Year
26.	5282	1981.

Fobes, J.L. and CC. Smock.

Sensory capacities of marine mammals.

Psychological Bulletin 89(2):288-307.

(Review paper)

Abstract/UniqueContribution

0 “...Relative intensity sensitivity in best media indicates that amphibious mammals have an aerial loss comparable to the aquatic loss for humans. Aquatic mammals have discrimination capacities for frequency, intensity,

duration, and localization approximating those of humans.” (Portion of original authors’ abstract)

0 An excellent review of the range of hearing adaptations comparing the three categories of aerial mammals, amphibious mammals and aquatic mammals, Describes study limitations and current informational gaps.

Keywords: acoustic sensitivity, behavioral testing, calls (vocalizations), directional hearing (localization), echolocation, harmonics, hearing, methods, operant conditioning (training), tympanic membrane

	Ref. code	Year
27.	5283	1987.

Gerstein, E.R., G.W. Patton and W.N. Tavolga.

Preliminary Underwater Acoustical Thresholds of a Captive Manatee, *Trichechus manatus,* a Quantitative Behavioral Approach.

Proceedings of the Seventh Biennial Conference on the Biology of Marine Mammals, December 5-9, 1987, Miami, Florida.

(Poster abstract)

Abstract/UniqueContribution

A simple two-choice paradigm was initiated to measure the ability of an adult male manatee to hear a range of amplified frequencies projected underwater. A hearing threshold minimum range of 0.15 kHz to 15 kHz is demonstrated at $p< .05$. Results show significant hearing beyond acoustical limits previously determined through behavioral and physiologically evoked brain potential studies. The learning ability of this subject encouraged further study. The applied goal is to evaluate the manatee’s sensory awareness and investigate and develop an effective acoustical warning system or sonic device to alert manatees of a boat’s proximity. (Abbreviated original authors’ abstract)

	Ref. code	Year
28.	5284	1968.

Giraud-Sauveur, D. and M. Miloche.

Sur la structure particuliere des os de I'oreille moyenne des cetaces odontocetes.

J. Microscopie, Paris, 7: 1093-1098.

Abstract/Unique Contribution

0 Primarily on Odontocetes, presents electron microscopy data on the dimensions of hydroxyapatite crystals in the West African manatee *(Trichechus senegalensis).*

Keywords: anatomy, hearing, hydroxyapatite, methods, ossicle (bulla, stapes, malleus, incus), West African manatee *(Trichechus senegalensis)*

	Ref. code	Year
29.	5285	1946.

Goodwin, G.G.

Mammals of Costa Rica.

American Museum of Natural History Bulletin 87:445

Abstract/UniqueContribution

0 External ear small, squamosal (bone) with a large and massive zygomatic process

Keywords: anatomy, anecdote, auditory meatus, squamosal bone, zygomatic process

	Ref. code	Year
30.	5286	1954.

Gunter, G.

Mammals of the Gulf of Mexico.

In: Gulf of Mexico; Its Origin, Waters, and Marine Life, Fishery Bulletin of the U.S. Fish and Wildlife Service 55:545.

Abstract/Unique Contribution

0 When manatees lie quietly, their small mouth is hidden.

0 When disturbed, two captives in a broad shallow tank "would raise a plaintive cry... in its half nasal strain, was much like that of an infant".

0 Otherwise, they lay quietly.

0 When not particularly hungry, they would "utter a sort of nasal or guttural strain of satisfaction" when fed peeled bananas. If grass or turnip tops were then offered, "they would utter their whining petulant cry of dissatisfaction as if they were weanlings." (see: Scammon, C.M., 1889)

0 Parent animals produced "lamentations" when attacked by humans. (Original author's statements in quotes)

Keywords: anecdote, artificial feeding, behavior, feeding, mood-specific noises, response, resting

	Ref. code	Year
31.	2527	1965.

Harrison, R.J. and J.E. King.

Manatees and dugongs.

In: Marine Mammals. Hutchinson and Co., London. Pp. 150-175.

Abstract/UniqueContribution

0 "Manatees can only be taught to do the simplest tricks."

0 “The corpora quadrigemina (of the dugong), especially the inferior, are prominent... suggesting perhaps that auditory responses are not lacking.” (Original author’s statements)

Keywords: anecdote, anatomy, auditory meatus, behavior, brain, dugong, hearing

	Ref. code	Year
32.	5299	1971.

Hartman, D.S.

Behavior and ecology of the Florida manatee, *Trichechus manatus latirostris* (Harlan) at Crystal River, Citrus County.

Ph.D. thesis, Cornell University, Ithaca, New York, 285 pp.

Abstract/Unique Contribution

Production of Sound:

0 Normally silent

0 Exceptions:
fear, aggravation, protection, internal conflict, male sexual arousal, play .

0 Noises produced with mouth and nostrils closed and no accompanying escape of air.

0 Not complex:
Non-navigational,
Lack ultrasonic, pulsed or directional signals,
More impulsive than intercommunicative.

0 Only predictable vocal exchange is alarm duet between mother and calf.

0 Cows increase vocalization in turbid water.

Response to Sound:

0 Startled by fish splashing and birds diving (pelicans). They flee a few meters then return to investigate.

- Efficient in localizing surface noises even in turbid waters (arrive immediately to investigate).

- When startled:
  "Wince" at diver splashes, snorkel clearing, camera shutter click, regulator wheezing, outboard gear changing;
  Sensitive to above water sounds - jet noise, fishermen talking, and shouting.

- Animals attracted by splashing hand from 15 m, one animal calling from 40 m, conspecifics from 50 m, mother response to calf from 60 m.

<u>Motorboat Approach:</u>

- In deep water, dive to bottom.

- From shallow water, head to deeper water.

- "Panic" when surprised.

- Outboard noise at close range does not interfere with or disrupt sound exchange between animals or disorient them.

- Manatees recognize each other by sound through variations in pitch, intensity and timbre.

- No response to ultrasonic transmitter beeping at 70,000 cps even when held next to ear opening.

Keywords: Mother, calf, calls, hearing, response (sound reaction), startle response

	Ref. code	Year
33.	52527	1979.

Hartman, D.S.

Ecology and behavior of the manatee *(Trichechus manatus)* in Florida.

Amer. Soc. Mammal. Spec. Publ. 5:1-153.

Abstract/Unique Contribution

- Chirp-squeaks, screams, squeals produced with mouth and nostrils closed and with no accompanying escape of air.

- Normally silent, manatees convey information by varying the intensity and duration of their calls rather than by emitting mood-specific noises.

