The 4th Program of China-ASEAN Academy on Ocean Law and Governance

Marine mammals and recent bioacoustics research on marine mammals in Chinese waters

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16 Nov. 2018, Haikou

  

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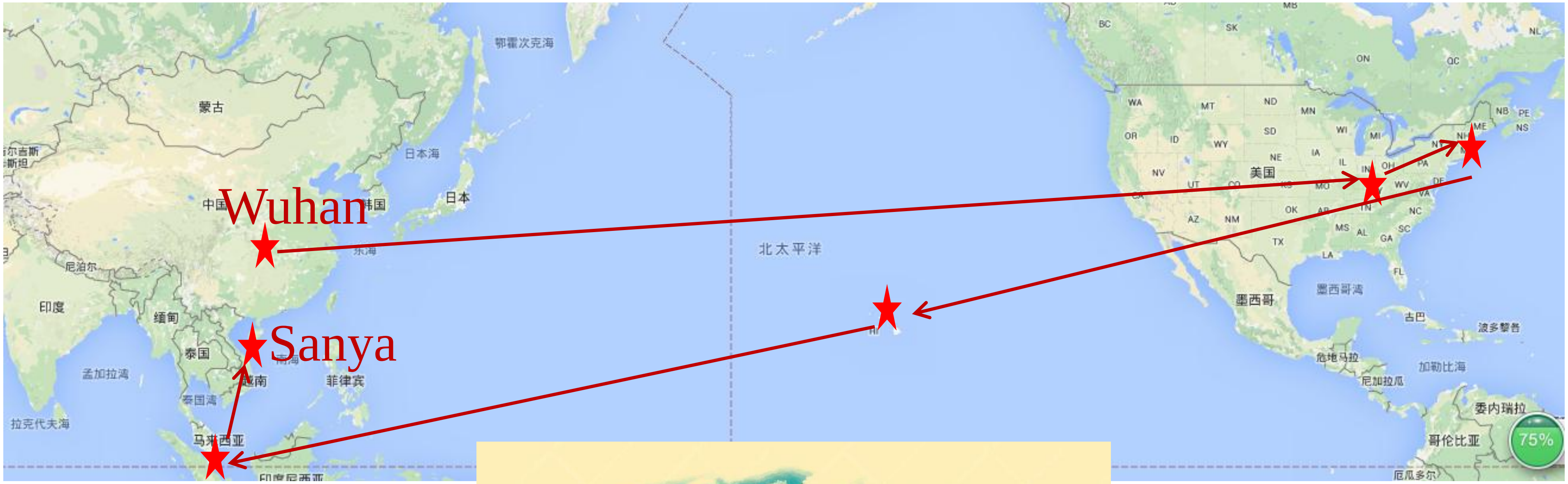
Marine Mammals

My education and research footprint





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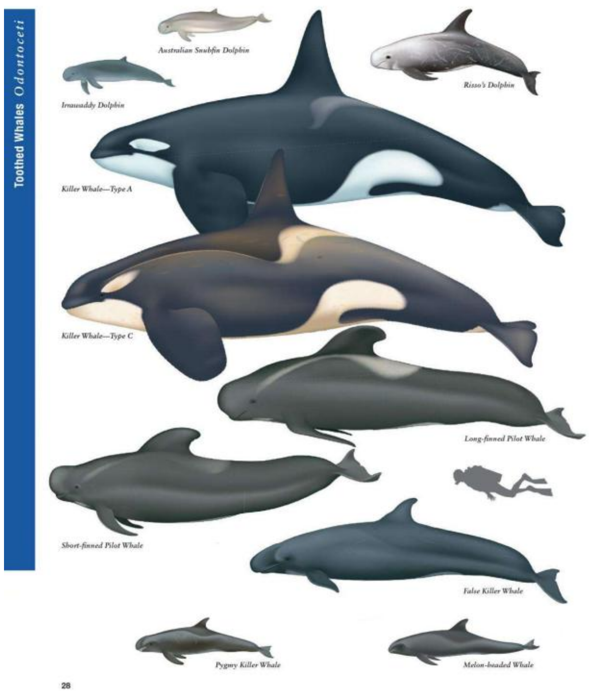
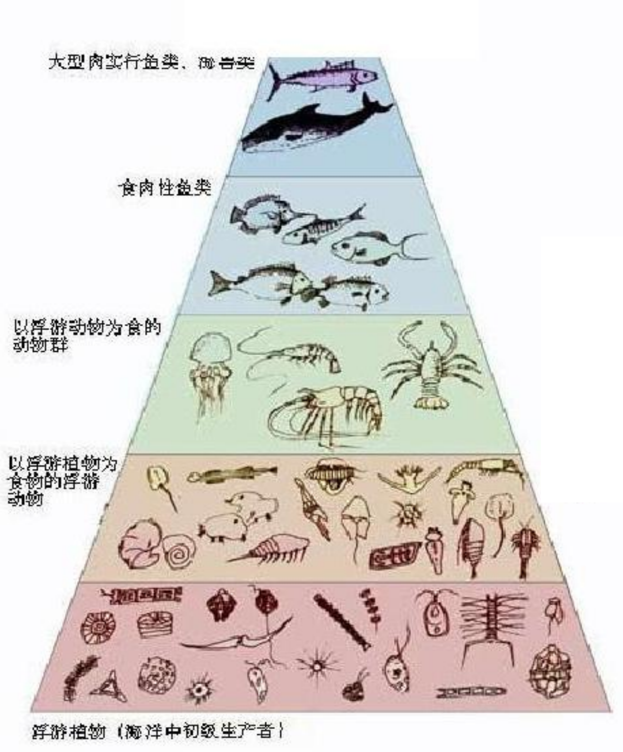
Marine Mammals

- Are protected under the **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);**
- Most marine mammals are at the top of the food chain in the ocean ecosystem;
- A lot of marine mammals in our region.







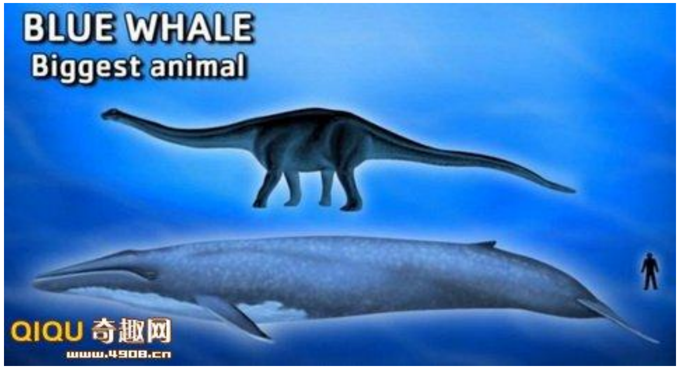
Marine Mammals

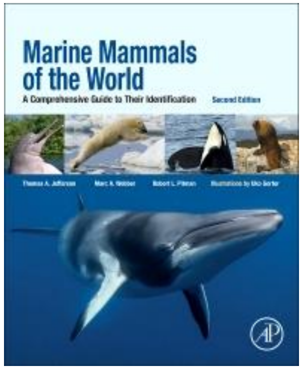
- Charismatic mammals living in the ocean;
- Marine mammals have the same characteristics as all other mammals:
  - Warm-blooded
  - Having hair or fur
  - Breathing air through lungs
  - Bearing live young
  - nursing their young with milk produced by mammary glands
  - Having adapted to living all or part of their life in the ocean. To keep warm in the ocean, most of them depend on a thick layer of blubber (or fat). They have streamlined bodies to help them swim faster.
- Cetacean, Sirenian, and Carnivora, about 130 species

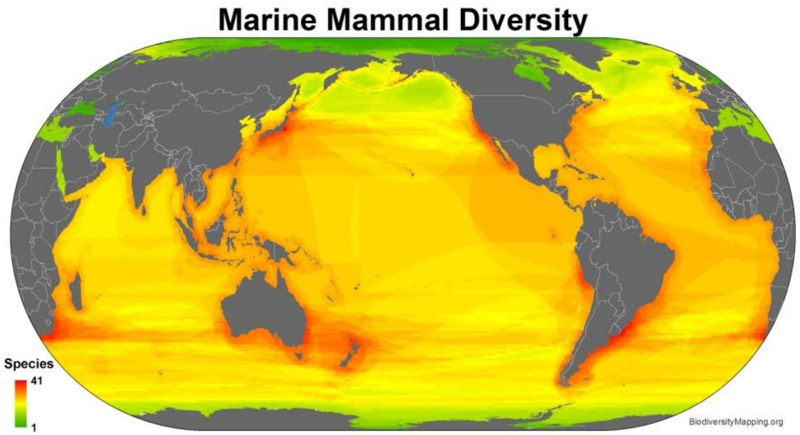


Marine Mammals

- The size range of marine mammals is immense, varying from a sea otter weighing about 20 kilogram (kg) with length of 1.5 m to the largest female blue whale weighing about 180,000 kg with 30 m in length;
- Their habitats are also quite varied; they can be found worldwide, encompassing all seas and numerous coastal areas and shores as well as freshwater lakes and rivers.









Marine Mammal Classification

Order Cetacea includes the whales, dolphins, and porpoises

- 90 species;
- Completely aquatic, and cannot survive on land;
- Two front flippers, and a tail uniquely shaped into two horizontal extensions, called fluke, which provide swimming power.

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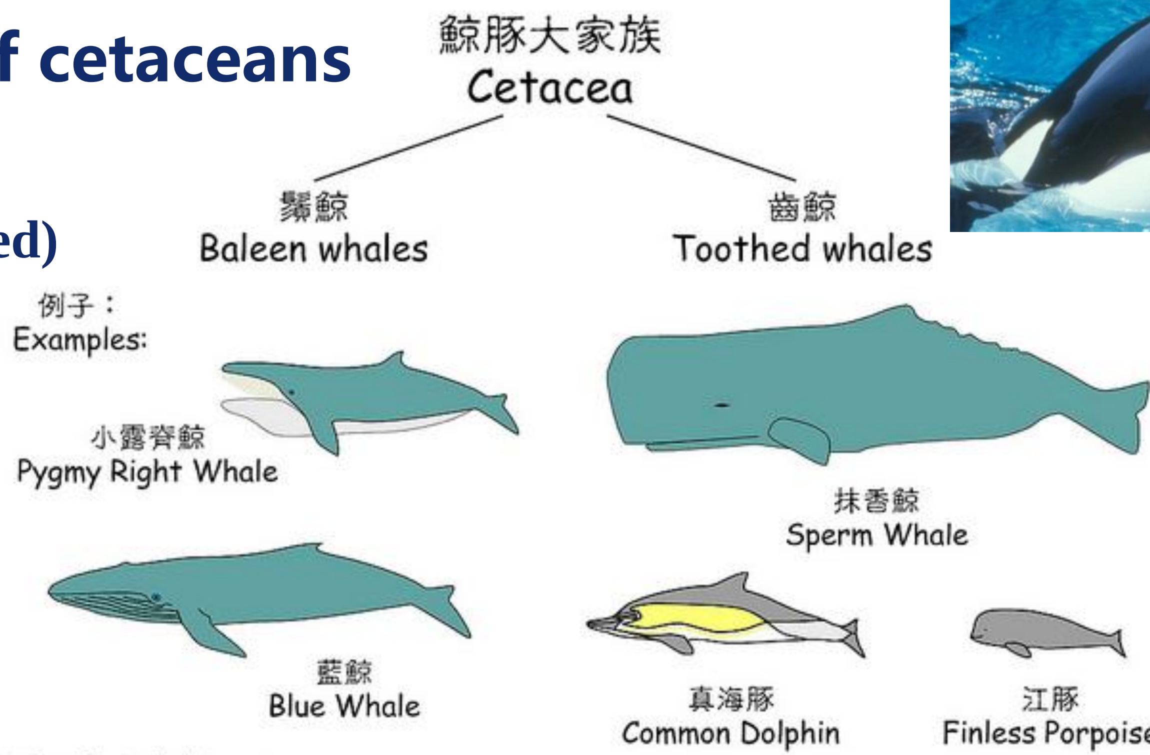
Marine Mammal Classification

Two suborders of cetaceans

- Mysticeti (baleen)
- Odontoceti (toothed)



(c) Care for Dolphins.net

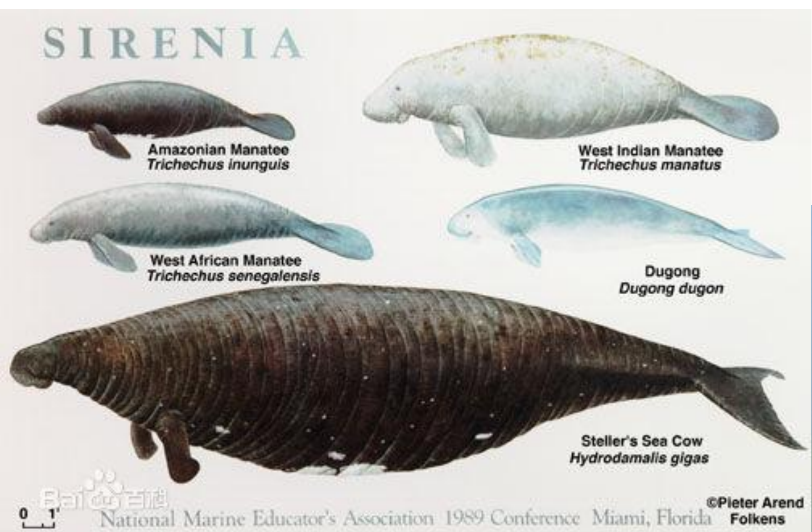
- **Baleen whales include blue, gray, humpback, and bowhead whales. Instead of teeth, baleen whales have rows of strong, closely spaced baleen plates along both sides of their upper jaws. These plates filter out and trap small fish and plankton, which the whale then swallows. Baleen whales breathe though a pair of blowholes;**
- **Toothed whales are highly variable in body shape and size and include dolphins, porpoises, narwhal, beluga, beaked, and sperm whales. Toothed whales have variable numbers of teeth, or may have no functional teeth at all, and breathe through a single blowhole.**



Marine Mammal Classification

Order Sirenia includes the dugongs and manatees

- All species live in warm or tropical waters and feed on plants. Another species of sirenian, called the Steller sea cow, once inhabited Arctic waters, but was hunted to extinction by 1768 within 27 years of its discovery. They are fully aquatic as well and therefore are obligate water dwellers

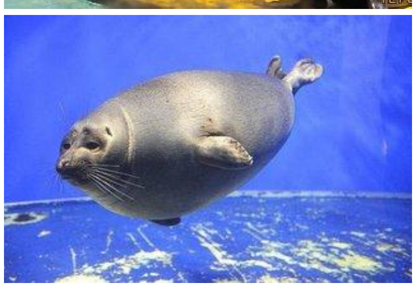




Marine Mammal Classification

Order Carnivora includes five families of marine mammals:

- Otariidae (sea lions and fur seals), Phocidae (true seals), and Odobenidae (walruses), i.e., Pinnipeds. They are semiaquatic and regularly come out on land to rest, breed, and give birth;
- Sea otters and polar bears. Sea otters are the only marine member of the mustelid family; Polar bears are designated as marine mammals because they depend on the ocean for a majority of their food.

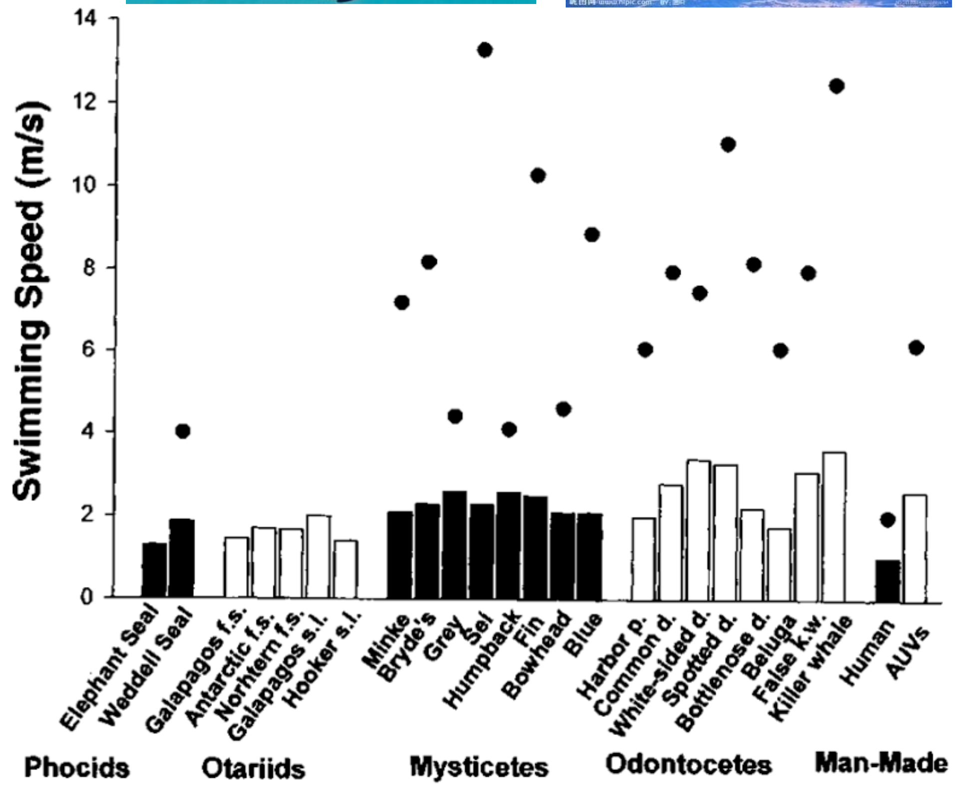

photograph©Mitsuaki IWAGO



Marine Mammal Locomotion

Swimming is the primary mode of locomotion for marine mammals


- A streamlined body shape with the possible exception of polar bears;
- For cetaceans, it is the only form of locomotion.
- As short as several seconds when moving between prey patches;
- As long as several months during seasonal migrations across entire ocean basins.



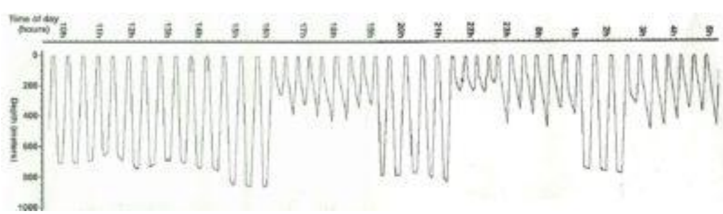
- Routine speeds of marine mammals;
- Filled circles are the sprinting speeds recorded for each species;
- Range of routine speeds are similar for the marine mammals regardless of body size.