- Manatees emit sounds only because of: fear, aggravation, protest, internal conflict, male sexual arousal, play.

- Sounds not used for navigation.

- Manatees sometimes chirp-squeaked or squealed while rubbing themselves against logs or when the author caressed their backs, They sometimes emit snort-chirps when investigating divers and groaned while stretching.

- Additional details of types of sounds emitted and under what circumstances, including calf-mother calls.

- Manatees recognize each other by sound.

Keywords: chirps, mood-specific noises, squeaks, squeals

	Ref. code	Year
34.		1820.

Home, E.

Particulars respecting the anatomy of the dugong, supplement to T.S. Raffles' (1820) account of that animal.

Philosophical Transactions of the Royal Society of London, Part 1:315-323.

Abstract/UniqueContribution

- Calls like cry of young child.

- Larynx cartilage different from whales.

Keywords: anatomy, dugong, larynx

35. Ref. code 5287 Year 1967.

Johnson, C.S.

Sound detection thresholds in marine mammals.

In: Marine Bio-Acoustics, vol 2 (W.N. Tavolga ed.), pp. 247-260. Pergamon Press, Oxford.

Abstract/UniqueContribution

0 A detailed description of how holding tank was constructed and equipped to obtain reliable audiogram data on auditory threshold of *Tursiops truncatus.* Tables, illustrations, charts and data plots. Gives specific information re: length of each test, warm-up period, signal variations, number of tests, animal, day, type and amount of food used as reward.

Keywords: auditory threshold, click-free system, methods

36. Ref. code 5288 Year 1988.

Johnson, J.I., R.L. Reep, R.C. Switzer Ill, J.A.W. Kirsch, W.I. Welker.

Well-developed auditory nuclei in manatees *Trichechus manatus.*

Society for Neuroscience Abstracts 14(1):491. 18th Annual Meeting, Toronto, Ontario, Canada, November 13-18,1988.

Abstract/UniqueContribution

0 Sections through brain stems of 5 manatees, in 3 planes, with Nissl, myelin or cytochrome oxidase stains show: Cochlear nuclei as in other auditorily specialized animals -- the anteroventrals are large, as are the posteroventrals which hang outside the brain stem along with the eighth nerve, capped by the rudimentary dorsals. The superior olives show prominent small-celled lateral nuclei, linear medial nuclei bounded by cell-free regions and large-celled nuclei of the trapezoid body. The nuclei of the lateral lemniscus are particularly massive with distinctive nuclei. The large inferior colliculi resemble those of other audition-oriented species. (Original author's abstract)

Keywords: anatomy, brain, hearing

	Ref. code	Year
37.	5289	1961.

Jonklaas, R.

Some observations on dugongs *(Dugong dugon* - Erxleben).

Loris 9: 1-8 (A Journal of Ceylon Wild Life).

Abstract/UniqueContribution

0 It is likely that dugongs communicate by sounds that are so far imperceptible to humans.

0 Devise methods by means of which sound waves or impulses can be transmitted underwater to attract or repel dugongs as an aid to their preservation.

Keywords: acoustic sensitivity, anecdote, calls (vocalizations), dugong, methods, hearing

	Ref. code	Year
38.	5290	1970.

Kaiser, H.E. and H.P. Schropfer.

Comparative investigations of the behavior of water mammals, especially sea-cows *(Trichechus manatus latirostris).*

American Zoologist 10(3):294.

(Published abstract)

Abstract/UniqueContribution

0 Earliest suggestion that investigations to compare elephant and manatee communication/hearing might provide increased understanding of the evolution of hearing.

Keywords: behavior, elephants

	Ref. code	Year
39.	5291	1971

Kingdon, J.

East African Mammals: An Atlas of Evolution in Africa.

Academic Press Vol. 1, New York. P. 446.

Abstract/UniqueContribution

0 Without citation claims dugongs have keen but short-ranged hearing, that their squeaky calls have been positively tested for ultrasound unlikely to be used for navigation but only for communication.

0 Whistle when distressed may stimulate males' defense behavior.

Keywords: anecdote, behavior, calls, defense, dugong, hearing, mood-specific noises, social behavior, squeaks, whistles

	Ref. code	Year
40.	5292	1983.

Kinnaird, M.F.

Evaluation of potential management strategies for the reduction of boat-related mortality of manatees.

Site-Specific Reduction of Manatee Boat/Barge Mortality Research, Report Number 3, Florida Cooperative Wildlife Research Unit, Gainesville, Florida. pp.1-5.

Abstract/UniqueContribution

0 High intensity sounds have been used to deter pinnipeds. Degree of response has been highly variable between species. Ineffective with otters.

0 Sound response tested on two captive animals at Homosassa Springs on Dec. 16-17, 1982. Intensity increased from 75 dB to 197 dB at 12 kHz. No significant response from animals.

0 Assuming success, practical applications may be a problem. Manatees may habituate to sound of boat engines (Reynolds, J.E.,

1981). Manatees may become confused when surrounded by numerous boats (Tiedemann 1980).

Keywords: behavioral testing, methods, response (sound reaction), startle response

	Ref. code	Year
41.	52528	1975.

Kinne, 0.

Orientation in space: Animals: Mammals.

In: Marine Ecology, vol. II, Physiological Mechanisms, Part 2 (0. Kinne, ed.). pp. 709-852. Wiley, London.

Abstract/UniqueContribution

0 A restatement of findings by Schevill & Watkins (1965), Hartman (1969), Evans & Herald (1970).

	Ref. code	Year
42.	5293	1990.

Klishin, V.O., R. Pezo Diaz, V.V. Popov and A. Ya. Supin.

Some characteristics of hearing of the Brazilian manatee, *Trichechus inunguis.*

Aquatic Mammals 16.3:139-144.

Abstract/UniqueContribution

0 Auditory brain-stem responses (ABR) and slower auditory cortical responses were recorded from the head surface of a non-anaesthetized and non-relaxed Brazilian manatee, *Trichechus inunguis.* The ABR was used to measure some characteristics of the manatee's hearing. The region of best ABR recording was shown to be located 2-5 cm caudal to the line connecting the eyes. The threshold values were about 25 dB re. 1 mPa for clicks and for tone bursts of the optimal frequency (5-20 kHz). The maximum sound frequency at which ABR could be evoked was 50 kHz. ABR's were able to follow rhythmic stimulation at rates up to 500/sec. (Original authors' abstract)

Keywords: acoustic sensitivity, anatomy, auditory- brain stem response (abr), brain, clicks, hearing, methods, recording, response (sound reaction), signal

	Ref. code	Year
43.	5294	1978.

Marsh, H., A.V. Spain and GE. Heinsohn.

Physiology of the Dugong.

Comp. Biochem. Physiol. 67 A(2):159-168.

Abstract/UniqueContribution

0 The corpora quadrigemina (esp. the inferior) are prominent suggesting auditory sensitivity. [Abstractor’s note: possibly from another source.]

0 Native hunters consider the dugong’s hearing acute and visual powers less developed.

0 Australian aboriginals report presence of “whistlers” whom they regard as dominant individuals.

Keywords: Corpora quadrigemina, aboriginals

	Ref. code	Year
44.	5295	1872 (1870).

Murie, J.

On the form and structure of the manatee (Manatus americanus).

Transactions of the Zoological Society of London 8:188.

Abstract/UniqueContribution

0 “In the absence of pinna a small orifice, a line in diameter, into which a probe could be passed, alone represents the external meatus. It is situated on a level with the posterior end of the malar bone, 4 inches behind the eye. A narrow cord-like fibrous tube, 3 inches long, with an s-shaped bend, leads to the membrana tympani. The latter is a wide ellipsoidal thickish membrane, the fibres of which from above and below obliquely

meet the tube as it passes across the center. A thin narrow edge of the malleus abuts against the inside of the membrane in the same oblique direction, and divides the tympanic cavity into an upper and lower chamber. The swollen malleolar head rests in the anterior cavity of the periotic; and, with a tricuspid facet, the much smaller but wide-limbed incus is attached superiorly and posteriorly to it. The fork of the incus embraces a descending process of the posterior half of the periotic; and the shorter incudal limb articulates with the stapes. The latter, a nearly solid, straight bone, inferiorly rests in a groove of the petrous portion of the periotic. In both instances none of the small ear-bones was ankylosed (see: Robineau, D., 1965) to the tympano-periotic. The large Eustachian tube communicates with the auditory chamber just in front of the stylo-hyal cartilage." (Original author's statement)

Keywords: anatomy, eustachian tube, ossicle, tympanic membrane

	Ref. code	Year
45.	5296	1975 (1977).

Nair, R.V. and R.S.L. Mohan.

Studies on the vocalization of the sea-cow *Dugong dugon* in captivity.

Indian Journal of Fisheries 22(1-2):277-278.

Abstract/UniqueContribution

0 Water drained from tank of young male and adult female.

0 Only young male made sound which increased in number and intensity the longer they were out of the water.

0 Wrinkles appeared in frontal area during vocalization. Apparent coordination of wrinkles and sound production.

Keywords: Calls in air, dugong, wrinkles

	Ref. code	Year
46.	5297	1964.

Norris, K.S.

Some problems of echolocation in cetaceans.

In: Marine Bio-Acoustics (W.N. Tavolga, ed.), pp. 317-336. Pergamon Press, Oxford.

Abstract/UniqueContribution

0 Sound provides a sensory window where sight is obscured (in the abyssal deep, murky water, dark caves, moonless nights, etc.).

0 "Clicks and creaks" are explosive sound bursts by porpoises, each burst about 1 millisecond in length at a frequency peak 20-30 kcps.

0 Porpoises have been trained to respond to signals as high as 153, though response was ragged to signals over 120 kcps.

0 Tests of response to sound must be very carefully constructed: Do not present sound stimulus and reward (fish) simultaneously. The best porpoise locate fish by echolocation instead of responding only to sound stimulus. Arrange enclosure so that animal must turn and approach a specific site to claim his reward. Present the award below the water surface. Locate the test site away from interfering underwater sounds (as of snapping shrimp). Arrange physical test site so animal must choose from a distance which side of a net to pass to take his reward. Build barriers, hang poles vertically, through and around which animal must navigate (to test echolocation capacities).

0 Rate at which animal repeats sound emission increases as he approaches his target (up to 600 clicks/sec), but not in any systematic pattern.

0 Inner ear is isolated from self-produced sounds by enclosure in dense bone suspended by a ligament inside a cavity in cetaceans' head filled with mucus foam.

0 Sound production mechanisms of odontocetes not clearly understood. Blowhole, larynx, premaxillary nasal sacs or claps of the jaws may be involved. Nobody knows how clicks and whistles can be produced simultaneously.

- 0 Central nervous system correlates of echolocation behavior (lists studies of brain structure).

- 0 Field observations of echolocation behavior (lists species on which studies have been made).

- 0 The relationship of anatomical structures to echolocation:

  1. Detailed discussion and illustrations of crania of various species.

  2. Nasal sacs and air-filled spaces of the head, including illustrations of sequence of expulsion of air through tubular nasal sacs and associated passages.

  3. Rapid head swings while clicking (Q: Scanning?).

Keywords: Brain, clicks, whistles, tubular sacs, melon, nasal plug, larynx, arytenoid cartilage, head swings

	Ref. code	Year
47.	52531	1969.

Norris, K.S.

The echolocation of marine mammals.

In: The Biology of Marine Mammals. (H.T. Andersen, ed.), Academic Press. Pp 391-421. New York.

Abstract/UniqueContribution

- 0 Speculates that nerve foramina in the jaws of *Tursiops* and *Trichechus* might serve as sound conducting channels, perhaps for echolocation in manatees.

Keywords: acoustic sensitivity, anatomy, echolocation, hearing, social behavior

48. Ref. code 5298 Year 1967.

Oke, V.R.

A brief note on the dugong *Dugong dugon* at Cairns Oceanarium.

International Zoo Yearbook 7:220-221.

Abstract/UniqueContribution

0 "It showed some intelligence and would come to a gong for feeding." (Original author's statement)

Keywords: acoustic sensitivity, dugong, feeding, hearing, operant conditioning (training), response,

49. Ref. code 52501 Year 1985.

O'Shea, T.J. and R.L. Reep.

Brain-body weight relationships in sea cows.

Abstracts of Papers and Posters, Fourth Theriological Congress, Edmonton (Canada), 13-20 August, 1985.

(Published abstract)

Abstract/UniqueContribution

0 Much recent work has centered on the topic of relative brain size in mammals. Comparative studies to date have typically not included the Sirenia, however sirenians are an interesting outlying group in terms of encephalization, with brain sizes much smaller than would be predicted on the basis of body size using the average mammalian plot. We have directly determined brain and body weights for over 30 West Indian manatees. EQ's range form about 0.03 to 0.08 in the 10 adults from our sample (mean = 0.06 +/- 0.01), some of the lowest values of all living mammals. We calculated EQ values of about 0.07 for dugongs, using data published by Japanese investigators. Steller's sea cows were also characterized by low EQ's. In addition to these recent forms, fossil sirenians also had small brains. Unlike the proboscidians, which have evolved relatively large

brains, the sirenians have retained the small-sized brains typical of their basal ancestors. We discuss the possible importance of metabolic rate and other physiological, developmental, behavioral and life history characteristics of the Sirenia in relation to brain size. (Original author's abstract)

Keywords: Anatomy, brain, elephants, EQ (encephalization quotient)

	Ref. code	Year
50.	52502	1868.