Marine Mammal Diving

- Mammals are warm blooded air breathers, not ideal for the conditions in deep sea;
- Marine mammals have thrived in the ocean, and evolved adaptations to dive to extraordinary depths;
- The sperm whale is the diving champion of marine mammals, and can stay under water for over 2 hours and dive to depths of nearly 3000 m. It has an extraordinary array of adaptations that allow it to dive so deep. All marine mammals can make dives that are deep compared to human beings.

Species	Body mass (kg)	Routine depth (m)	Maximum depth (m)	Routine duration (min)	Maximum duration (min)
Human	70	5	133	0.25	6
Elephant seal	400	500	1500	25	120
Bottlenose dolphin	200		535		
Sperm whale	10000	500	>3000	40	132



Seal-diving-profile



Marine Mammal Life History

- All species of whales and dolphins, sirenians, and sea otters, without exception, typically give birth to single, large, and precocial young;
- Gestation times are approximately a year;
- The breeding cycle varies from one year to several years;
- Relatively long-lived;
- Age at attainment of sexual maturity is delayed from ages of 3 years to 10 years or more.




Marine Mammal Values

- **Economics values:** Certain species of marine mammals, including whales and dolphins, are increasingly important drivers of economic growth for tourism and related industries.
- **Ecological and conservation values:** Marine mammals play a varied role in marine ecosystems, may act as top level predators feeding on other marine mammals, on fish, or feed at much lower levels on benthic and pelagic invertebrates. They play a very clear role in structuring marine ecosystems.
- **Scientific research values:** Bioacoustics, animal behavior, evolution, bionics…



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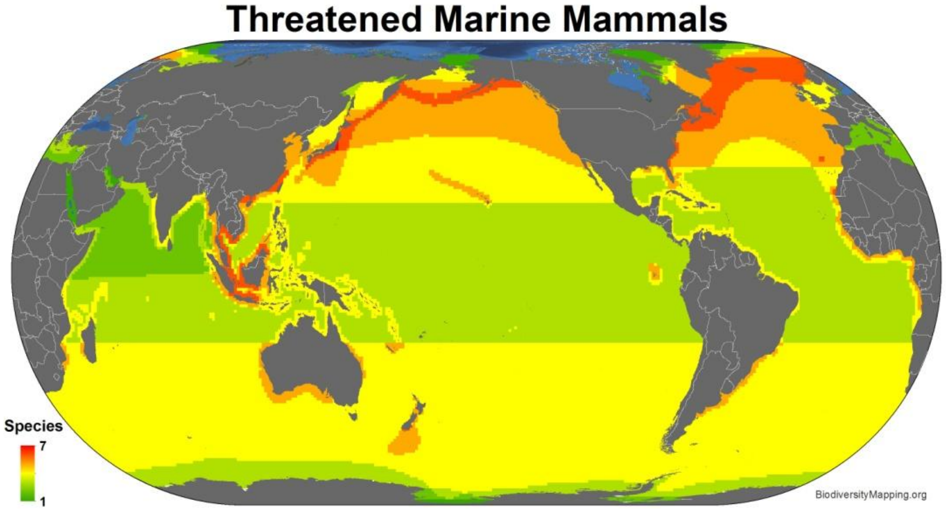
Challenges in Marine Mammals

Life for a marine mammal in today’s world is tough. They are facing a lot of issues due to human negligence and interference.



- Ship Strikes
- Acoustic Pollution
- Open Net Fishing
- Oil Spills
- Agricultural Runoff
- Commercial Hunting
- Climate Change
- Entertainment and Captivity
- Tourism
- Habitat Loss



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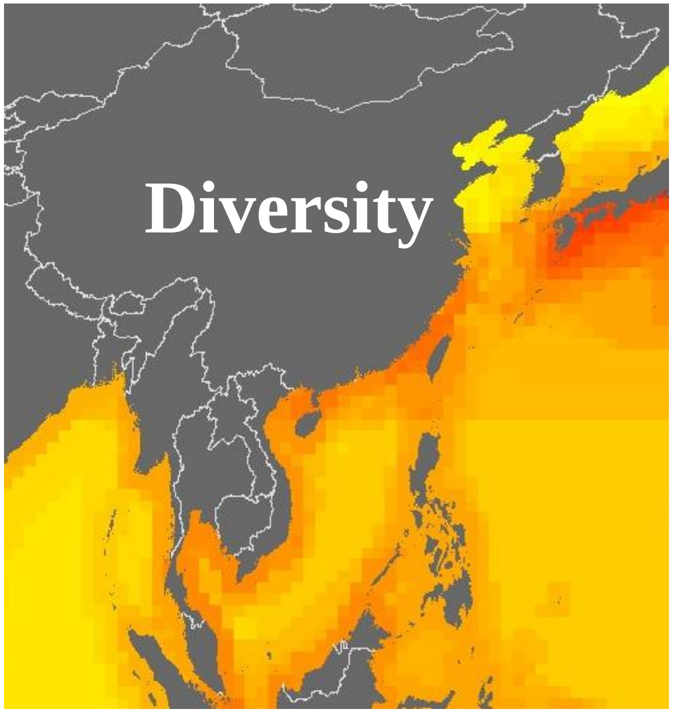
Marine Mammals in Chinese Waters



- More than 40 species;
- Nationally protected under wildlife protection law;
- Most concerned species are Baiji, Finless porpoise, and Indo-Pacific humpback dolphin

Baiji

Finless

IPHD

Dugong

Sperm whale

Bottlenose



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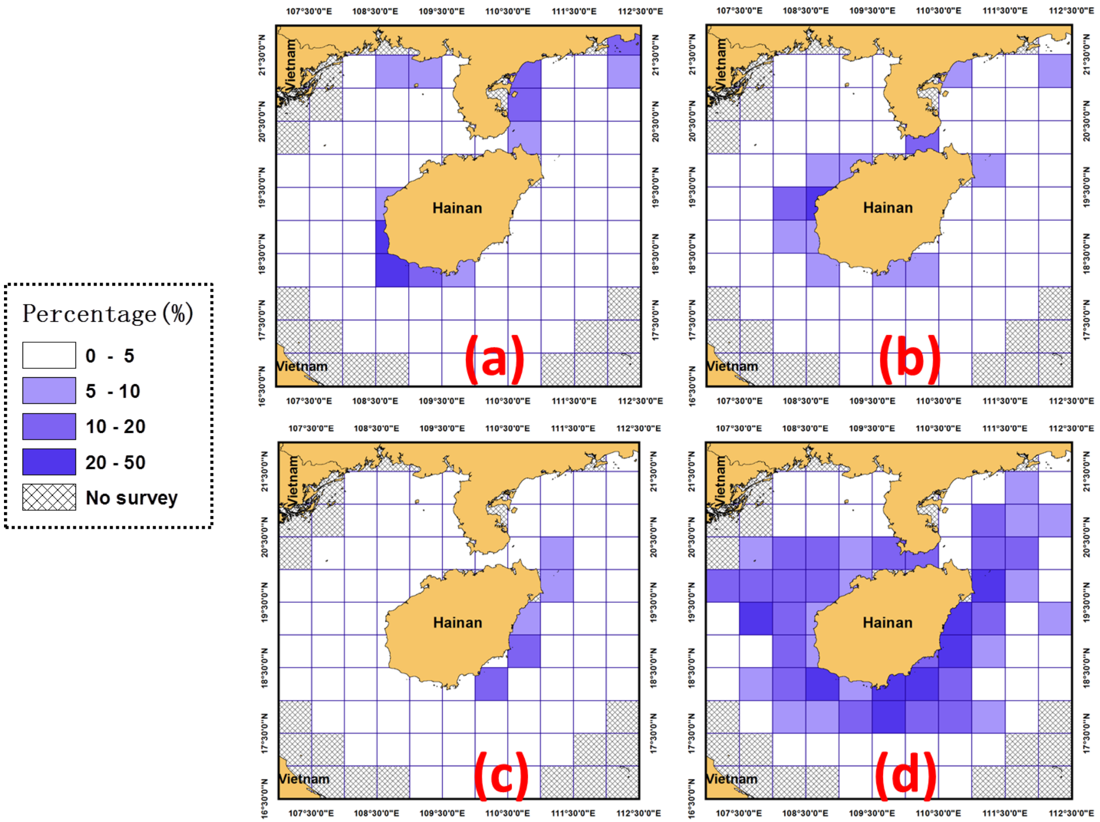
Marine Mammals in Chinese Waters

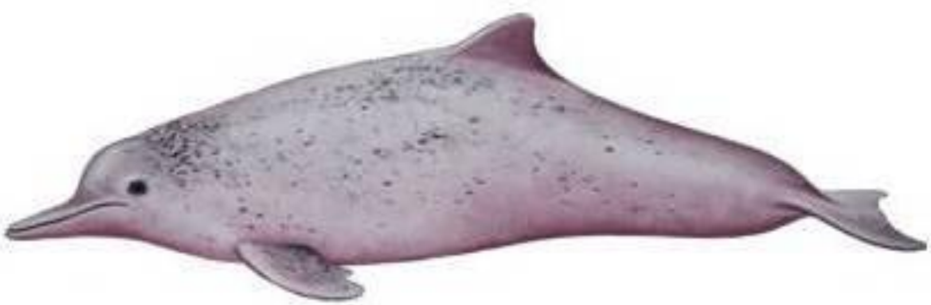


Distribution maps of marine mammal encounter rate around Hainan Island: (a) Indo-Pacific humpback dolphins; (b) Indo-Pacific finless porpoises; (c) baleen whales; (d) other dolphins.



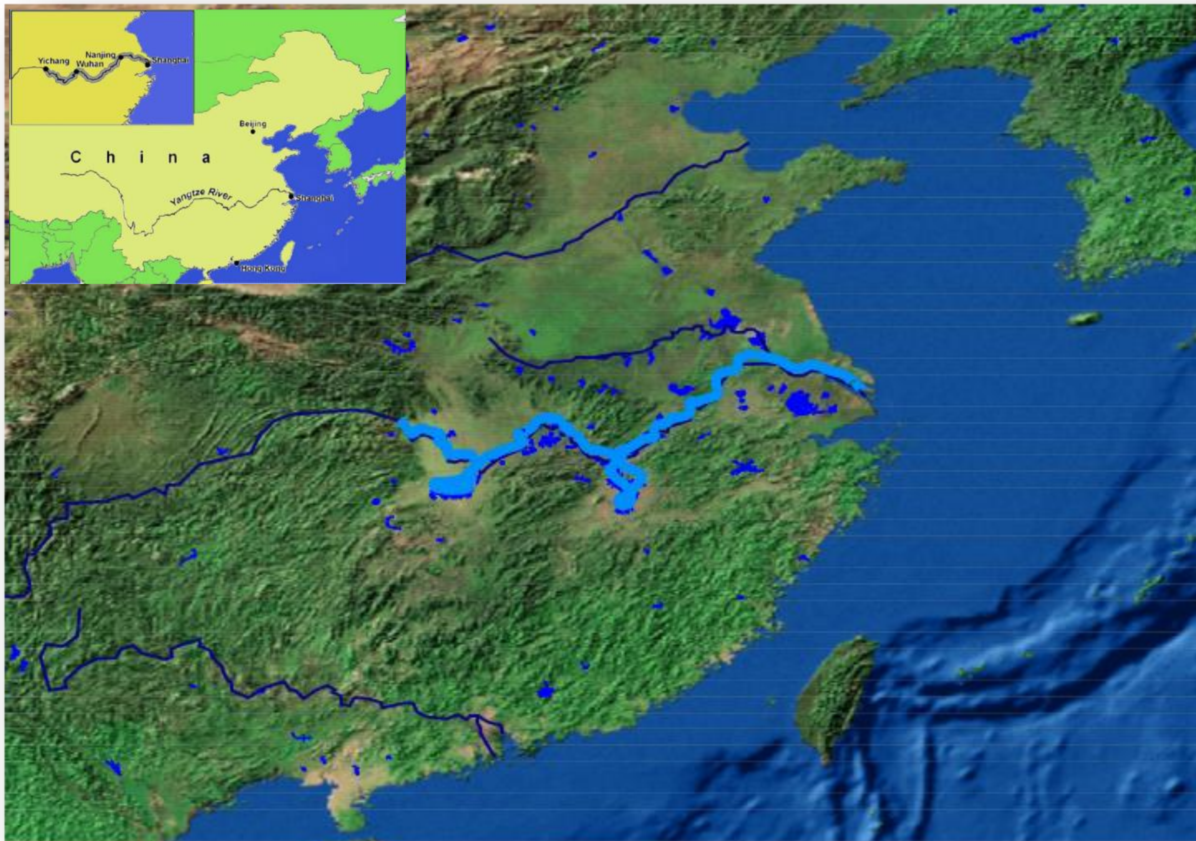
Marine Mammals in Chinese Waters







Baiji and Yangtze finless porpoise



Yangtze River dolphin, or Baiji

(*Lipotes vexillifer*)

Yangtze finless porpoise

(*Neophocaena asiaeorientalis a.*)

- **Endemic species of the Yangtze River;**
- **The Yangtze River is the largest and most important river in China with rich and unique biodiversity.**



Baiji and Yangtze finless porpoise

- “Yangtze Goddess”, was listed as one of the Grade 1 National Key Protected Animals by China’s Wild Animal Protection Law issued in 1988.

- “River Pig”, was listed as one of the Grade 2 National Key Protected Animals by China’s Wild Animal Protection Law issued in 1988, but now revised to Grade 1.



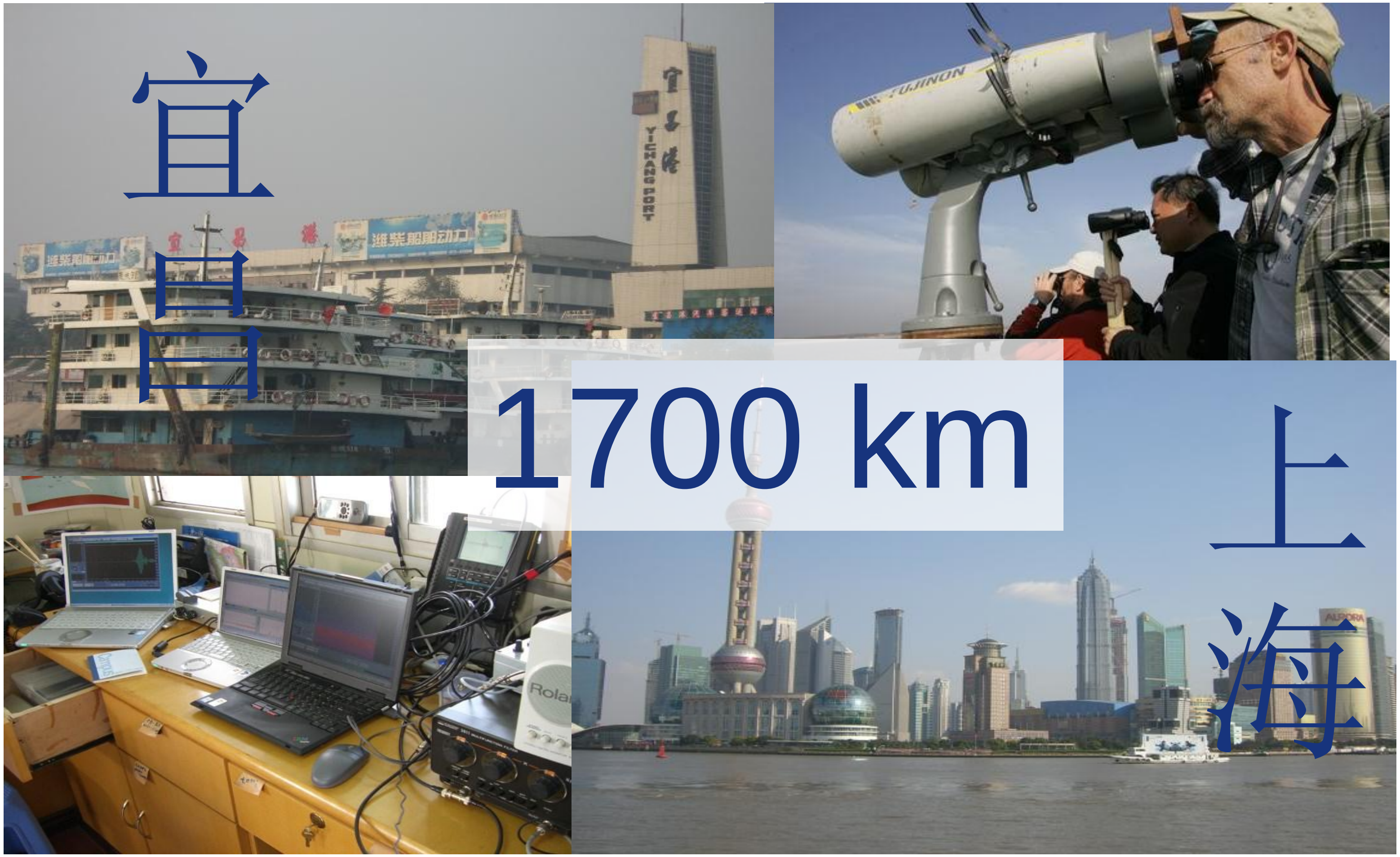
Baiji and Yangtze finless porpoise

Yangtze: the Golden Channel

- With the increasing demands of development, various anthropogenic activities have been increasing rapidly, and the habitat of the Yangtze cetaceans has been vastly deteriorated.



Baiji and Yangtze finless porpoise



- A range-wide visual-acoustic joint survey was conducted in 2006 from Yichang to Shanghai covering the main potential habitat of the Baiji. No baiji was sighted.



Baiji and Yangtze finless porpoise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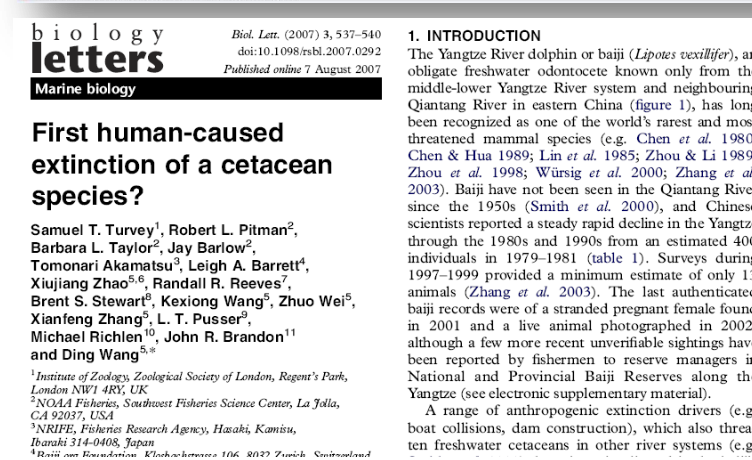

biology letters
Marine biology
Biol. Lett. (2007) 3, 537–540
doi:10.1098/rsbl.2007.0292
Published online 7 August 2007

First human-caused extinction of a cetacean species?