Owen, R.

Organ of hearing.

In: Anatomy of Vertebrates, Vol. 3 (Mammals)., Longmann, Green and Co., London. P. 226.

Abstract/UniqueContribution

0 "In *Sirenia* the acoustic capsule is small, but dense in structure; it coalesces with the tympanic and mastoid, and the compound ear-bone is partly lodged in a large hemispheric cavity of the squamosal, and partly projects into the wide vacuity between that bone, the basisphenoid, and the basioccipital.

0 The otosteals are relatively large, especially the stapes, (fig.) which forms a massive, elongate conical, subcompressed ossicle, truncate atop and obliquely perforated above its oval convex base: the incus is a much smaller bone with one crus thick, the other short and styliform: the malleus has a large irregularly globose head and a handle terminated by an abrupt point." (Original author's statement)

Keywords: anatomy, ossicle

51. Ref. code 52525 Year 1992.

Patton, G.W. and E. Gerstein.

Toward understanding mammalian hearing tractability: preliminary acoustical perception thresholds in the West Indian manatee, *Trichechus manatus.*

In: The Evolutionary Biology of Hearing. Proceedings of the First International Conference on the Evolutionary Biology of Hearing, Sarasota, Florida, May 20-24, 1990. D.B. Webster, A.N. Popper and R.R. Fay (eds.). Springer-Verlag, New York. p. 783.

(Published abstract)

Abstract/UniqueContribution

0 "Sirenians (manatees and dugongs) share common ancestry with the proboscideans (elephants). As in elephants, manatees may exhibit low frequency hearing capabilities. Such an ability could be as extraordinary as odontocete (toothed whales, porpoises and dolphins) ultrasonic echolocation and communication. Knowing the thresholds for these species will aid management strategies for preserving this endangered species. A simple two-choice paradigm determined the ability of an adult manatee to detect a range of amplified frequencies projected underwater. Trained on command to discriminate between two submerged paddles, the subject pushed one if a tone was detected, and the other if no tone was detected. Electrical switches on each paddle insured the reliable recording of test selections. Double-blind and randomized tone presentations served as precautions against experimental and Clever Hans biases. A signal generator delivered single tones through an underwater speaker, while a hydrophone monitored background and acoustical signal strength. After establishing a reliable behavioral baseline for paddle selections @ 80% accuracy, 16 test trials were run for a total of 240 discrimination trials. A nominal frequency range of hearing of 0.15 kHz - 15 kHz was demonstrated ($p < .05$). Results show significant hearing beyond the frequency limits previously determined through behavioral and physiological evoked brain potential studies." (Abbreviated original authors' abstract)

Keywords: acoustic sensitivity, auditory threshold, behavioral testing, directional hearing (localization), double-blind, elephants, low frequency (infrasound), methods, operant conditioning (training)

	Ref. code	Year
52.	52506	1985.

Pirlot, P. and T. Kamiya.

Qualitative and quantitative brain morphology in the sirenian *Dugong dugon.*

Z. Zool. Syst. Evolutionsforsch. 23(2):147-155.

Abstract/UniqueContribution

0 Ratio of indices for diencephalon and medulla oblongata for dolphins and dugongs are equal.

0 Mesencephalon progression is greater during cetacean than sirenian history.

0 Enlargement of the mesencephalon in cetacean evolution corresponds to increase in mesencephalic tissues devoted to acoustic high frequency perceptions in dolphins. Mesencephalic underdevelopment in the dugong probably points to the absence of extreme specialization. This is suggested by the large colliculi posteriores of the dolphin.

Keywords: Anatomy, brain, dugong, mesencephalon

	Ref. code	Year
53.	52522	1968.

Poulter, T.C.

Marine mammals.

In: Animal Communication: Techniques of Study and Results of Research, (T.A. Sebeok, ed.), Indiana University Press, Bloomington, IN. Pp. 405-465.

Abstract/UniqueContribution

0 Of 117 recognized species of marine mammals including sea otters, pinnipeds, sirenians and cetaceans, all 83 studied to this date generate underwater sounds.

0 The authors states the assumption that if sounds are made, they can be and probably are used for some sort of communication.

0 As of this date there were no known recordings of the dugong or West African manatee; Kellogg published a phonograph recording of the West Indian manatee in 1955 and described it as squeaking like a mouse.

0 Author refers to “Zipf’s law” and states that the data for all studied marine mammals supports the view that marine mammals talk and that what they say makes sense to others of the same species.

Keywords: behavior, hearing, squeaks

	Ref. code	Year
54.	52505	1989.

Preen, A.

Observations of mating-behavior in dugongs *(Dugong dugon).*

Marine Mammal Science 5(4):382-387.

Abstract/UniqueContribution

0 Splashing behavior may function as a means of communication or display.

0 Splashing behavior may indicate a heightened level of tension.

Keywords: anecdote, behavior, cavorting (mating), damage (injury), dugong, mood-specific noises, response, social behavior, whistles

	Ref. code	Year
55.	52507	1953.

Quiring, D.P. and C.F. Harlan.

On the anatomy of the manatee.

Journal of Mammalogy 34(2):192-203.

Abstract/UniqueContribution

0 Minute ear openings were located 7 inches posterior to the eyes of a 3.25 m female manatee taken from Miami Bay.

0 "A tiny canal led inward from the ear-opening but soon lost itself in the underlying blubber, and there was no direct connection from the surface to the middle ear." (original authors' statement)

Keywords: anatomy, auditory meatus, squamosal bone, zygomatic process

	Ref. code	Year
56.	52508	1820.

Raffles, T.S.

Some account of the dugong.

Philosophical Transactions of the Royal Society of London, Part 1:174-182.

Abstract/UniqueContribution

0 Young have short, sharp cry which is frequently repeated.

Keywords: anecdote, calls, calf, dugong

	Ref. code	Year
57.	52511	1979.

Reynolds, J.E. III

The semisocial manatee.

Natural History 88(2):44-53.

Abstract/UniqueContribution

0 Body surfing and following behaviors seem to require communication.

0 At Blue Lagoon, manatees vocalize infrequently.

0 "Squeaks and squeals... may simply indicate excitement, fright, or the presence of an animal in the area." (Original author's statement)

0 Mechanoreception (via body hairs) may play a role in interactive behaviors.

Keywords: anecdote, behavior, bodysurfing, mechanoreception, mood-specific noises, social behavior, squeaks, squeals

	Ref. code	Year
58.	52509	1981.

Reynolds, J.E. III

Aspects of the social behaviour and herd structure of a semi-isolated colony of West Indian manatees, *Trichechus manatus.*

Mammalia 45(4):431-452.

Abstract/Unique Contribution

0 Situations in which vocalizations were recorded:

Bodysurfing - frequent;

Approach of newcomer - feeding manatees vocalize while resting animals did not;

Female - calf duets: mean duration of calf vocalizations was about 142 msec (n = 11 vocalizations, range = 20-300 msec). Mean pulse duration of female's call = 385 msec (n = 16 vocalizations, range = 140-1000 msec). Mean interval between calf vocalization and female's answer (measured from beginning of first call to beginning of second) was 1995 msec (n = 10 intervals, range = 800-3200 msec). Mean interval between female call and answering calf was 995 msec (n = 10 intervals, range = 600-1200 msec). The mean interval between the two female vocalizations with no intervening calf calls was 3920 msec (n = 5, range = 2300-6600 msec).

Female and calf separated by flood control gate: female - 250 msec between 2.0 and 2.5 kHz, calf - similar duration between 2.5 and 3.0 kHz.

0 Manatees in herds not much more vocal than single animals.

0 Larger herds more vocal than 2-animal herds (intermittent with occasional bursts. Most occurred following synchronous breaths.

- Reacted to approaching boats, metal objects dropped in canoe, people jumping in water, and conspecifics vocalizing.

Keywords: Herds, bodysurfing, duets, feeding, newcomer, calf, response (sound reaction), resting

	Ref. code	Year
59.	52532	1991.

Reynolds, J.E. III and D.K. Odell.

The Florida manatee.

In: Manatees and Dugongs, A Facts On File book, R.R. Donnelley & Sons, New York. Pp. 192.

Abstract/Unique Contribution

- Manatees have large ear bones and vocalizations (duets) help keep the mother and calf together.
- An anecdote relating how a calf was used to catch its mother for protective reasons is given to illustrate the strength of the animals' communicative abilities in turbid conditions. The same technique is reported to be used in South America to hunt the animals.
- States that sounds are described as chirps, whistles or squeaks in the 3-5 kHz range, probably formed in the larynx.
- States that optimal hearing may be through cheek areas rather than auditory meatus region and suggests that they may be able to hear infrasound, explaining the gathering of males to estrus females.
- Dugongs make whistles or bleats In the 1-8 kHz range and may be particularly important in mother-calf bonds.

Keywords: acoustic sensitivity, anecdote, Miami Seaquarium, auditory evoked potential (aep), auditory meatus, behavior, bleats, calf, calls (vocalizations), chirps, duets, dugong, elephants, herds, larynx, low frequency (infrasound), ossicle (bulla, stapes, malleus, incus), social behavior, chirps, squeaks, whistles

	Ref. code	Year
60.	52513	1965.

Robineau, D.

Le osselets de l'ouie de la rhytine.

Mammalia 29:412-425.

Abstract/UniqueContribution

0 After having defined briefly the middle ear of sirenians, the author describes the ossicles of the ear of *Rhytina gigas* which he compares to those of *Trichechus* and *Dugong.* He concludes that the ossicles of *Rhytina* (with the exception of the stapes) are the biggest mammalian ossicles. He characterizes the ossicles of the sirenians as: big dimensions, bulky aspect, and the anterior process of the malleus is ankylosed (see: Murie, J., 1872). (Abbreviated original author's abstract)

Keywords: anatomy, dugong, ossicle (bulla, stapes, malleus, incus), tympanic membrane

	Ref. code	Year
61.	52512	1969.

Robineau, D.

Morphologie externe du complexe osseux temporal chez les sireniens.

Memoires du Museum National D'Histoire Naturelle, Serie A: Zoologie, 60(1):1-32.

Abstract/UniqueContribution

0 (not abstracted)

Keywords: anatomy, dugong, ossicle (bulla, stapes, malleus, incus), tympanic membrane

	Ref. code	Year
62.	5319	1978.

Ronald, K., L.J. Selley, and E.C. Amoroso.

Structure and Function: Part 2., Hearing, Phonation.

In: Biological synopsis of the manatee, Chapter 5 p. 27. College of Biological Science. Univ. of Guelph, Ontario, Canada.

Abstract/UniqueContribution

0 Structure of the ear as reported by Harrison and King (1965), Quiring and Harlan (1953), Bertram and Bertram (1964, 118), Robineau (1965), Hartman (1971), Verhaart (1972).

0 Crystallography and transmission electron microscope findings on ear structure by Giraud-Sauveur and Miloche (1968).

0 Acoustic sensitivity measurements of Hartman (1971), Bertram and Bertram (1964).

0 Sounds emitted by manatees come from laryngeal cartilage vibration not from vocal cords (Sirenia have no vocal cords) Dexler and Freund (1906). Other phonation studies by Schevill and Watkins (1965), Evans and Herald (1970).

0 Excellent list of references.

Keywords: Acoustic sensitivity, hydroxyapatite, harmonics

	Ref. code	Year
63.	52514	1889.

Scammon, C.M.

The sea cow.

Overland Monthly, Second Series 14(84):581-585.

Abstract/UniqueContribution

0 Cry like an infant.

0 When not particularly hungry, they would "utter a sort of nasal or guttural strain of satisfaction" when fed peeled bananas. If grass or turnip tops were then offered, "they would utter their whining petulant cry of dissatisfaction as if they were weanlings." (see: Gunter, G., 1959)

0 Named "Lamantin" by French because of whines and sighs as opposed to loud cries.

0 Sight and hearing appear to be very weak.

Keywords: calls, feeding, hearing

	Ref. code	Year
64.	5253	1965.

Schevill, W.E., and W. A. Watkins.

Underwater calls of *Trichechus* (manatee).

Nature 205:373-374.

Abstract/UniqueContribution

0 Description of test environment (in natural conditions).

0 Description of sounds (dB. duration, distance, frequency, harmonics, tones, intensity).

0 Description of recording equipment and location of hydrophone.

0 Description of animals' behavior during test (eating vegetation, moving about, startle response). No evidence of echolocation behavior or hearing. 3 illustrations of call harmonics.