Samuel T. Turvey[1], Robert L. Pitman[2], Barbara L. Taylor[2], Jay Barlow[2], Tomonari Akamatsu[3], Leigh A. Barrett[4], Xiujiang Zhao[5,6], Randall R. Reeves[7], Brent S. Stewart[8], Kexiong Wang[5], Zhuo Wei[5], Xianfeng Zhang[5], L. T. Pusser[9], Michael Richlen[10], John R. Brandon[11] and Ding Wang[5,*]

[1]*Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK*
[2]*NOAA Fisheries, Southwest Fisheries Science Center, La Jolla, CA 92037, USA*
[3]*NRIFE, Fisheries Research Agency, Hasaki, Kamisu, Ibaraki 314-0408, Japan*
[4]*Baiji.org Foundation, Klosbachstrasse 106, 8032 Zurich, Switzerland*

1. INTRODUCTION

The Yangtze River dolphin or baiji (*Lipotes vexillifer*), an obligate freshwater odontocete known only from the middle-lower Yangtze River system and neighbouring Qiantang River in eastern China (figure 1), has long been recognized as one of the world's rarest and most threatened mammal species (e.g. Chen *et al.* 1980; Chen & Hua 1989; Lin *et al.* 1985; Zhou & Li 1989; Zhou *et al.* 1998; Würsig *et al.* 2000; Zhang *et al.* 2003). Baiji have not been seen in the Qiantang River since the 1950s (Smith *et al.* 2000), and Chinese scientists reported a steady rapid decline in the Yangtze through the 1980s and 1990s from an estimated 400 individuals in 1979–1981 (table 1). Surveys during 1997–1999 provided a minimum estimate of only 13 animals (Zhang *et al.* 2003). The last authenticated baiji records were of a stranded pregnant female found in 2001 and a live animal photographed in 2002, although a few more recent unverifiable sightings have been reported by fishermen to reserve managers in National and Provincial Baiji Reserves along the Yangtze (see electronic supplementary material).

A range of anthropogenic extinction drivers (e.g. boat collisions, dam construction), which also threaten freshwater cetaceans in other river systems (e.g.

– **Then the baiji was announced functionally extinct in 2007, which was actually the first extinct cetacean species caused by human activities.**



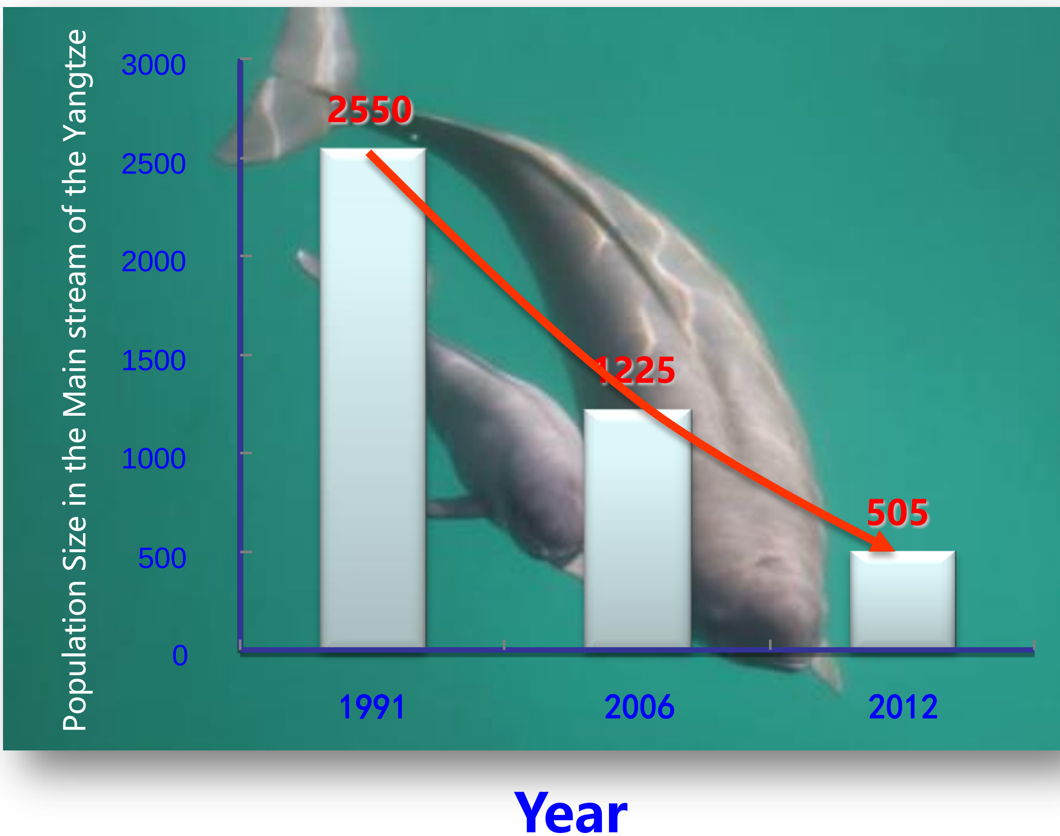
Baiji and Yangtze finless porpoise

- Yangtze finless porpoise is a subspecies of genus of finless porpoise;
- Narrow-ridged finless porpoise: Japanese coastal waters, Yellow Sea, Yangtze River…
- Indo-Pacific finless porpoise: India Ocean, Bengal Bay, SouthEast Asia, Southeast China.



Baiji and Yangtze finless porpoise

- **The Yangtze finless porpoise is also facing significant population decline due to similar threats**



Decline rate

- **Pre -1993: 1.58%**
- **1993-2006: 6.06%**
- **2006-2012: 13.73%**

Present: around 1000



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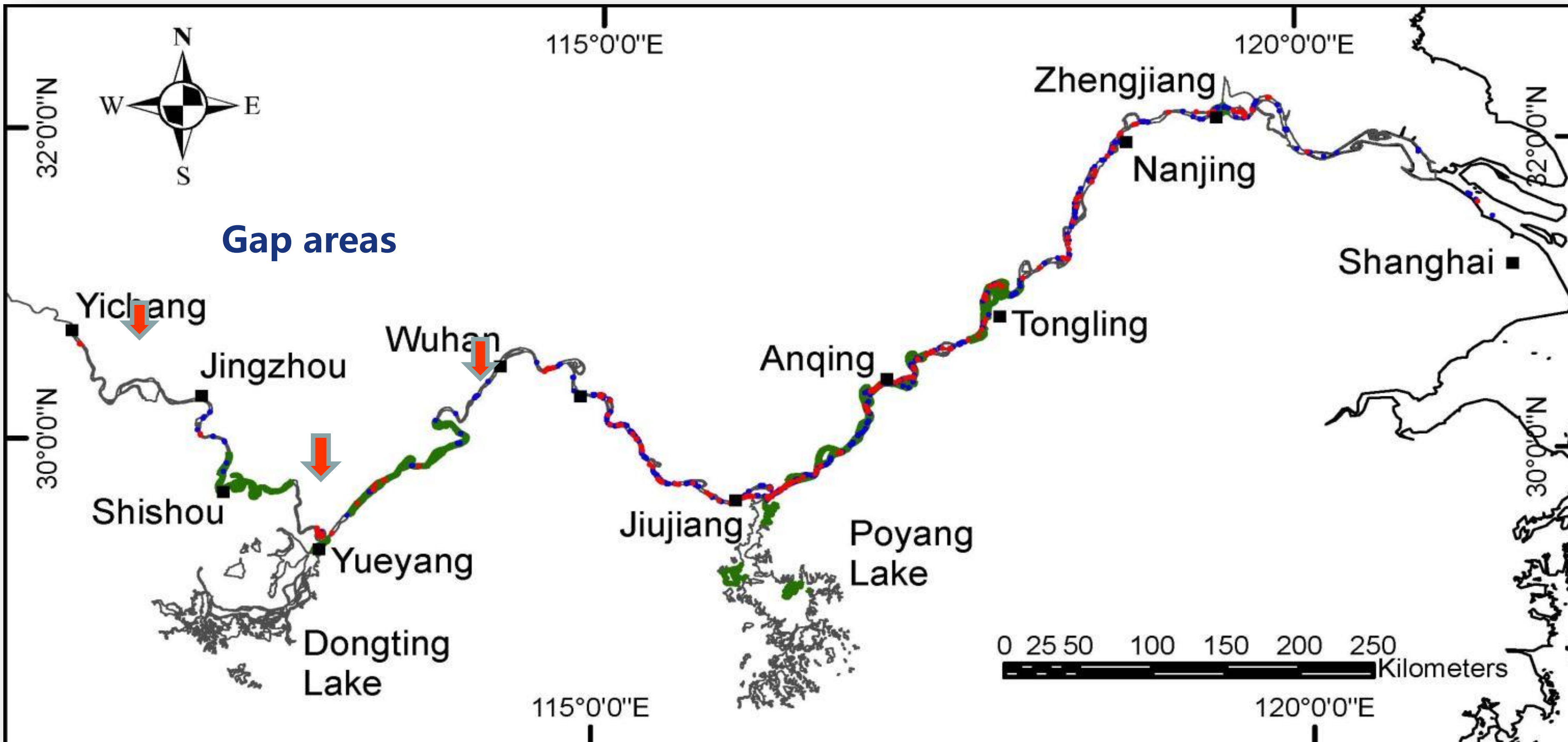
Baiji and Yangtze finless porpoise

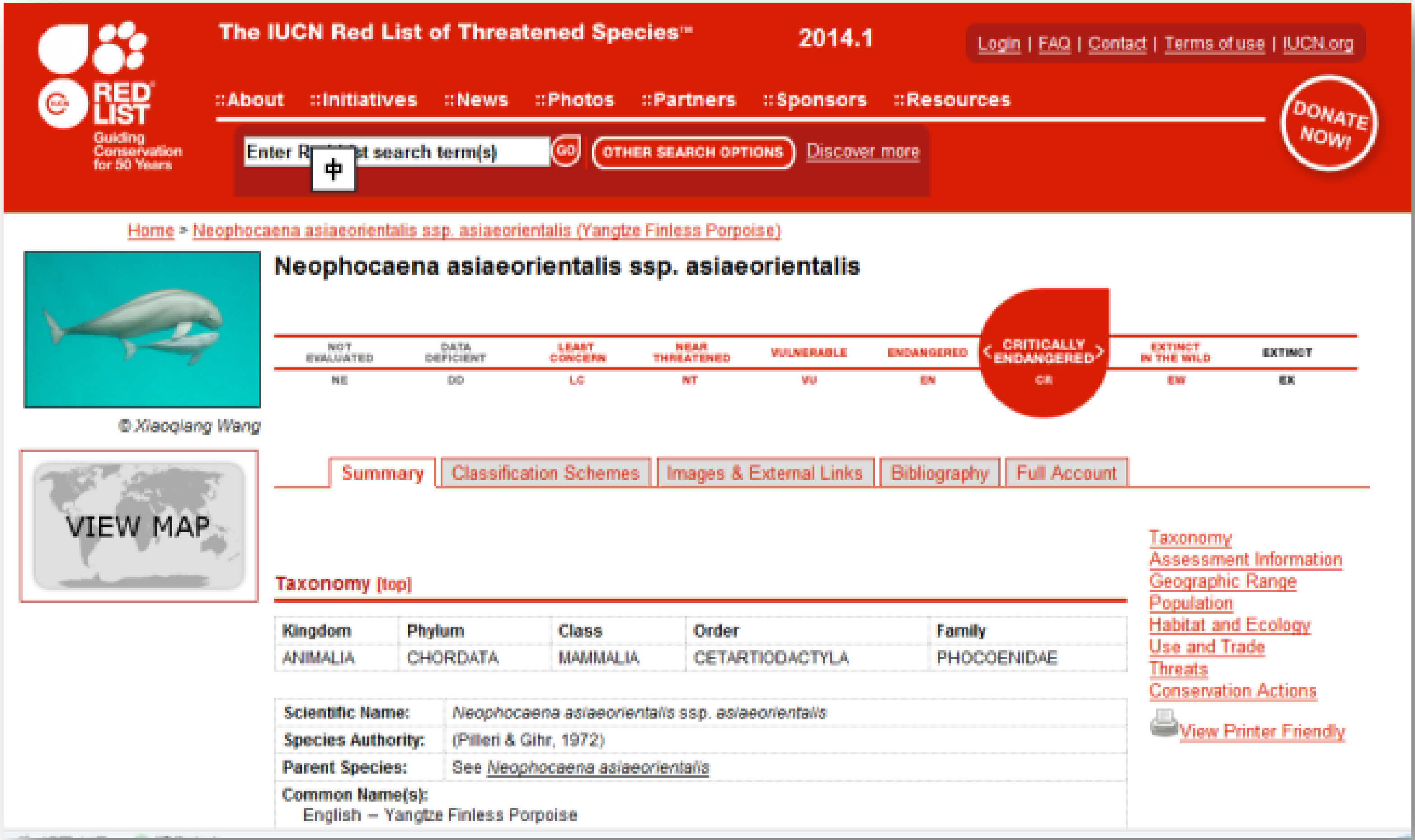
- **Distribution in the main stream: discrete**



- **Sightings in 2006**
- **Sightings in 2012**
- **Protected area**

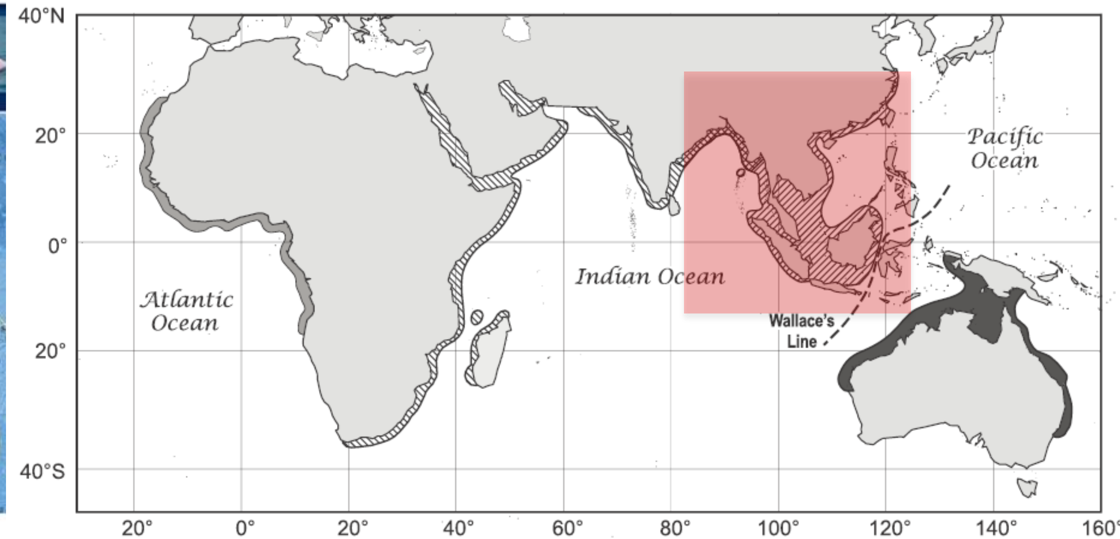
Baiji and Yangtze finless porpoise



- **The Yangtze finless porpoise was identified as Critically Endangered by IUCN**

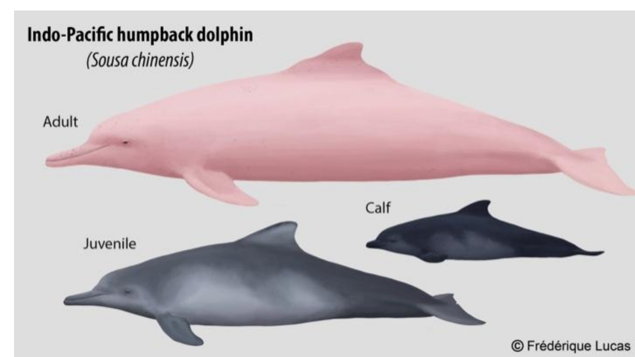


Indo-Pacific humpback dolphin



Jefferson and Rosenbaum, 2014

- One of the four species in humpback dolphin;
- Nearshore small odontocete;
- Tropical coastal waters of Southeast Asia Region;
- Coastal waters of southeast China;
- Called as Chinese White Dolphin in China, “Panda”;
- Was listed as one of the Grade 1 National Key Protected Animals by China’s Wild Animal Protection Law issued in 1988, and received the same priority of protection as the Baiji.



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Indo-Pacific humpback dolphin

Aquatic Mammals 2004, *30*(1), 149-158, DOI 10.1578/AM.30.1.2004.149

A Review of the Status of the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) in Chinese Waters

Thomas A. Jefferson[1] and Samuel K. Hung[2]

[1] *Southwest Fisheries Science Center, NOAA, NMFS, 8604 La Jolla Shores Drive, La Jolla, CA 92037 USA*
[2] *Hong Kong Cetacean Research Project, 12 Kak Tin Kung Miu Village, Tai Wai, New Territories, Hong Kong*

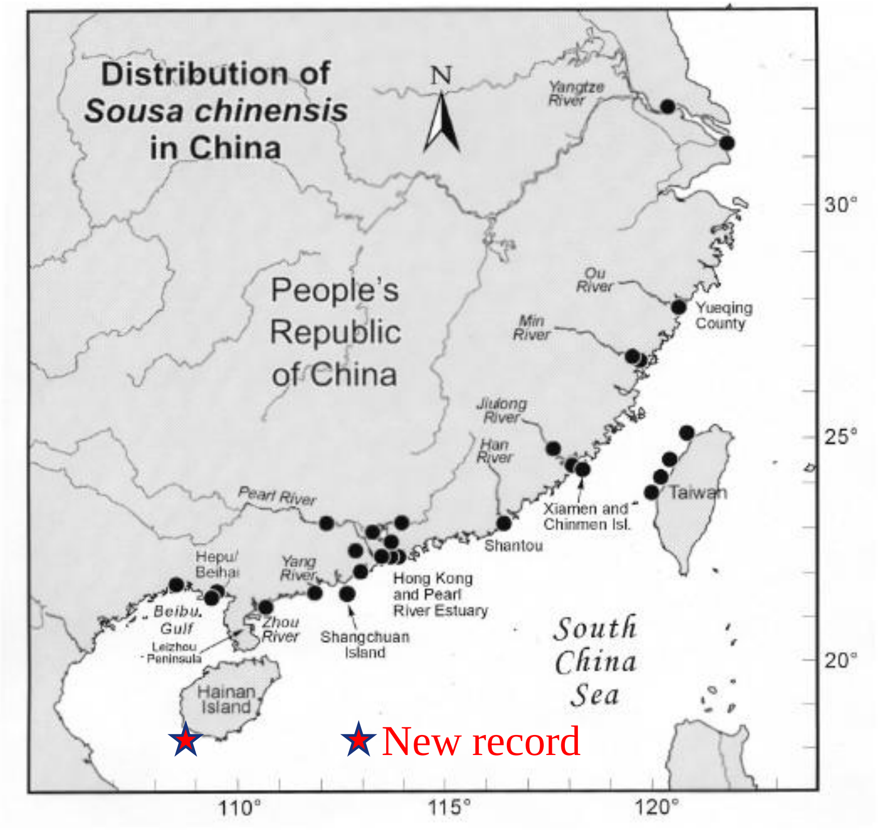

Figure 1. Reliable records of occurrence of *Sousa chinensis* in Chinese waters; updated from Jefferson (2000).

Jefferson and Hung, 2004

- **Sporadically distributed in the coastal waters of Southeast China from Beibu Gulf, near the border of Vietnam, to the mouth of the Yangtze River;**
- **It was thought there is no Indo-Pacific humpback dolphin in the waters around Hainan.**



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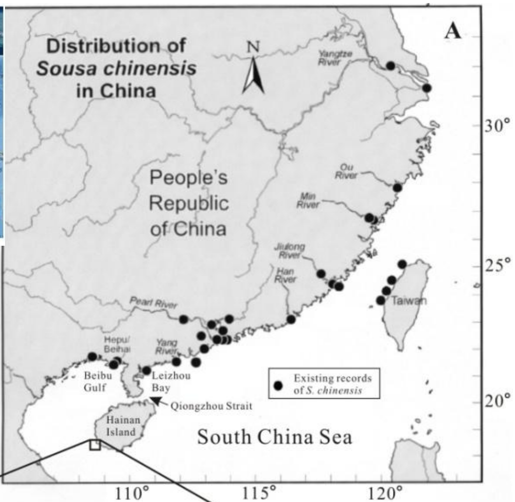
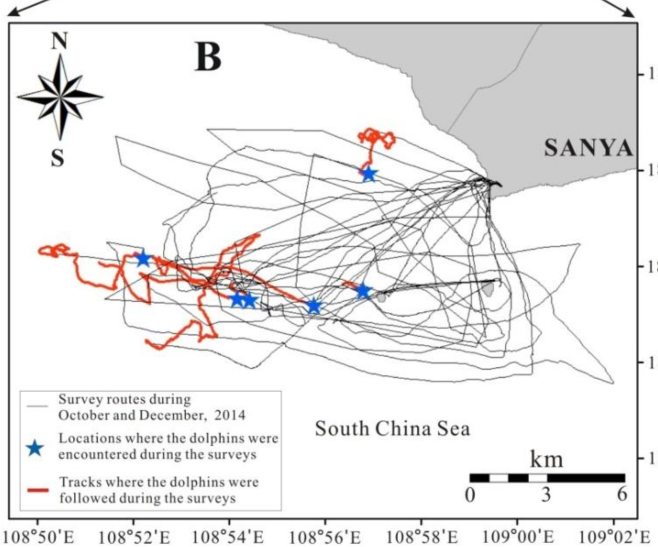
Indo-Pacific humpback dolphin





- **A new population was recorded Southeast of Hainan Island in 2014**

RESEARCH Open Access

First record of the Indo-Pacific humpback dolphins (*Sousa chinensis*) southwest of Hainan Island, China

Songhai Li[1*], Mingli Lin[1], Xiao Xu[1,2], Luru Xing[1], Peijun Zhang[1], Rodolphe E. Gozlan[3], Shiang-Lin Huang[1] and Ding Wang[4]

Abstract

Background: Populations of Indo-Pacific humpback dolphins (*Sousa chinensis*) in China were known to be distributed from the Beibu Gulf near the border with Vietnam to the mouth of the Yangtze River. According to existing studies, the waters around Hainan Island, China, were not considered to be part of the humpback dolphins' distribution.

Results: In 2014, for the first time, we recorded humpback dolphins in waters southwest of Hainan Island.

Conclusions: This record expands the known southern distribution range of this dolphin in Chinese waters by more than 300 km.

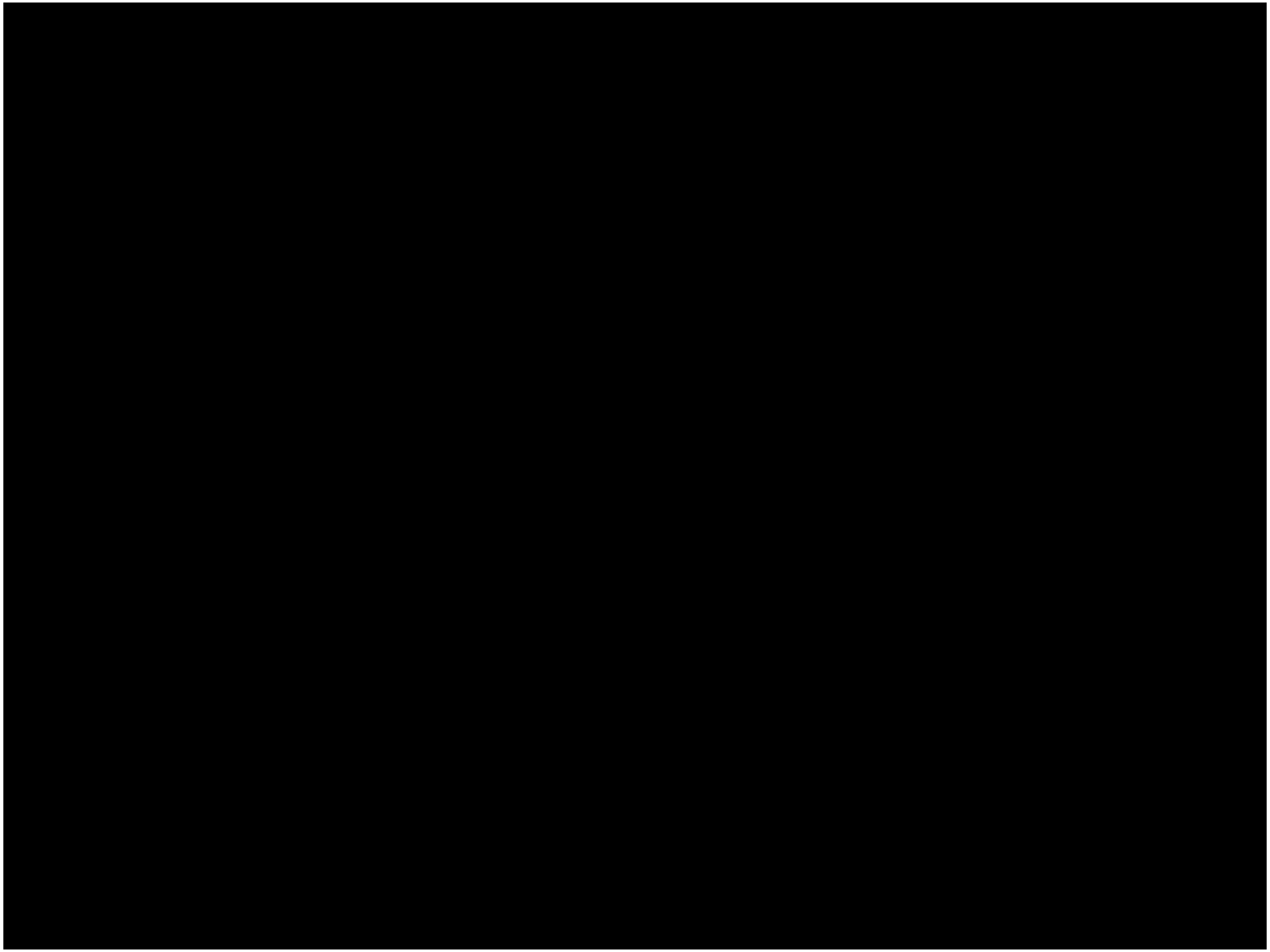
Keywords: Chinese white dolphin, Marine mammals, Conservation, Distribution



Indo-Pacific humpback dolphin

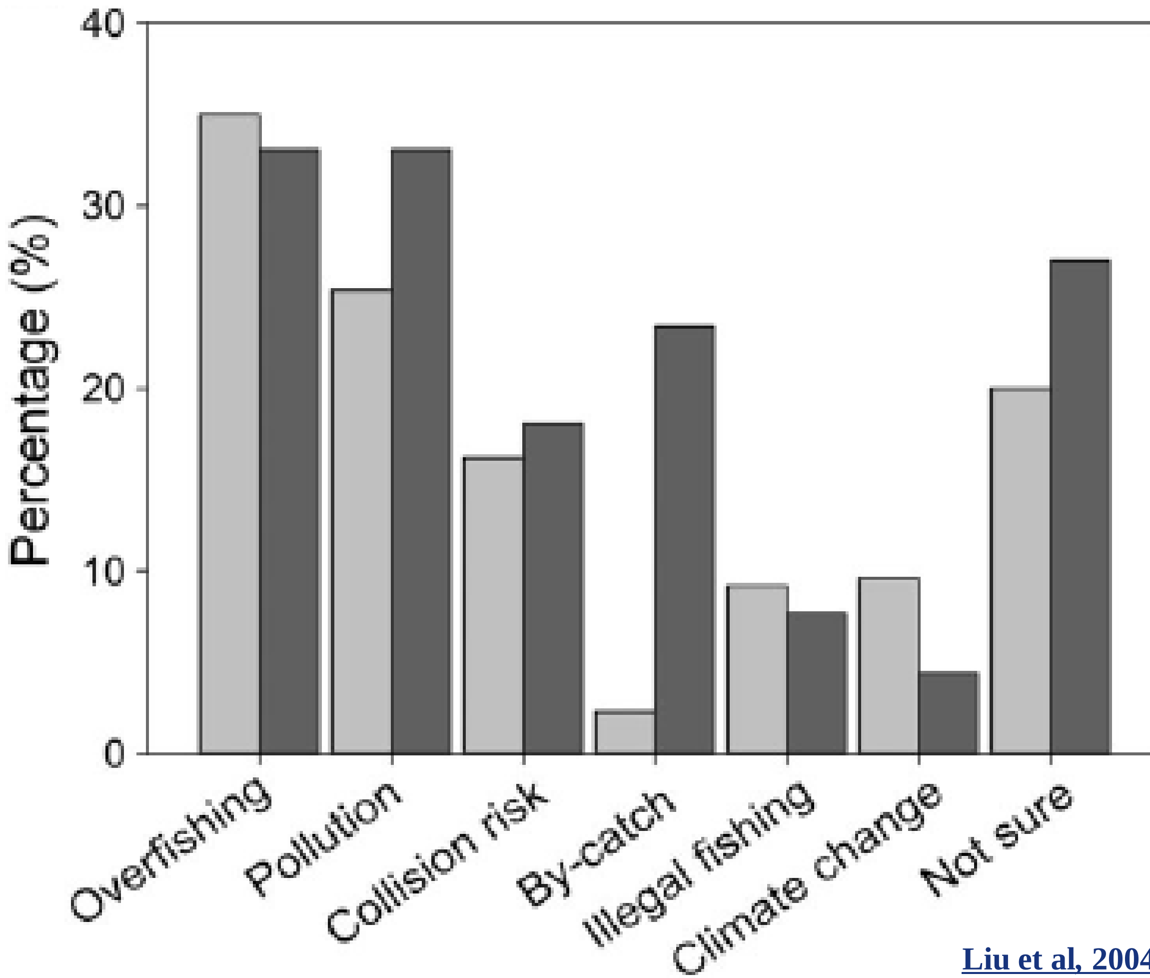


Indo-Pacific humpback dolphin



Indo-Pacific humpback dolphin

- It's suffering from…
- Population is decreasing quickly;
- "Vulnerable" by the IUCN.



Liu et al, 2004



Dugong

- Dugong can be found in warm coastal waters from East Africa to Australia, including the Red Sea, Indian Ocean, and Pacific;
- Graze on underwater grasses day and night;
- It distributed in Chinese waters around Hainan Island and in the Beibu Gulf;
- Was listed as one of the Grade 1 National Key Protected Animals by China’s Wild Animal Protection Law issued in 1988; Extinct in Chinese waters.



Spotted seal


- It's a "true seal";
- Primarily found along the continental shelf of the Beaufort, Chukchi, Bering and Okhotsk Seas and south to the northern Yellow Sea;
- The only Pinnipeds could breed in Chinese waters;
- Was also listed as one of the Grade 2 National Key Protected Animals by China's Wild Animal Protection Law.



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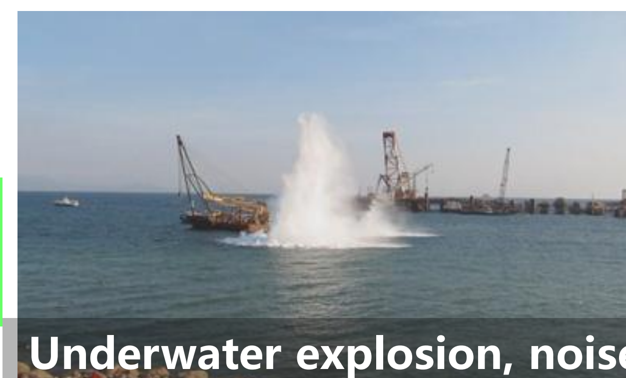
Challenges for the marine mammals in China

- **Increasing threats**

Decreasing in food

Habitat destruction

Direct injury by Human activities



Challenges for the marine mammals in China

- **Scarce research and investigation**

Baiji

Yangtze finless porpoise

Humpback dolphin

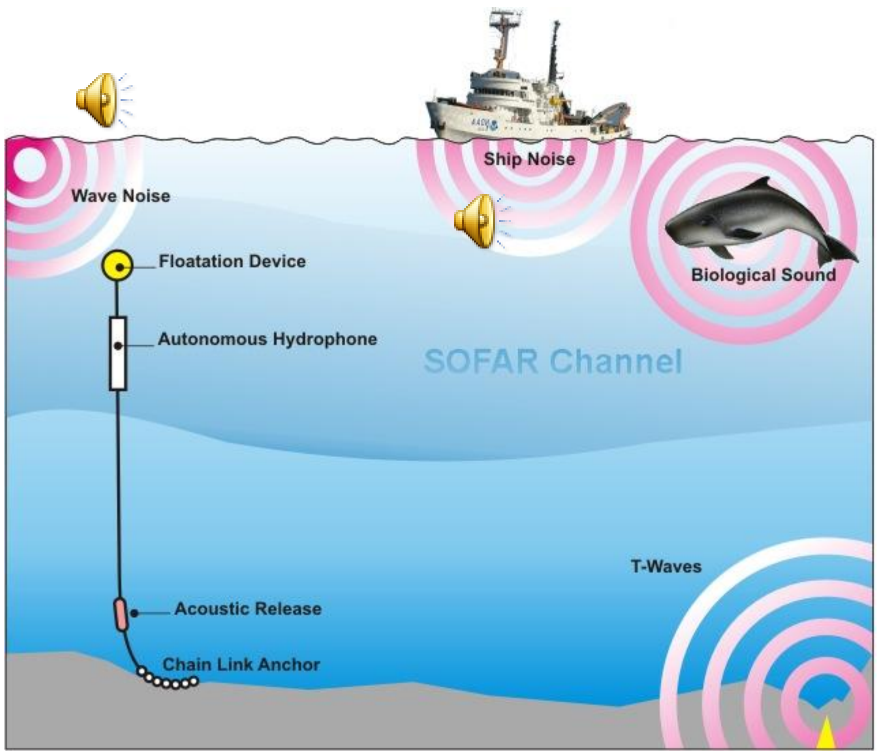
– **Research and investigation on other marine mammals have been very scanty;**

– **Little is known about feeding habits, prey composition, life history, population status, patterns of distribution and migration, threats, and behavioral features of the other marine mammals in Chinese waters.**



Bioacoustics of Marine Mammals

- Sound travels far greater distances than light under water;
- The ocean is filled with sound;
- Underwater sound is generated by a variety of natural and man-made sources.



Undersea sounds made by natural and man-made sources

Deep-sea fish

Deep-sea shrimps

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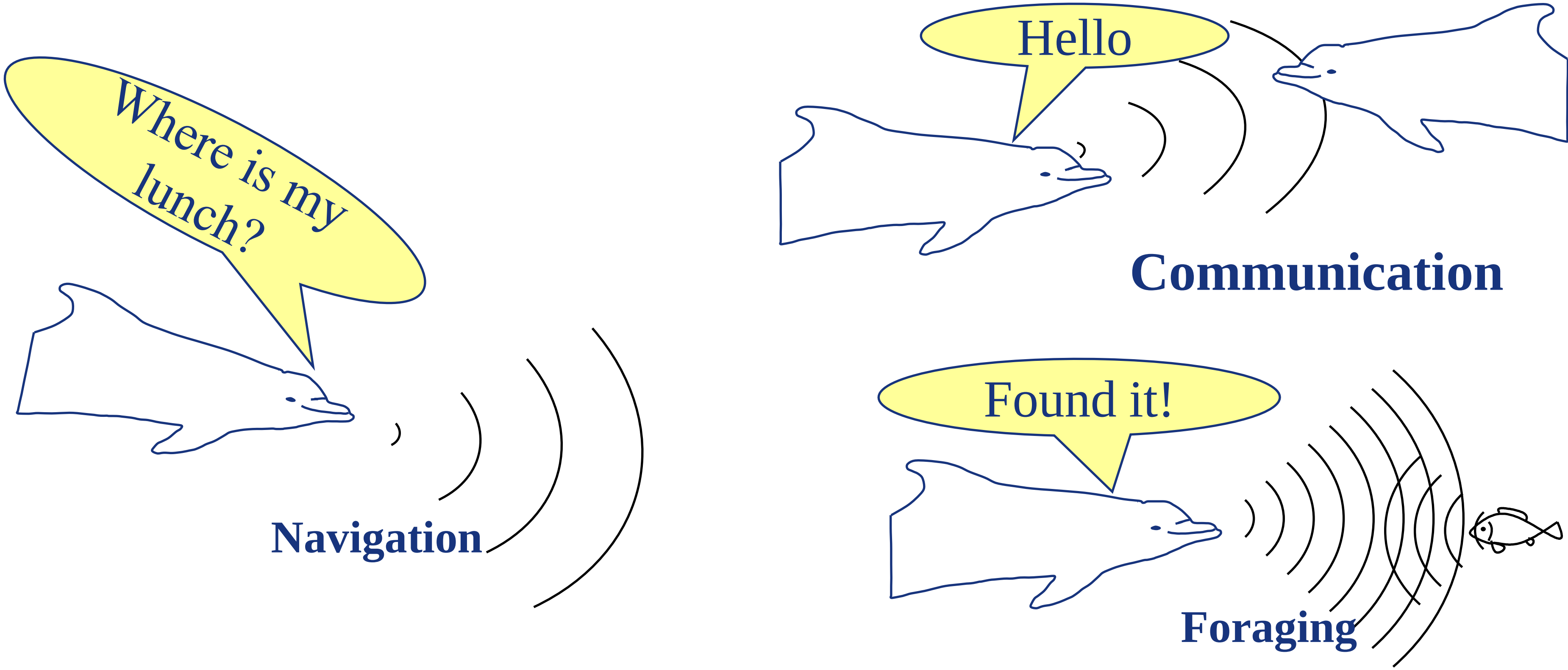
Bioacoustics of Marine Mammals

- All marine mammals rely on sound for survival (communication, mating, foraging, and migration);
- Developed unique adaptations that enable them to communicate, protect themselves, locate food, navigate underwater, and/or understand their environment by sounds;
- Produce sounds and listen to the sounds around them.