Keywords: echolocation, harmonics, methods, startle response, whistles

	Ref. code	Year
65.	52533	1973.

Sonoda, S. and A. Takemura.

Underwater sounds of the manatees, *Trichechus manatus* and *T. inunguis* (Trichechidae).

Report Inst. Breeding Research, Tokyo Univ. Agriculture. No. 4:19-24.

Abstract/UniqueContribution

0 Description of the specimen animals, the test pool, submergence duration, equipment used.

0 Analysis of calls (illustrations, charts, tables):

T. manatus manatus

clicks and frog-like calls
no synchronism in start or finish of layers of calls with a single animal
grinding of molars during eating produced sound.

T. inunguis

emitted sounds (whistles and frog-like, but no clicks) and swam about more than *T. manatus*
whistle calls resembled bird chirps; short duration and only made when man moved toward pool or tapped water surface
most calls frog-like, duration 0.2 s, frequency 2-3 kHz (rare 10 kHz) short duration, weak.

Keywords: behavior, calls (vocalizations), chirps, feeding, methods, recording, response (sound reaction), whistles

	Ref. code	Year
66.	5260	1982.

Steel, C.

Vocalization patterns and corresponding behavior of the West Indian manatee *(Trichechus manatus).*

Ph.D. thesis, Florida Institute of Technology, Melbourne, FL.

Abstract/UniqueContribution

- 0 The West Indian manatee, *Trichechus manatus,* demonstrated an extensive use of vocalization to communicate or express moods. Sounds were short in duration, ranging from .15-.43 seconds with dominant frequencies ranging from 1000-12,000 Hz. Signals were categorized by their physical characteristics and "sound" to the human ear. Variations in tone, dominant frequency range, amount of noise, and frequency pattern were determined. In this way, sex and age groups could be distinguished.

- 0 Adult female sounds included the female squeal and "rusty pump" call. These sounds were distinctly lower in tone than male squeals. Adult squeaks, unlike squeals, were non-harmonic and often higher in tone than male and female squeals. Squeak-squeals contained intermediate characteristics between squeaks and squeals. Miscellaneous adult signals included whistles, fluctuating squeals, fluctuating squeaks, and the "sneeze" call.

- 0 Infant vocalizations were squeaky in nature and had a chirp-like quality. The squeak-chirp (type I) had a much higher tone than the squeak-chirp (type II). A two-toned chirp, containing two distinct tones was also emitted by an infant. Juvenile squeals retained the infant chirp-like quality, but were less noisy than the infant calls; they also began to show the harmonic banding of adult squeals.

- 0 Manatee signals displayed rapid frequency and amplitude modulation in many cases. The dominant frequency pattern was one frequency dominant throughout; however, many signals also demonstrated frequency modulation upward, downward, or in both directions. Changes in amplitude also occurred in the majority of signals, and a drop in sound energy was observed in the last portion of most vocalizations.

0 Behavior patterns associated with manatee vocalizations were also determined. Common activity patterns occurring with the emission of sounds included approach of one manatee to another, submergence from breathing when near another manatee, exploration of the environment, and play. A rise in amplitude of vocalizations occurred under conditions of stress, annoyance, and alarm. No distinct alarm call was determined except for the infant type II squeak-chirp, recorded when infants were alarmed by boats or divers. Constant dialogues were recorded between mother-calf pairs in order to maintain contact, particularly under stressful situations.

0 Conclusions:

1. The use of vocalization to communicate is important to manatees, especially in the turbid waters they often inhabit.

2. Manatees use a variety of calls to express mood; however, it cannot yet be determined whether these vocalizations constitute a language.

3. In order to distinguish categories of calls, several factors must be used, including tone, amount of noise, and dominant frequency range.

4. By distinguishing vocalizations emitted by the different sex and age groups, a possible way to study the manatee without clear observation may be established.

5. The change from infant to juvenile to adult is accompanied by a change in vocalization patterns. This change may arise through physical development of the vocal cavities.

6. Behavior patterns may eventually lead to the linking of specific sounds to specific activities. However, many more studies need to be conducted to gain this knowledge.

7. Aside from the infant squeak-chirp (type I!), no distinct alarm call is evident. This may relate to the lack of natural predators or enemies of the manatee.

8. Acoustics could be a valuable tool in studying the manatee. Future studies could greatly enhance our present knowledge of manatee ecology and behavior. (Original author’s abstract in its entirety.)

67. Ref. code 52515 Year 1982.

Steel, C. and J.G. Morris.

An investigation of manatee *(Trichechus manatus)* acoustics.

Florida Scientist 45 (Suppl. 1), 46th Annual Meeting of the Florida Academy of Sciences, Deland, Florida. April 22-24.

(Published abstract)

Abstract/UniqueContribution

0 Manatee sounds were recorded in captive and non-captive environments using USRD hydrophone and 4-channel tape recorder. Behavioral observations made simultaneously. Signals subsequently digitized to obtain plots of time and frequency domain. Speech frequency now plotted versus time and energy output.

68. Ref. code 52519 Year 1982.

Steel, C. and J.G. Morris.

The West Indian manatee *Trichechus manatus:* an acoustic analysis.

American Zoologist 22(4):925.

(Published abstract)

Abstract/UniqueContribution

0 Vocal and non-vocal (feeding) sounds of the West Indian manatee, *Trichechus manatus,* were analyzed. Manatee sounds were recorded in captive and non-captive environments using a hydrophore coupled to a four channel tape recorder. Behavioral observations were made simultaneously. From the digitized data, time and frequency domain plots were constructed as well as three dimensional plots of frequency, time, and energy output. Data demonstrated consistent patterns in sound production relative to age and sex of the animal. Generally, sounds were short in duration (0.6-.4 secs.) with the average frequency range occurring between 1000 and 12,000 Hz. Approximately 10 types of vocalizations

were recorded with the most common sound, the squeal, being composed of several harmonically related frequency components. Adult female calls were consistently lower in tone than adult males. Three categories of infant calls were recorded. Infant sounds were found to be much raspier than the adults with this raspiness gradually disappearing in the juveniles. Rapid amplitude and frequency modulation was common in many of the calls, (Original authors' abstract)

	Ref. code	Year
69.	52534	1963.

Tembrock, G.

Acoustic behavior of mammals.

In: Acoustic Behavior of Animals, (R.-G. Busnel, ed.), Elsevier Publishing co. P. 757.

Abstract/UniqueContribution

0 In a table "Frequencies of sounds of various mammals" lists *Trichechus manatus* L. at 4304 Hz, adding that many of the recordings were of one event on single animals with an equipment upper limit of 10 - 14 kHz.