Bioacoustics of Marine Mammals

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Bioacoustics of Marine Mammals

What can I do when I lost my mom in the turbid and muddy waters?

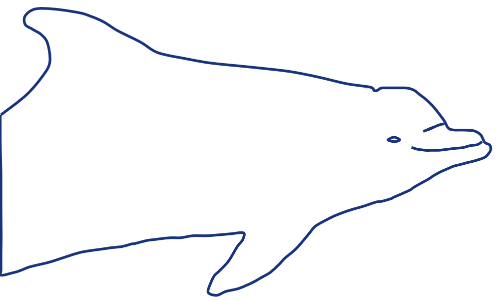
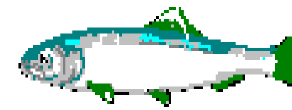
Looking for by vision? **No!**

It is by sound!

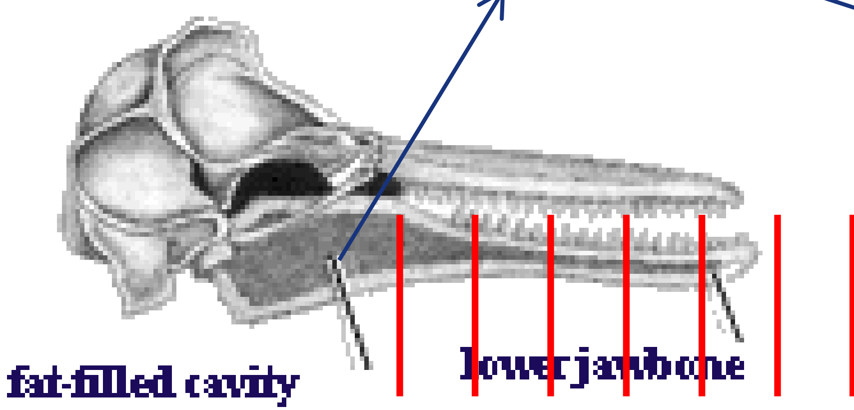


Bioacoustics of Marine Mammals

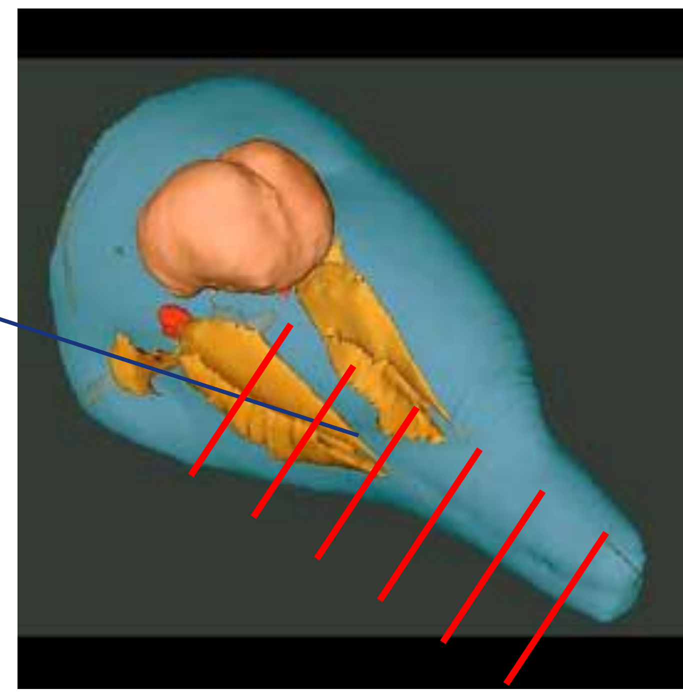
Echolocation (Biosonar) in Toothed whales

Receiving sound through pan bone in the lower jaw



http://www.seaworld.org/infobooks/Bottlenose/sensesdol.html



http://www.whoi.edu/csi/research/index.html

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Sounds of several cetacean species

Baleen whales

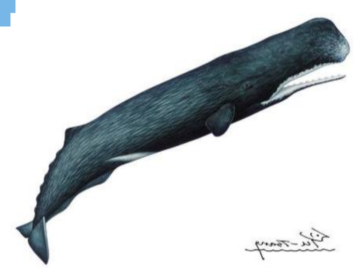
Humpback whale
Megaptera novaeangliae

Whistles of odontocetes

Baiji
Lipotes vexillifer

YFP
Neophocaena asiaeorientalis asiaeorientalis

High-frequency clicks of odontocetes



Sperm whale
Physeter macrocephalus



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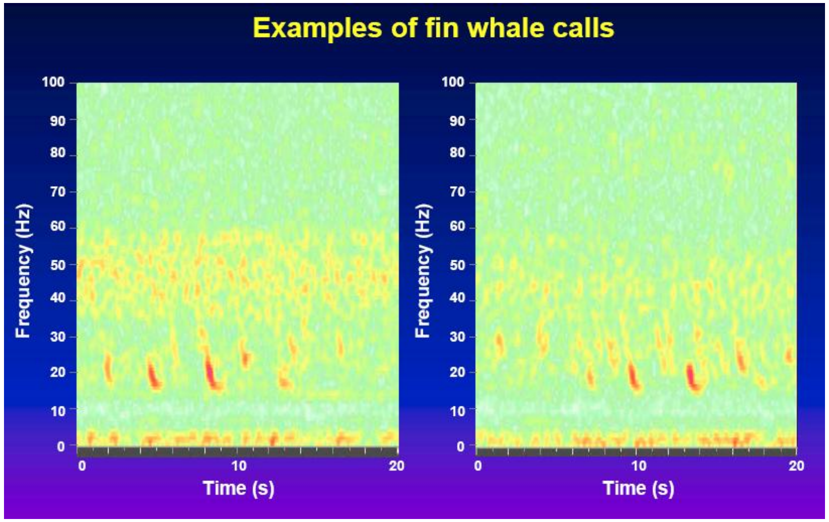

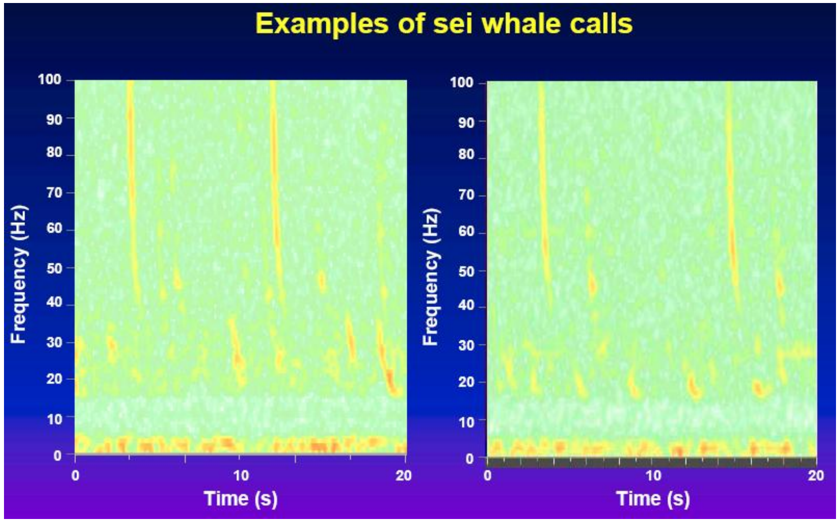

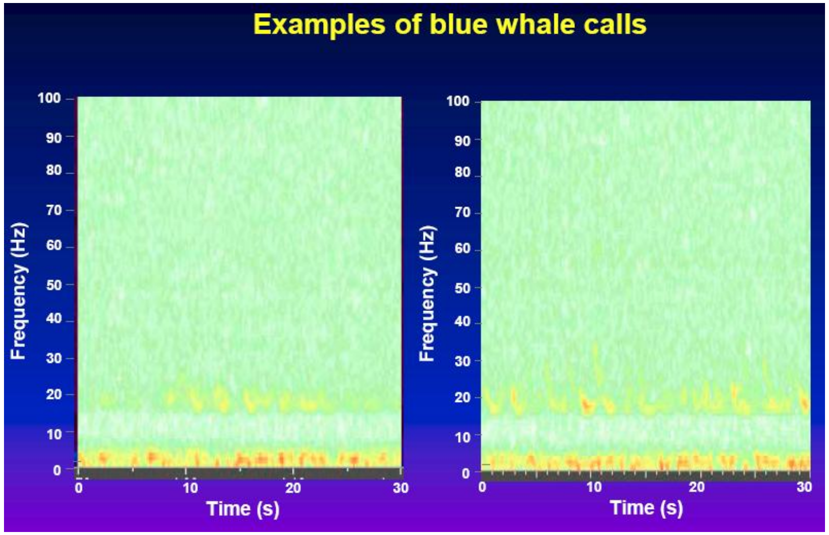

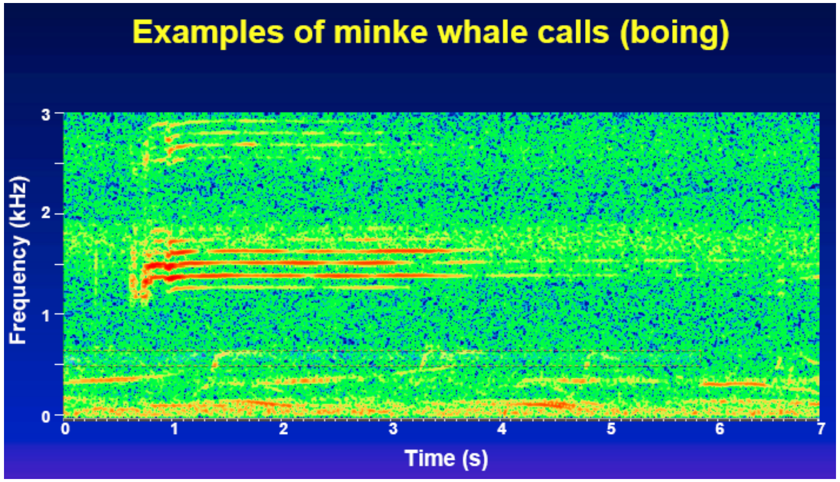

Personal communication



Bioacoustics of Marine Mammals

Frequency range of sounds from several baleen whale species

Species	Frequency range(kHz)	References
bowhead whale (*Balaena mysticetus*)	0.02-3.5	Thompson *et al*. 1979; Ljungblad *et al*. 1980, 1982; Norris and Leatherwood 1981; Clark and Johnston 1984; Wursig *et al*. 1985.
common minke whale (*Balaenoptera acutorostrata*)	0.06-6	Schevill and Watkins 1972; Winn and Perkins 1976.
sei whale (*Balaenoptera borealis*)	1.5-3.5	Thompson *et al*. 1979; Knowlton *et al*. 1991.
blue whale (*Balaenoptera musculus*)	0.012-0.4	Cummings and Thompson 1971, 1994; Edds 1982; Stafford *et al*. 1988.
fin whale (*Balaenoptera physalus*)	0.01-28	Thompson *et al*. 1979; Watkins 1981; Cummings *et al*. 1986; Watkins *et al*. 1987; Edds 1988; Clark 1990; Cummings and Thompson 1994.
southern right whale (*Eubalaena australis*)	0.03-2.2	Cummings *et al*. 1972; Clark 1982, 1983.
North Atlantic right whale (*Eubalaena glacialis*)	<0.4	Watkins and Schevill 1972; Thompson *et al*. 1979; Spero 1981; Clark 1990.
gray whale (*Eschrichtius robustus*)	0.02-20	Cummings *et al*. 1968; Fish *et al*. 1974; Norris *et al*. 1977; Swartz and Cummings 1978; Dahlheim *et al*. 1984; Moore and Ljungblad 1984; Dahlheim and Ljungblad 1990.
humpback whale (*Megaptera novaeangliae*)	0.02-10	Thompson *et al*. 1979; Watkins 1981; Edds 1982, 1988; K. Payne *et al*. 1983; Payne and Payne 1985; Silber 1986; Thompson *et al*. 1986.

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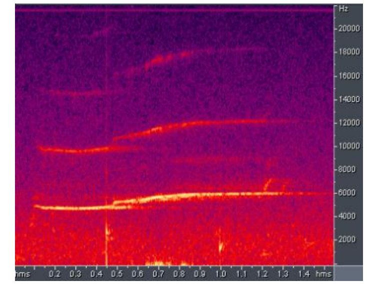
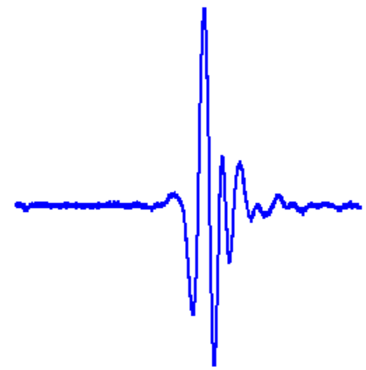
Baiji / Yangtze River dolphin

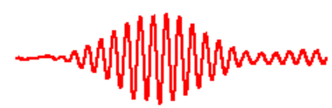
Finless porpoises



Whistle



Click

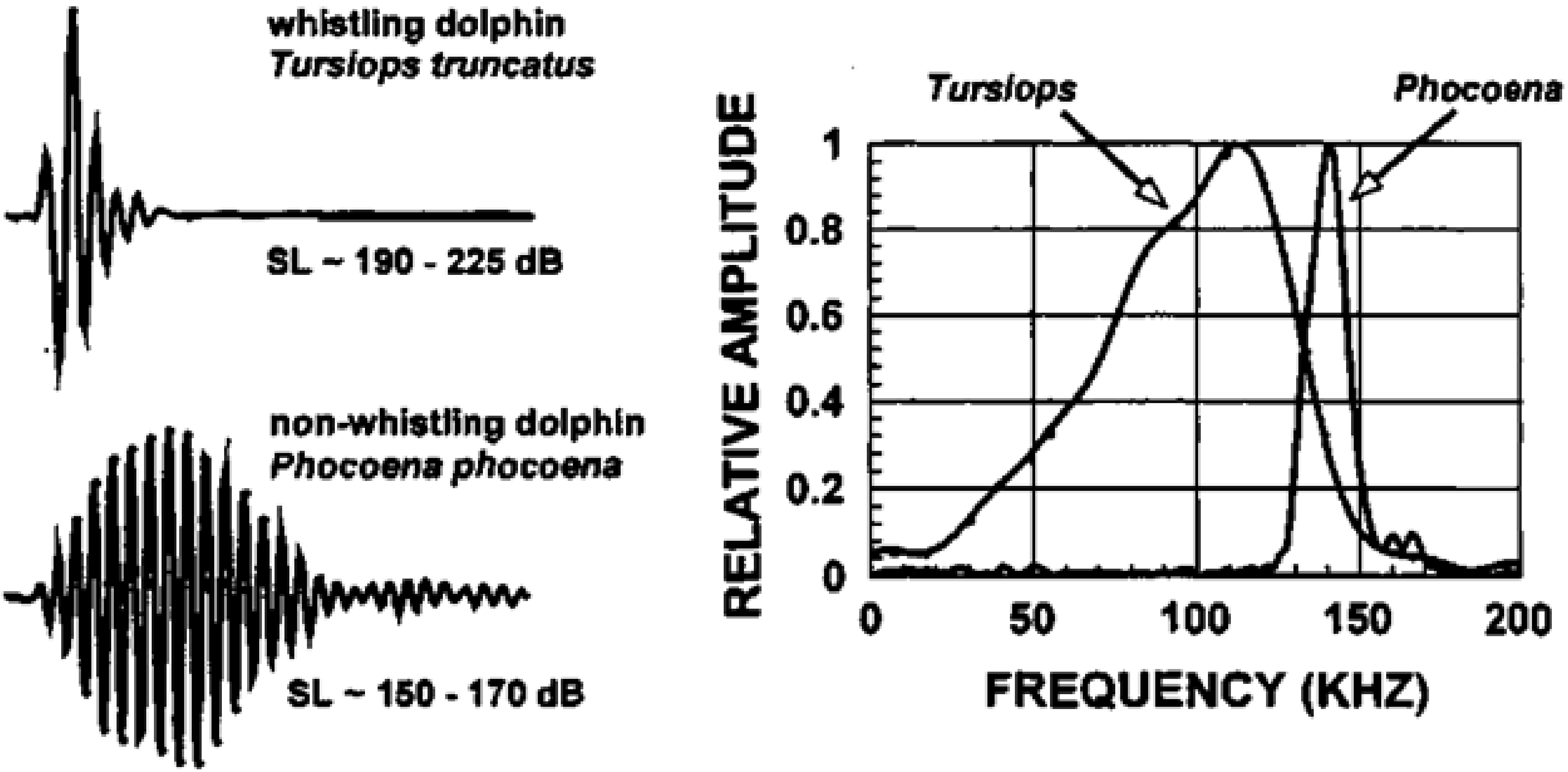


Click

50μ s

Bioacoustics of Marine Mammals

Two categories of echolocation clicks



Waveform and spectrum of the two click categories



Bioacoustics of Marine Mammals

Frequency range of whistles from several odontocete species

Species	Frequency range (kHz)	References
dusky dolphin (*Lagenorhynchus obscurus*)	1.04-27.3	Wang *et al.* 1995a.
Beluga (*Delphinapterus leucas*)	0.2-19.6	Karlsen *et al.* 2002; Matthews *et al.* 1999.
Baiji (*Lipotes vexillifer*)	3.8-6.8	Wang *et al*. 1999; Wang *et al*. 2006.
spinner dolphin (*Stenella longirostris*)	0.85-25	Barzua-Duran and Au 2002, 2004; Wang *et al.* 1995a.
Atlantic spotted dolphin (*Stenella frontalis*)	5-19.8	Wang *et al.* 1995a.
bottlenose dolphin (*Tursiops truncatus*)	0.94-41	Boisseau 2005; Wang *et al.* 1995a, b.
Amazon River dolphin (*Inia geoffrensis*)	0.22-64.63	May-Collado and Wartzok in prep.; Wang *et al.* 1995b, 2001.
tucuxi (*Sotalia fluviatilis*)	0.5-38.25	Azevedo and Simao 2002; Erber and Simao 2004; Podos *et al.* 2002; Wang *et al.* 1995a, 2001.
Indo-Pacific humpback dolphin (*Sousa chinensis*)	0.9-22	Van Parijs and Corkeron 2001; Zbinden *et al.* 1977.