0 Also contains a good generalized discussion on types of vocalizations and their typical functions.

Keywords: calls (vocalizations), mood-specific noises, recording, signal

	Ref. code	Year
70.	52516	1964.

Turner, R.N.

Methodological problems in the study of cetacean behavior.

In: Marine Bio-Acotistics (W.N. Tavolga, ed.). pp. 337-351. Pergamon Press, Oxford.

Abstract/UniqueContribution

0 A discussion of operant conditioning techniques to test response to stimuli (food or avoidance of pain in exchange for response to sound, sight).

Keywords: operant conditioning

	Ref. code	Year
71.	52517	1931.

Van der Klaauw, C.J.

The auditory bulla in some fossil mammals with a general introduction to this region of the skull.

Bulletin of the American Museum of Natural History 62:1-352.

Abstract/Unique Contribution

0 (not abstracted)

Keywords: anatomy, ossicle, squamosal bone, zygomatic process

	Ref. code	Year
72.	52521	1972.

Verhaart, W.J.C.

The brain of the sea *cow Trichechus.*

Psychiatr., Neurol., Neurochir. 75:271-292.

Abstract/UniqueContribution

0 A detailed anatomical study of the same specimens originally described by Jelgersma (1934) using updated knowledge and descriptions (excepting the cerebellum which is simply described as large and complicated). In spite of the above caveat,, this work seems to represent a scholarly, landmark work attempting to) understand if there are features characteristic of marine mammal brains.

0 The author notes that Jelgersma mistook the vestibular brain stem apparatus as hypertrophic where it is now known to be acoustic. This vestibular system is large in manatees but smaller than in cetaceans where supersonic sensory capabilities exist. The author suggests manatees possibly have similar capabilities.

0 Cerebral hemispheres are extraordinarily small for the body size and, merely on this basis, would rank manatees at the lowest level of mammalian development. All other factors of CNS development considered, though,

the author feels the animals rank just below Saimiri, a low middle level primate and that, rather than exhibiting CNS degeneration, is probably more an example of retarded development.

0 Acoustically, the manatee brain is remarkable because of the large size of the acoustic portions with the exception of the dorsal cochlear nucleus.

Keywords: anatomy, brain, echolocation, elephants

	Ref. code	Year
73.	52535	1975.

Whitfield, W.K. and S.L. Farrington.

An annotated bibliography of Sirenia.

Florida Marine Research Publication No. 7. Florida Department of Natural Resources. 44 pp. St. Petersburg, FL.

Abstract/UniqueContribution

0 As implied, the paper abstracts available literature to date including index category of “Acoustics and Sounds” (7 items listed, 1 omitted in error).

	Ref. code	Year
74.	52523	1977.

Winn, H.E. and J. Schneider.

Communication in sirenians, sea otters, and pinnipeds.

In: How Animals Communicate, T.A. Sebeok (ed.), Indiana University Press, Bloomington, IN. p. 809-840).

Abstract/UniqueContribution

0 Surf noise is the greatest amplitude noise the marine mammals naturally experience.

0 Manatees live in high particulate coastal areas with low noise levels. Stellar’s sea cow lived where both good vision and hearing could have been adaptive.

0 The turbulence and noise created by a rapid plunge may be communicative.

0 A. Myrberg reported a study of a male, female and calf each of which made sounds but of a limited vocabulary. Sounds described as gull-like shrieks, made in social interactions, with the calf making quite a few when isolated.

Keywords: anecdote, behavior, calf, calls (vocalizations), social behavior, startle response

	Ref. code	Year
75.	5250	1985.

Woodyard, H.D., M. Bowen and J. White.

An auditory frequency discrimination in a captive West Indian manatee *(Trichechus manatus).*

Abstracts of Papers and Posters, Fourth Theriological Congress, Edmonton (Canada), 13-20 August, 1985.

(Published abstract)

Abstract/UniqueContribution

0 Reports testing manatees for visual information processing: brightness, size, shape, color, motion, left/right, and horizontal/vertical orientation.

0 Reports demonstrating transpositional learning, reversal discriminations, learning sets, matching to sample, and long term memory (17 months).

0 Claims anatomical and evoked potential research suggest capacity to use auditory information but behavioral evidence is needed.

0 A manatee was trained to discriminate whether a 3 kHz signal was being presented, Then the frequency was varied with the animal responding over the full range of the equipment (200 Hz-12 kHz). Then the animal discriminated between a 500 Hz and a 5 kHz signal.

0 The conclusions were: 1) manatees can use auditory information, 2) they can use at 0.2-12 kHz, and 3) manatees can learn to discriminate using different pitch cues.

Keywords: Miami Seaquarium, double-blind, behavioral testing, auditory testing, acoustic sensitivity, acoustic sensitivity, hearing, methods, operant conditioning (training), signal.

	Ref. code	Year
76.	52518	1986.

Worthy, G.A.J. and J.P. Hickie.

Relative brain size in marine mammals.

American Naturalist 128(4):445-459.

Abstract/UniqueContribution

0 Echolocation systems based on broadband click signals may require more neural processing than do total systems (per Wood and Evans, 1980).

0 High encephalization quotient (EQ) may be a result of socialization and the need for central processing to understand their surroundings.

0 Sirenians, mysticetes and the sperm whales all have EQ's smaller than the mammalian average and are similar to large ungulates.

Keywords: Brain, clicks, EQ (encephalization quotient)

For those who enjoy a challenge, the following additional references are known to exist. If one should be fortunate enough to acquire any of these, the authors would like to know.

77. Ref. code 52536 Year 1982.

Anderson, P.K.

Title unknown

Australian Wildlife Research 9:85-99.

78. Ref. code 52537 Year 1908.

Beyer, H.

Studien uber den sogenannten Schalleitungsapparat bei den Wirbeltieren und Betrachtungen uber die Function des Schneckenfensters.

Arch. Ohrheilkunde 77:77-105.

79. Ref. code 52538 Year 1867.

Claudius, M.

Das Gehororgan von Rhytina stelleri.

Mem. Acad. Sci. St. Petersburg (7)11(5):1-14.

80. Ref. code 52539 Year 1868.

Claudius, M.

Uber Schallzuleitung zum Labyrinthe. Aus Einer Abhandlung uber Rhytina *Stelleri.*

Monatsschr. Ohrenheilkd., Kehlkopfheilkd. Nasen.-Rachenkr. 2:111.

81. Ref. code 52541 Year 1991.

Court, N. and J.-J. Jaeger.

Anatomy of the periotic bone in the Eocene proboscidean *Numidotherium* koholense; an example of parallel evolution in the inner ear of tethytheres.

Comptes Rendus de L 'Academic Des Sciences Paris, Serie II, 312:559-*565.*

82. Ref. code 52542 Year 1906.

Dexler, H. and L. Freund.

Zur Biologie und Morphologie von *Halicore dugong.*

Arch. Naturgesch. 72:77-106

Abstract/UniqueContribution

0 Sounds emitted by manatees come from laryngeal cartilage vibration, not from vocal cords (Sirenia have no vocal cords).

83. Ref. code 52543 Year 1971.

Fleischer, G.

Uber Schwingungs messungen am Skelett des Mittelohres von *Halicore* (Sirenia).

Z. Saugetierkd. 36:350-360.

84. Ref. code 52544 Year 1964.

Harrison, R.J. and J.D. Tomlinson.

Observations on diving seals and certain other mammals.

Zool. Soc. London, Symp. 13:59-69.

85. Ref. code 52545 Year 1947.

Harwood, K.

The sea cow is a tourist.

Sports Afield Nov. 1947:50,89.

86. Ref. code 52546 Year 1845.

Hyrtl, J.

Vergleichend-anatomische Untersuchungen uber das innere Gehororgan des Menschen und der Sangethiere.

F. Ehrlich, Prague. Pp. 139.

	Ref. code	Year
87.	52547	1955

Kellogg, W.N.

Title unknown

Folkway Records #FPX 125. (Phonograph record)

	Ref. code	Year
88.	52548	1982.

Kleinschmidt, A.

Wissenswertes uber die Saugerordnimg der Seekuhe (Sirenia) unter besonderer Berucksichtigung der Stellerschen Rieseneekuh *Rhytina gigas* (Zimmermann, 1780) sowie ihre hochgradige Anpassung an das Wasserleben im Vergleich zu den Walen.

Braunschweig. Naturk. Schr. 1(3):367-418.

	Ref. code	Year
89.	52549	1936.

Lopes, A.P.

Fauna Mozambicana Sirenios.

Mozambique, Documentario trimestral, Lourenco Marques 2:27-36.

	Ref. code	Year
93.	52551	1912.

Matthes, E.

Einige Bemerkungen uber das Gehorogan von Walen und Sirenen.

Anat. Anz. 41:594-599.

	Ref. code	Year
91.	52529	1984

Nietschmann, B.

Hunting and ecology of dugongs and green turtles, Torres Strait, Australia.

National Geographic Society Res. Rept. 17:625-651.

	Ref. code	Year
92.	52552	1945.

Pereira, N.

0 Peixe-boi da Amazonia. [On the steer-fish of the Amazon.]

Min. Agric., Tecn. Div. Caco Pesca, D.E.I.P.-S.S.A., Manaus-Amazonas.

	Ref. code	Year
93.	52553	1923.

Petit, G.

Sur le dugong de Madagascar: notes ethnographiques.

Soc. Antrop. Paris, Bull. and Mem. 7:75-83.

	Ref. code	Year
94.	52503	1955.

Petit, G.

Ordre des Sireniens.

In: Traite de Zoologie Vol. 17 (Mammiferes),fascicle 1:918-1001, Masson et Cie, Paris, P.P. Grasse (ed.).

	Ref. code	Year
95.	52504	1963.

Pfeffer, P.

Remarques sur la nomenclature du dugong *Dugong dugon* (Erxleben) et son statut actuel en Indonesie.

Mammalia 27(1):149-151.

	Ref. code	Year
96.	52554	1834.

Rijppell, E.

Uber den im Rothen Meere vorkommenden Dugong *(Halicore).*

Museum Senckenbergianum 1(2):99-114.

	Ref. code	Year
97.		1924-1925.

Vosseler, J.

Pflege und Haltung der Seekuhe.

In: Der Zoologische Garten. Organ der Zoologischen Garten Deutschlands. Pallasia 2(3):220-221.

	Ref. code	Year
58.	52555	1967.

Welsby, T.

The Collected Works of Thomas Welsby

Jacaranda Press, Brisbane 2:235.

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Andersen, H.T. (ed.). 1969. The Biology of Marine Mammals. Academic Press, New York. 511 pp.

Andersen, S. 1970. Auditory sensitivity of the harbor porpoise *(Phocoena phocoena).* In: Investigations on Cetacea, ed. G. Pillerie. University of Berne, Berne, Switzerland, Vol. 2:255-258.

Atema, J., R.R. Fay, A.N. Popper, and W.N. Tavolga (eds.). 1987. Sensory Biology of Aquatic Animals. Springer-Verlag, New York. 936 pp.

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Au, W.L.. and P.W.B. Moore. 1984. Receiving beam patterns and directivity indices of the Atlantic bottlenose dolphin *(Tursiops truncatus).* Journal of the Acoustical Society of America 75:255-262.

Bench, R.J., A. Pye and J.D. Pye (eds.). 1975. Sound Reception in Mammals. [Proceedings of a Symposium organized jointly by the British Society of Audiology and the Zoological Society of London, March 21-22, 1974, London.] Academic Press. 357 pp.

Busnel, R.-G. (ed.). 1963. Acoustic Behavior of Animals. Elsevier Publishing Company, New York. 933 pp.

Busnel, R.-G. (ed.). 1966. Les Systemes Sonars Animaux: Biologie et Bionique (Animal Sonar Systems: Biology and Bionics). North Atlantic Treaty Organization Advanced Study Institute, Frascati, Italy, September 26- October 3, 1966. Vol. I (pp. 1-713) and Vol. II (pp. 719-1233).

Busnel, R.-G. and A. Dzedzic. 1968. Caracteristiques physiques des signaux acoustiques de *Pseudorca crassiden* Owen (Cetacea Odontocete). Mammalia 32(1):1-5.

Busnel, R.-G. and J.F. Fish eds.). 1980. Animal Sonar Systems. Plenum Press, New York. 1135 pp.

Cleator, H.J. and I. Stirling. 1990. Winter distribution of bearded seals *(Erignathus barbatus)* in the Penny Strait Area, Northwest Territories, as determined by underwater vocalizations, Canadian Journal of Fisheries and Aquatic Sciences 47(6):1071-1076.

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Fish, M.P. and W.H. Mowbray. Sounds of Western North Atlantic Fishes: A Reference File of Biological Underwater Sounds. The Johns Hopkins Press, Baltimore, MD. 207 pp.

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Leatherwood, S. and R.R. Reeves. 1989. The Bottlenose Dolphin. Academic Press, New York. 653 pp.

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