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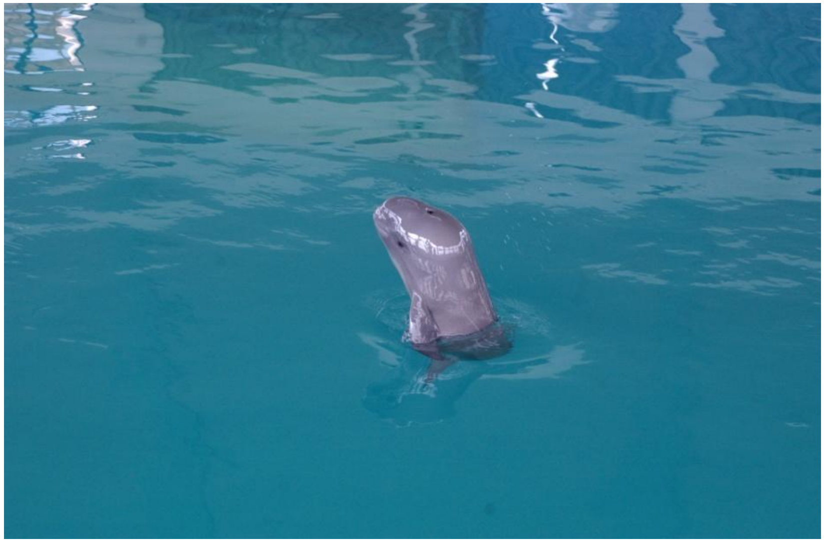
Bioacoustics of Marine Mammals

Species	Peak frequency (kHz)	3-dB bandwidth (kHz)	Source level (dB)	Time duration (us)	Location	References
Commerson's dolphin *Cephalorhynchus commersonii*	120-134	17-22	160	180-600	Pool	Kamminga and Wiersma (1982); Evans *et al.* (1988)
Beluga *Delphinapterus leucas*	100-115	30-60	225	50-80	Bay	Au *et al.* (1985); Au *et al.* (1987)
short-beaked common dolphin *Delphinus delphis*	23-67	17-45	–	50-150	Ocean	Dziedzic (1978)
long-finned pilot whale *Globicephala melaena*	30-60	-	180	-	Pool	Evans (1973)
Amazon River dolphin *Inia geofrensis*	95-105	-	-	200-250	River	Kamminga *et al.* (1989)
Baiji *Lipotes vexillifer*	50-100	37	156	-	Pool	Xiao and Jing (1989)
Finless porpoise *Neophocaena phocaenoides*	128 125	11 20	- 164-186	127 68	Pool, wild, wild	Kamminga (1988) Li *et al.* (2005a) Li *et al.* (2006)
Irrawaddy dolphin *Orcaella brevirostris*	50-60	~22	-	150-170	Pool	Kamminga *et al.* (1983)
killer whale *Orcinus Orca*	14-20	~4	178	210	Pool	Evans (1973)
harbor porpoise *Phocoena phocoena*	120-140	10-15	162	130-260	Pool	Møhl and Andersen (1973); Kamminga and Wiersma (1981); Hatakeyama *et al.* (1988)
false killer whale *Pseudorca crassidens*	100-130	15-40	228	100-120	Bay	Thomas and Turl (1990)
tucuxi *Sotalia fluviatilis*	95-100	~40	-	120-200	Pool and River	Wiersma (1982); Kamminga *et al.* (1989)
common bottlenose dolphin *Tursiops Truncatus*	110-130	30-60	228	50-80	Bay	Au (1980)



Bioacoustics of Marine Mammals

Day 1



Day 22

Mature porpoise



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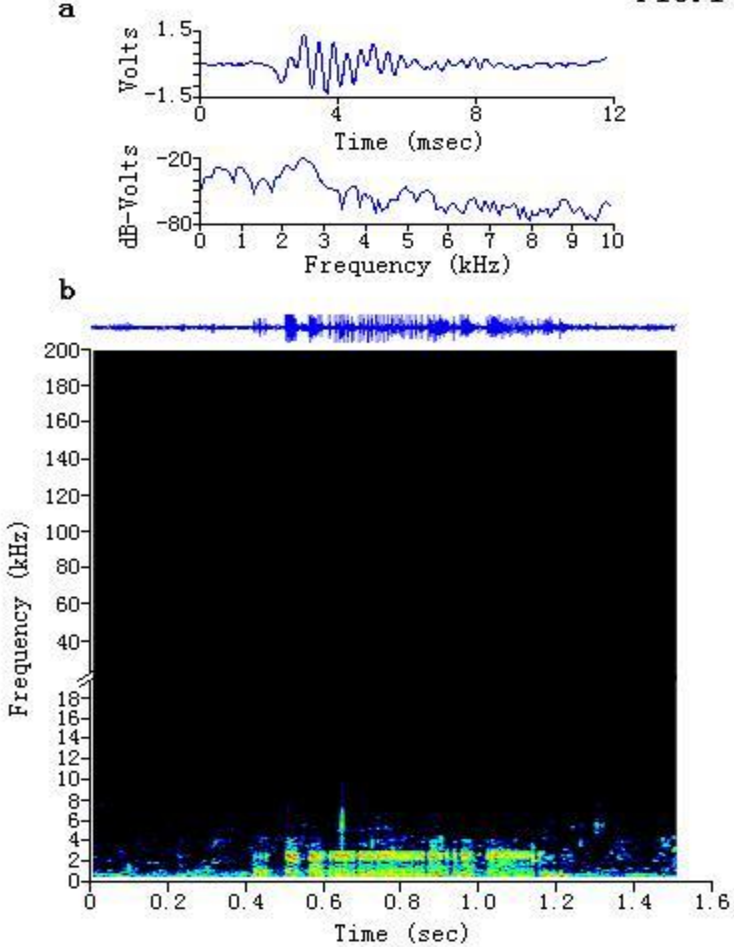
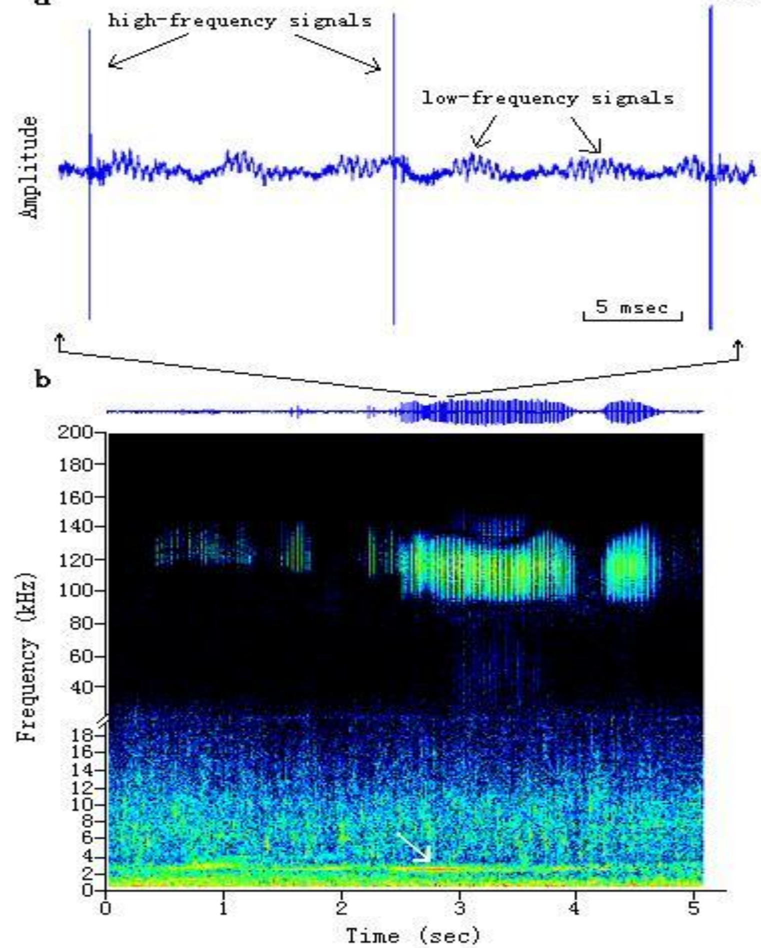
FIG. 1



Day 1

FIG. 2



Day 22

Li et al., JASA, 2008



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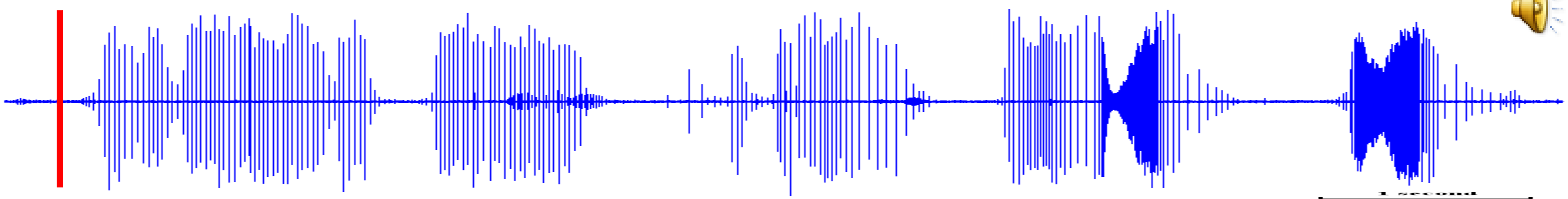
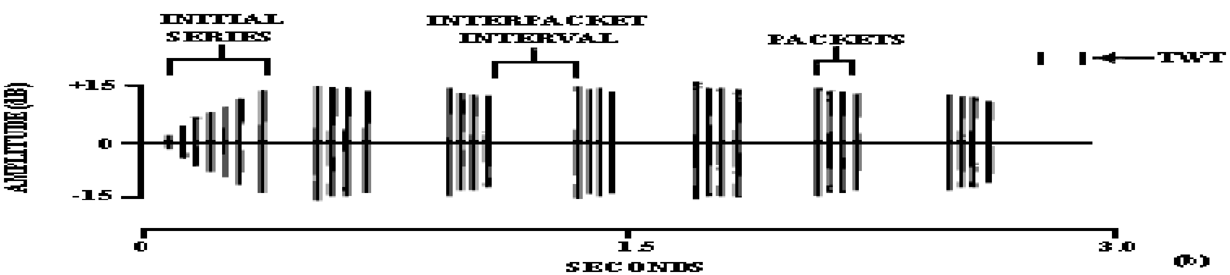
Bioacoustics of Marine Mammals

Characteristics of echolocation click train of odontocetes



Click train of YFP

Typical click train pattern of beluga during target detection



(From Turl and Penner, 1989)



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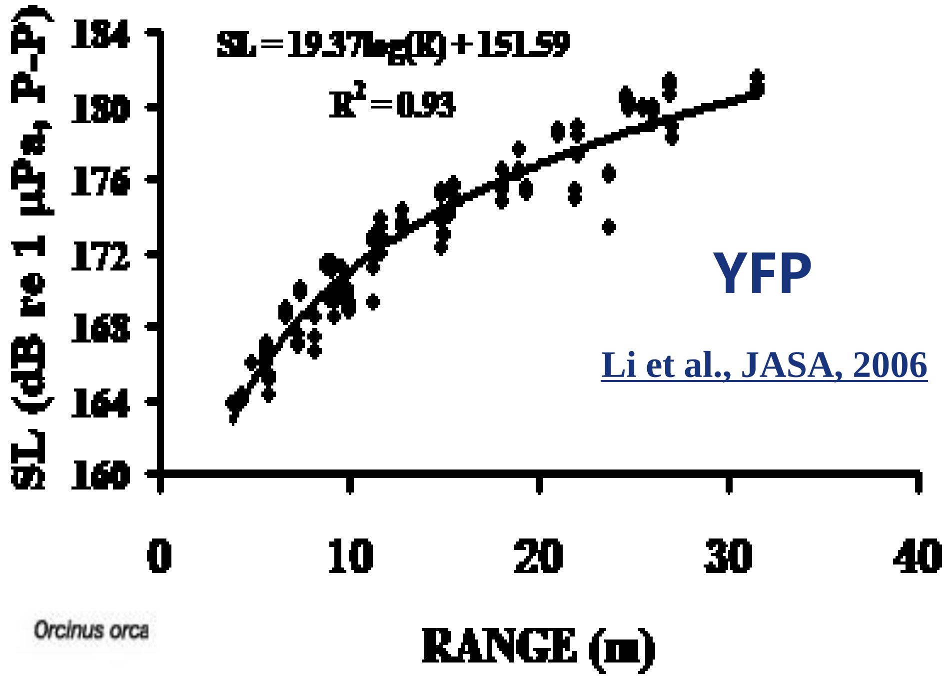
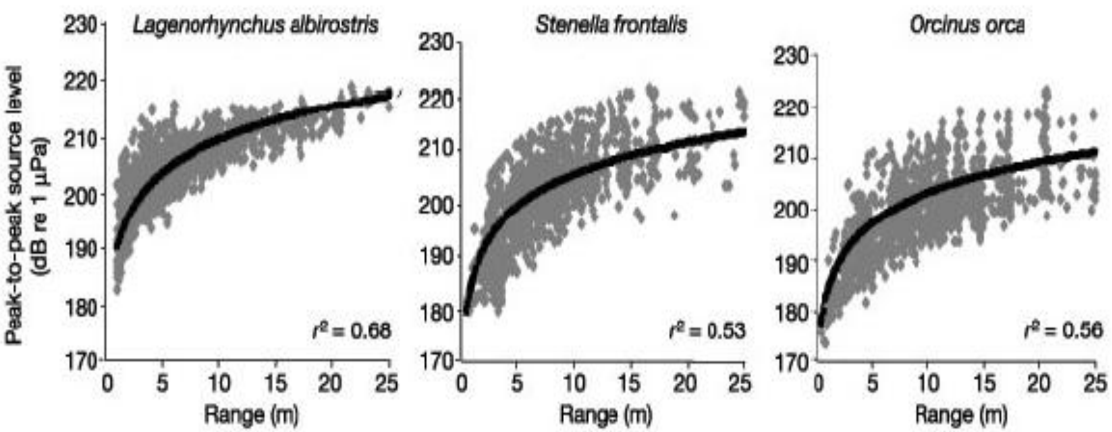
Sonar gain control



YFP

Li et al., JASA, 2006

6 dB/dh transmitting AGC



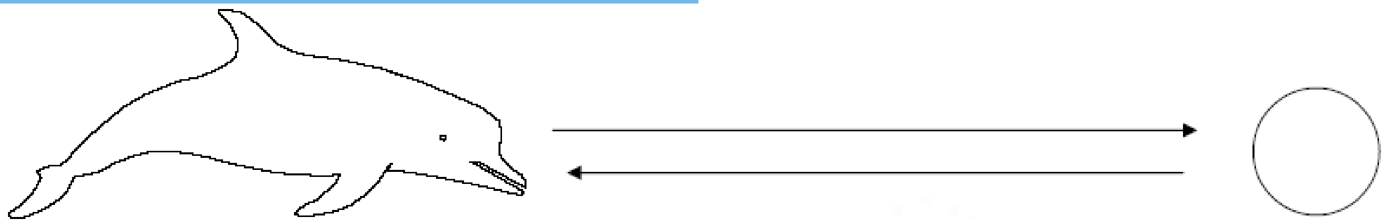
Au and Benoit-Bird, Nature, 2003

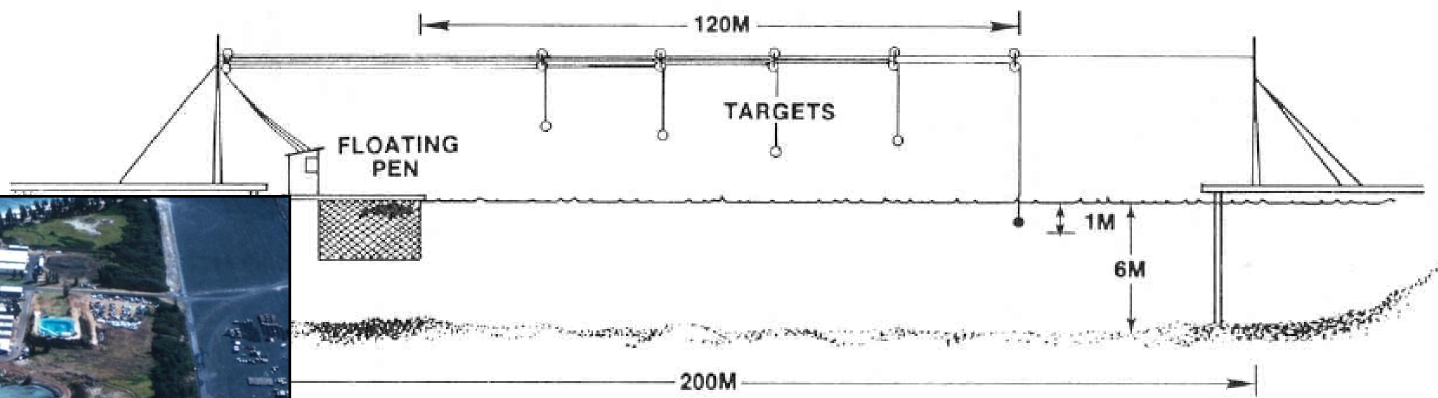
- Sound source levels of echolocation clicks increase with target distance;
- The source level increases 6 dB in each distance doubling



Bioacoustics of Marine Mammals

Biosonar detection capabilities





(Au, 1993)



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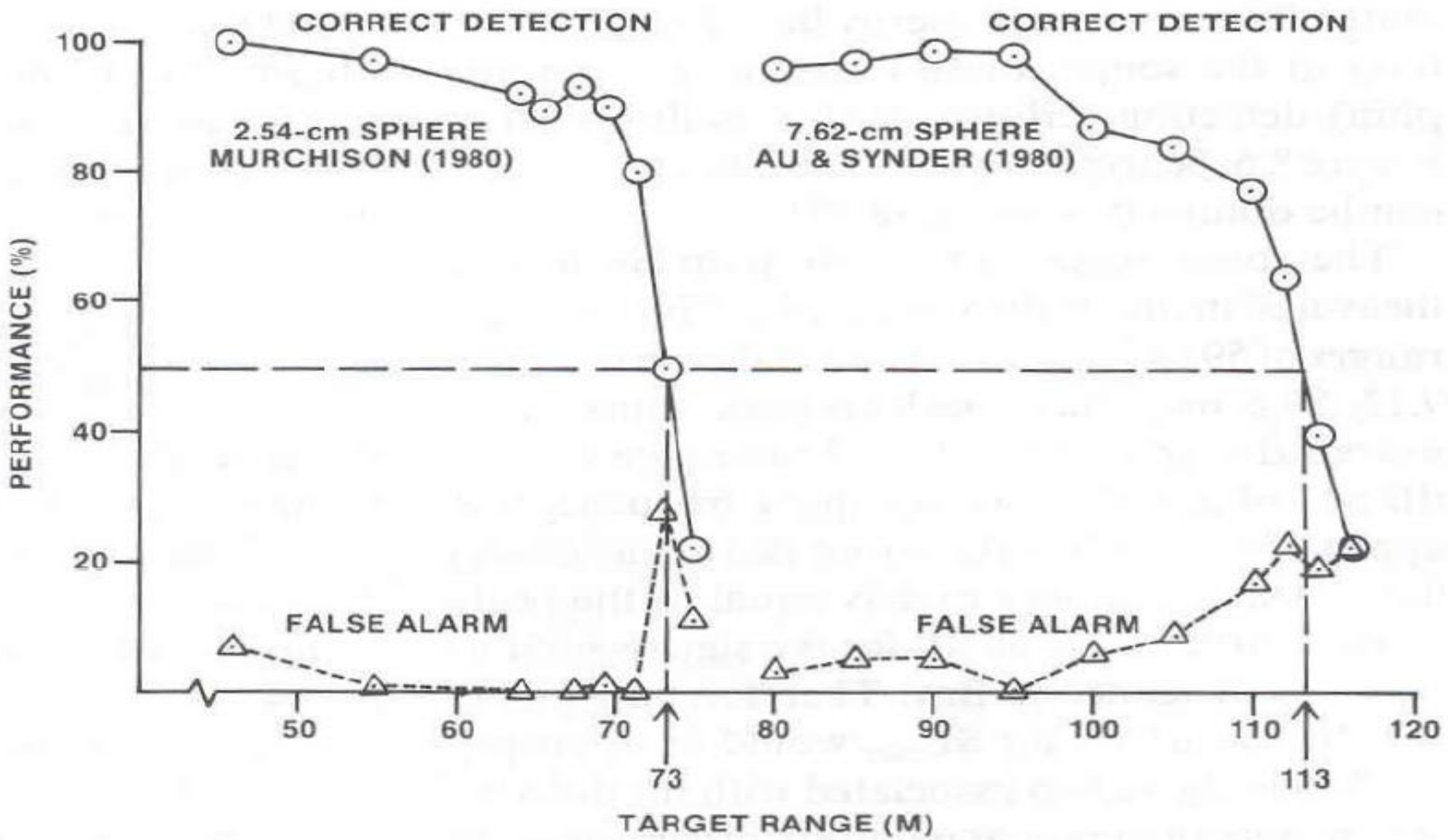

(Au, 1993)

- **Bottlenose dolphin is able to detect a 2.54-cm steel sphere up to 73 m, and 7.62-cm steel sphere up to 113 m**



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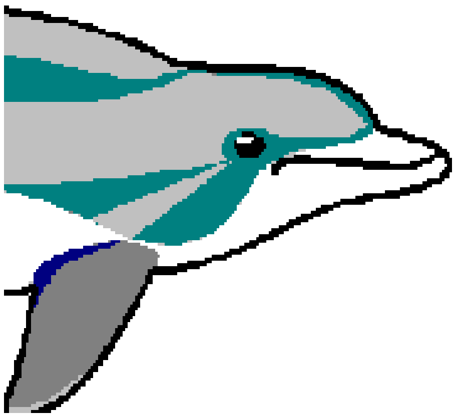
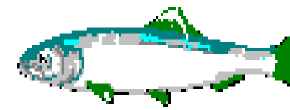
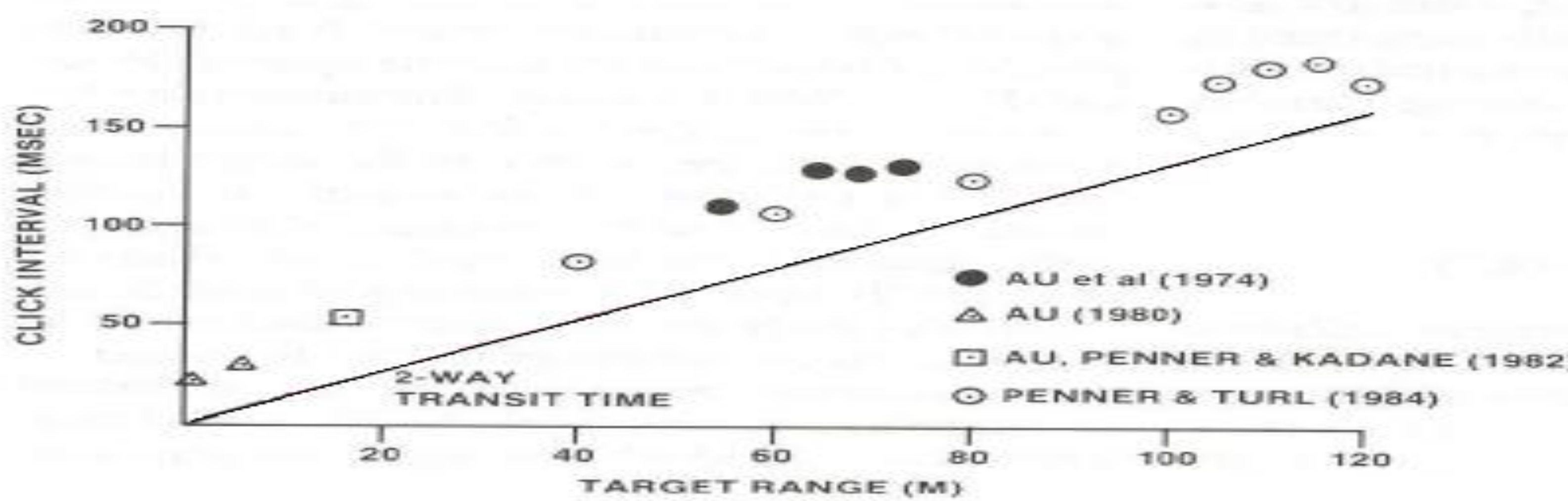
Biosonar range is also observable

ICI=TWT+20 msec lag time



(Au, 1993)



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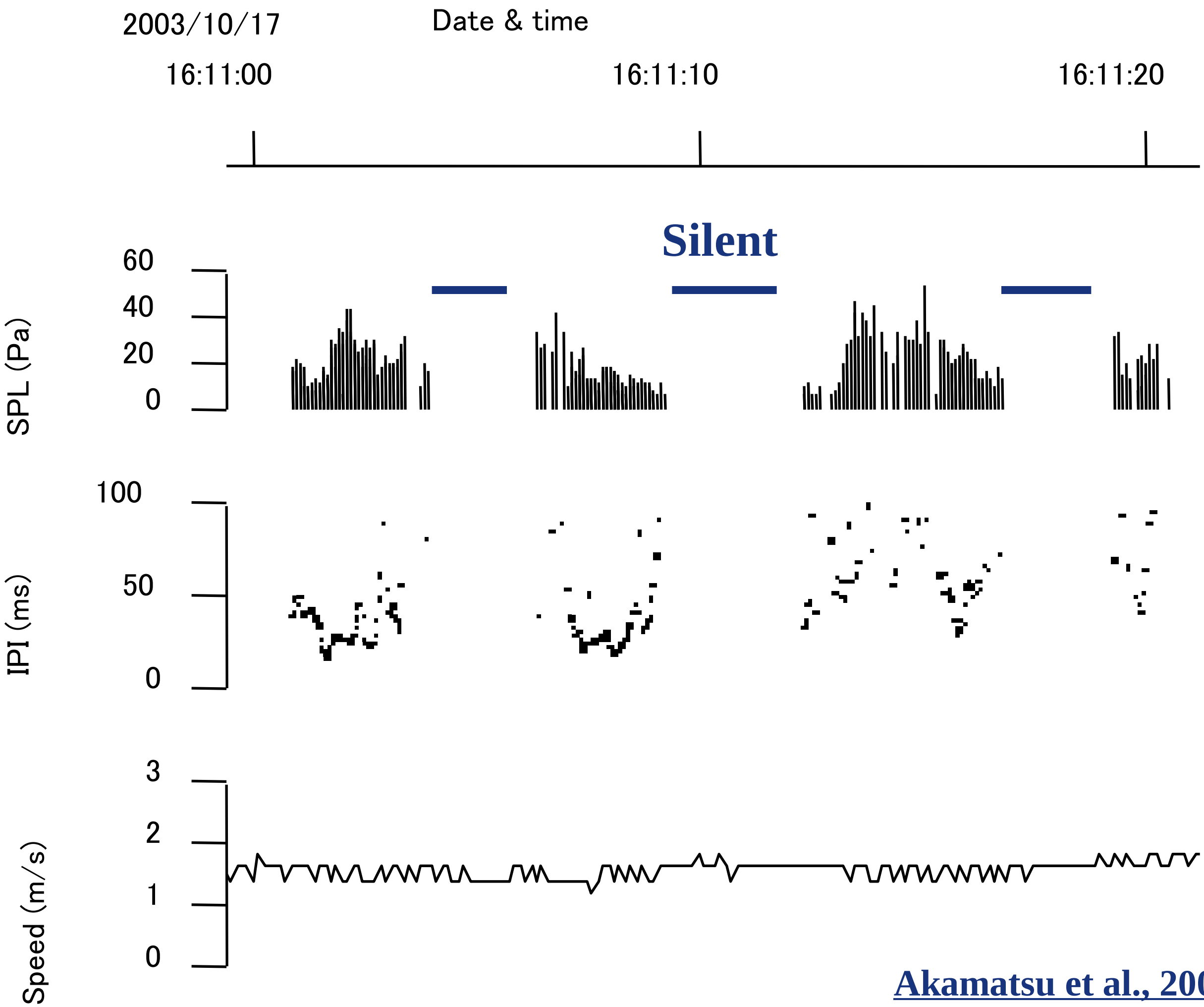

Time

SLs and Silent phase

Inter-click interval

Swimming speed

Akamatsu et al., 2005



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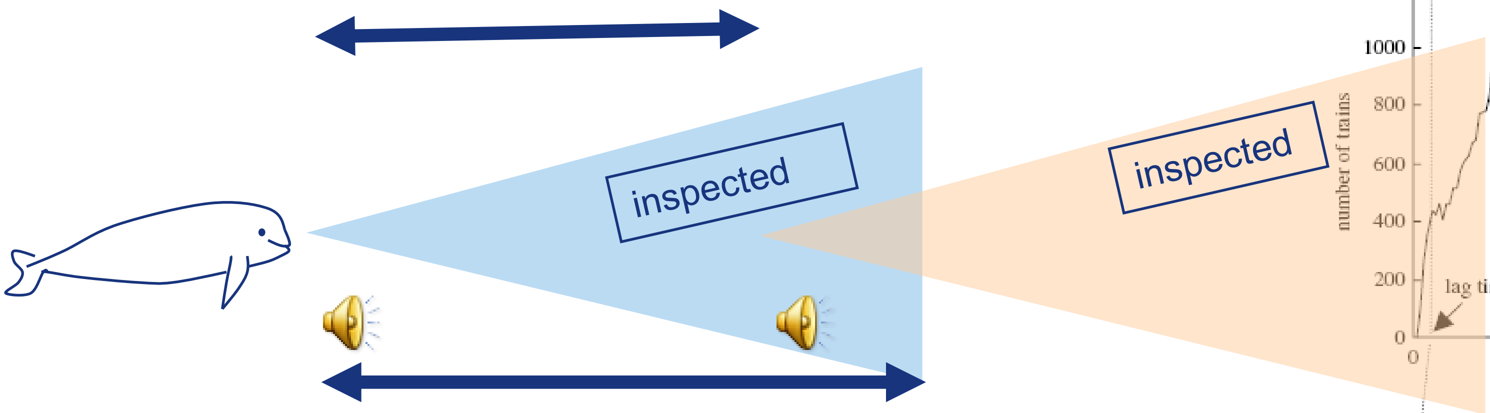

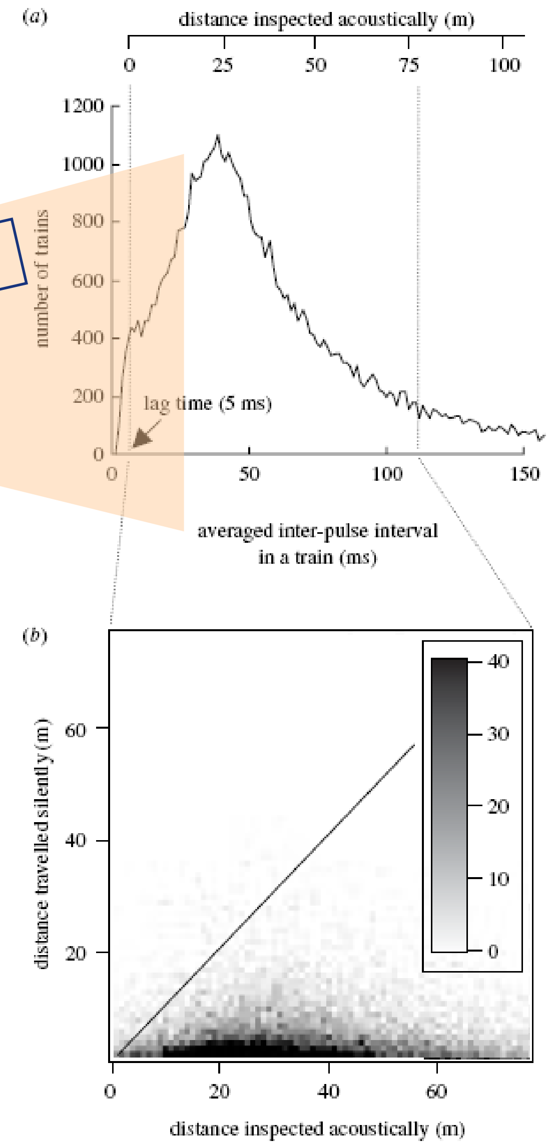

– **Silent Swimming Distance < Acoustically Inspected Distance**

Akamatsu et al., 2005

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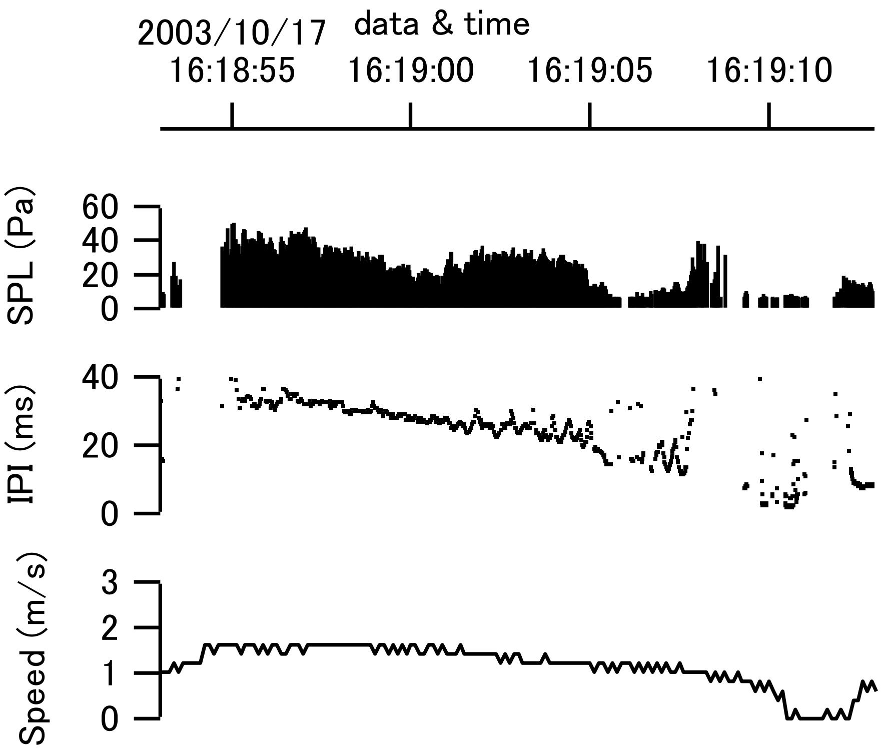

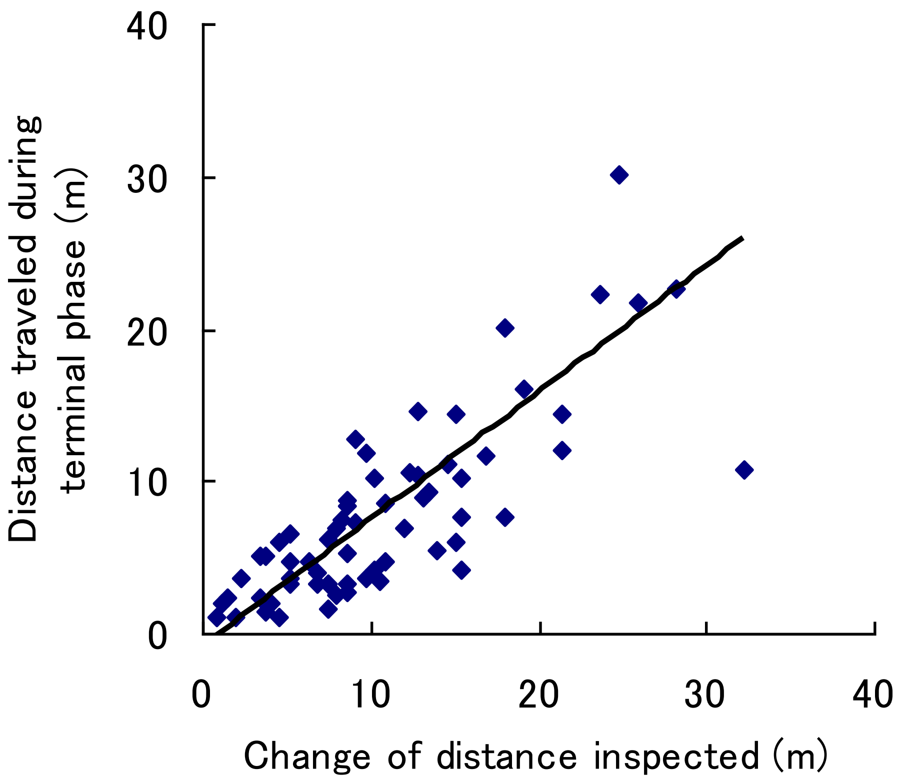

- **The distance traveled during terminal phase (approaching phase) correlated to the change of distance inspected acoustically, that means the porpoises do focus their target by sonar.**

Akamatsu et al., 2005

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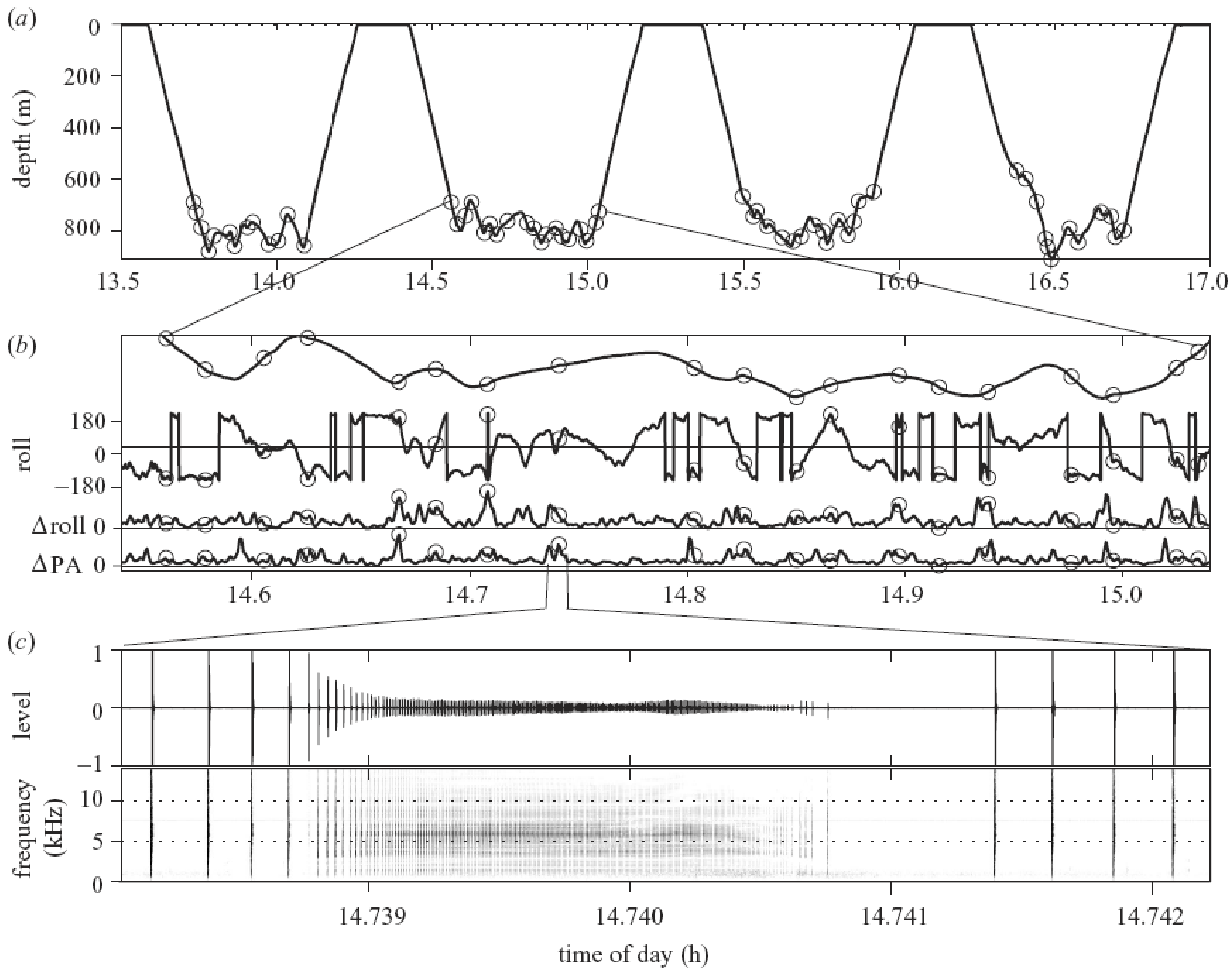

– **Sperm whales were also observed to produce the terminal phase (approaching phase) click trains**

Miller et al., 2004



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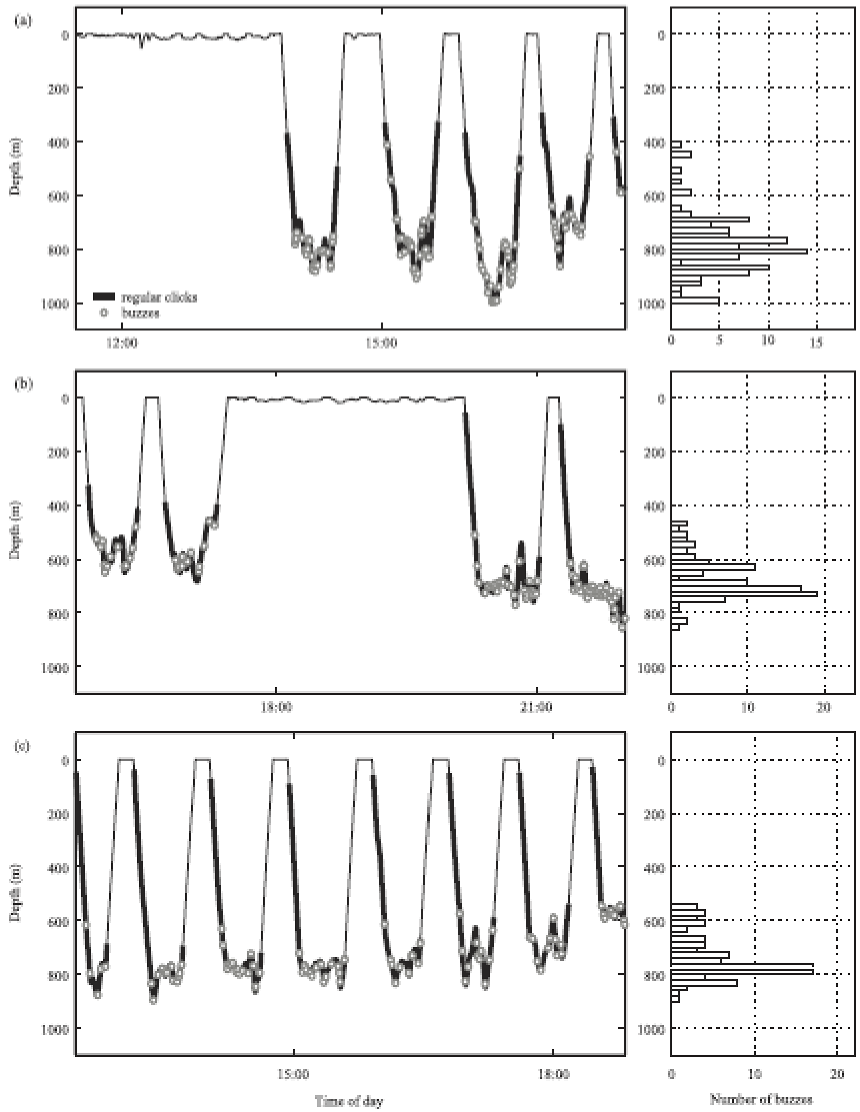

- Sperm whale only produces the terminal phase click trains at depth over 400 m.;
- May be related to its foraging behavior at the bottom.

<u>Watwood et al., 2005</u>



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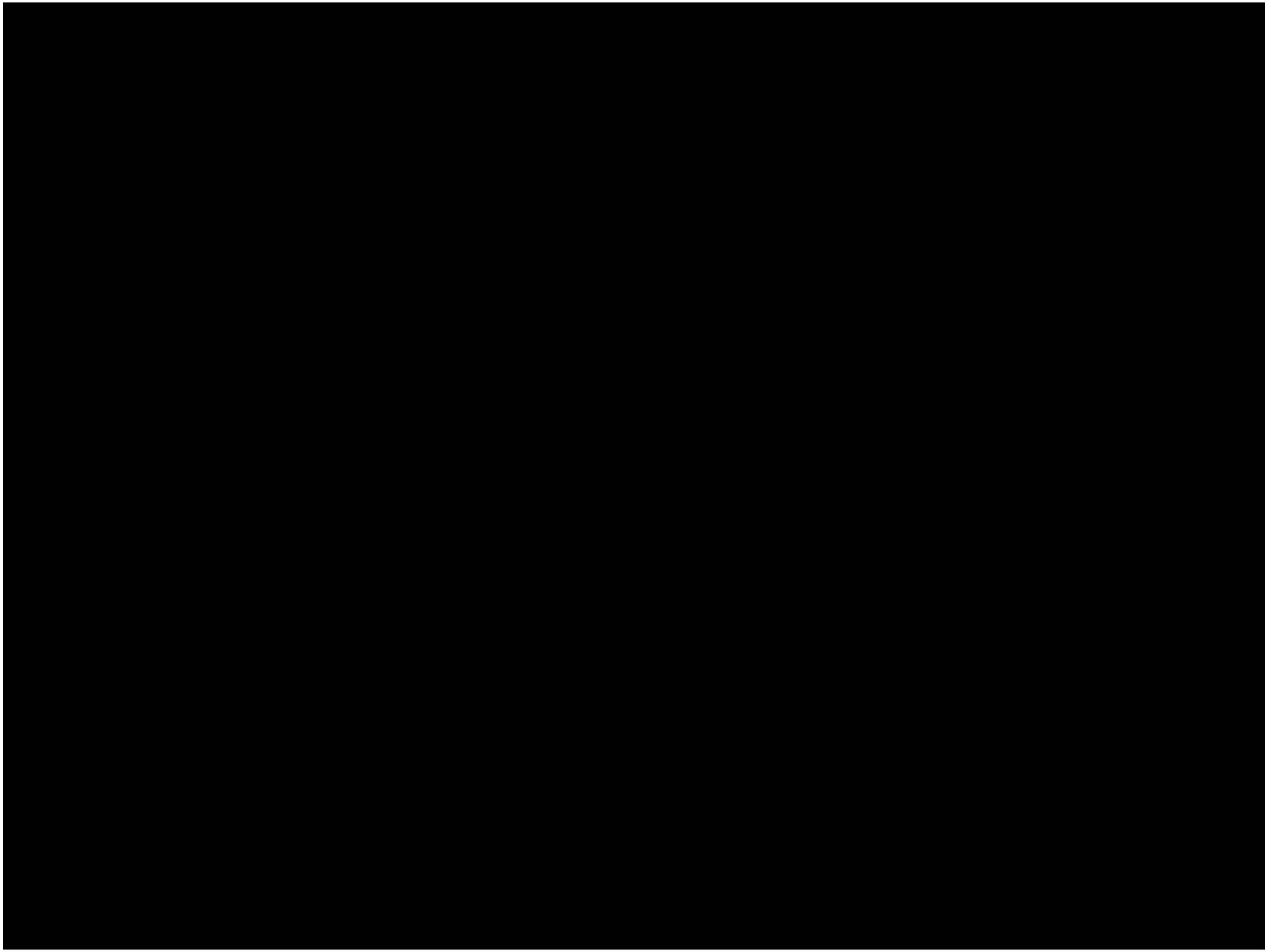

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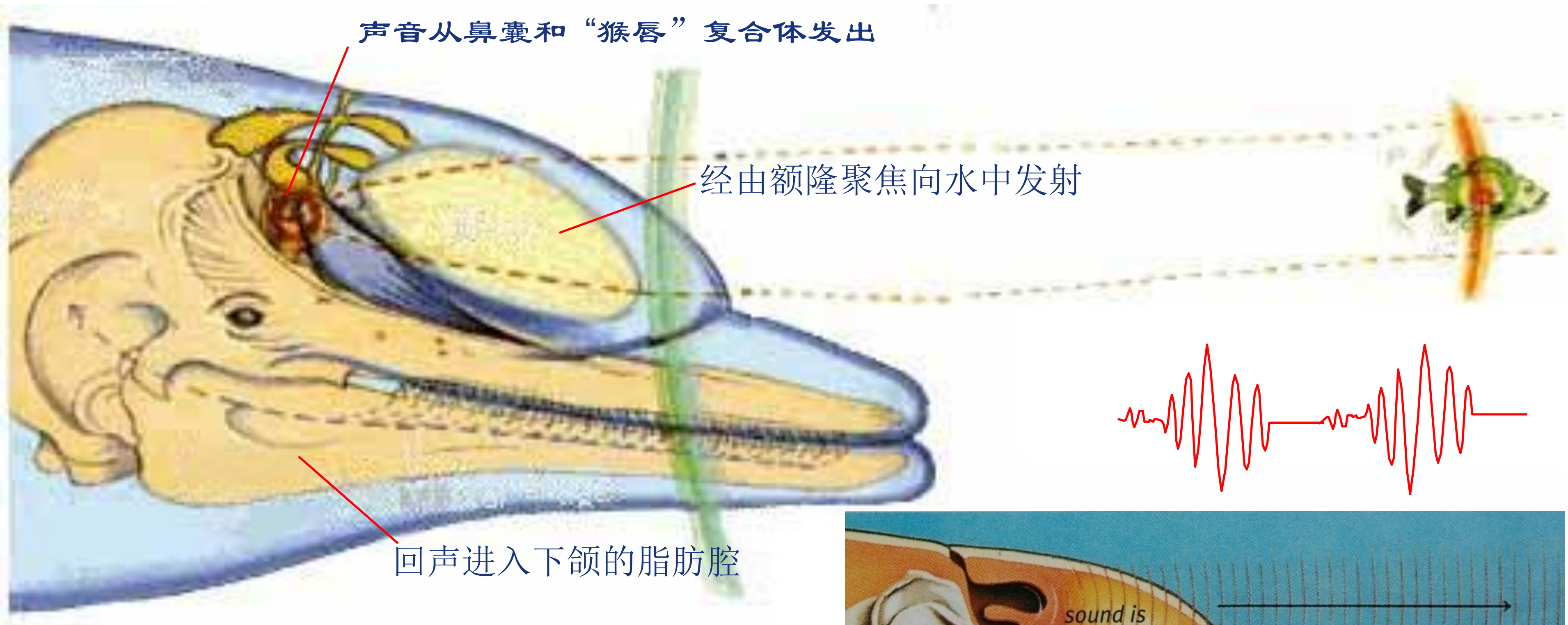

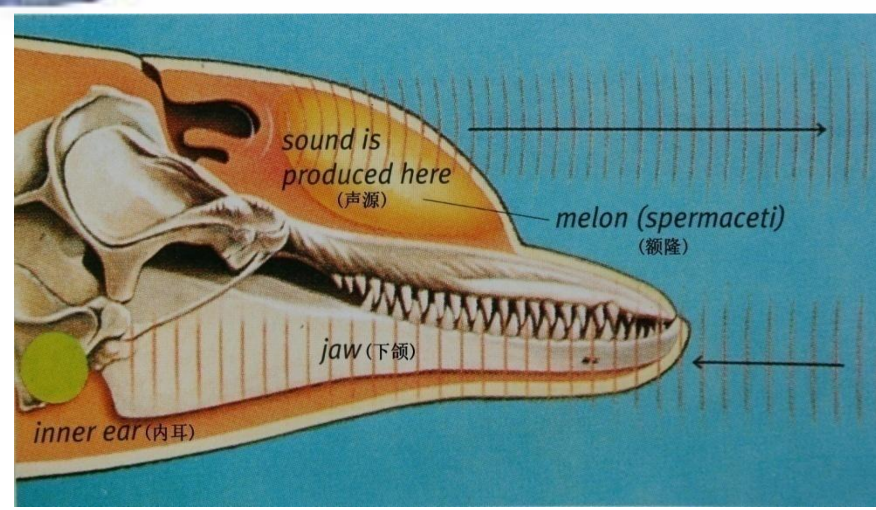

The biosonar system consists of both sound production and receiving parts



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Kastelein et al., JASA, 2002

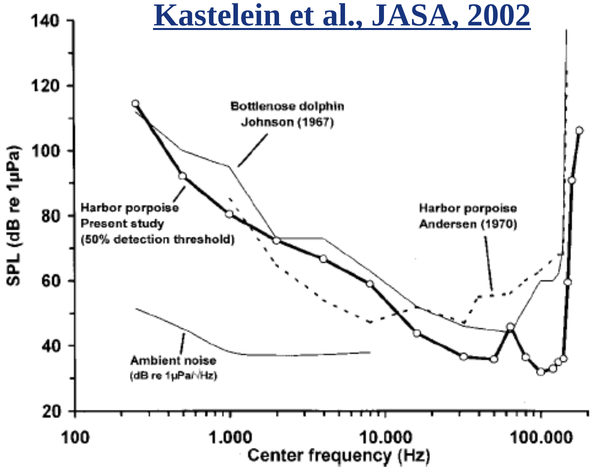
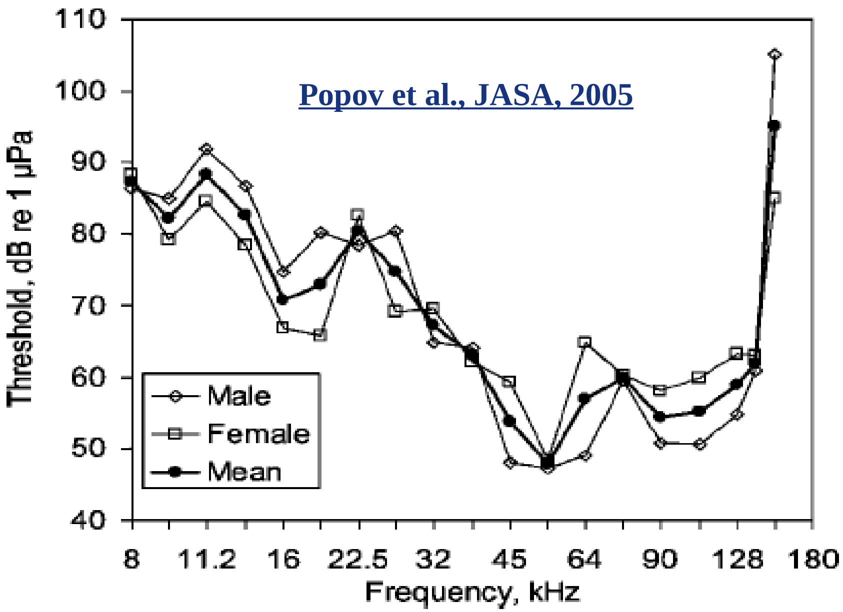


FIG. 4. The mean 50% detection thresholds in dB *re* 1 μPa (rms) for the tested narrow-band FM signals in the present study ($n = 12-15$ mean session threshold per frequency, for details see Table I). Also shown is the audiogram determined by Andersen (1970) for one harbor porpoise (sample size per frequency threshold unknown, and definition of the threshold unknown), and the audiogram of an Atlantic bottlenose dolphin (Johnson, 1967). The spectral level (dB *re* 1 μPa/$\sqrt{}$Hz; note that this is a different unit than the one along the Y axis) of the ambient noise in the pool is shown up to 8 kHz.

Harbor porpoise

Popov et al., JASA, 2005



Finless porpoise

FIG. 3. Audiograms of the two subjects and the mean of two.



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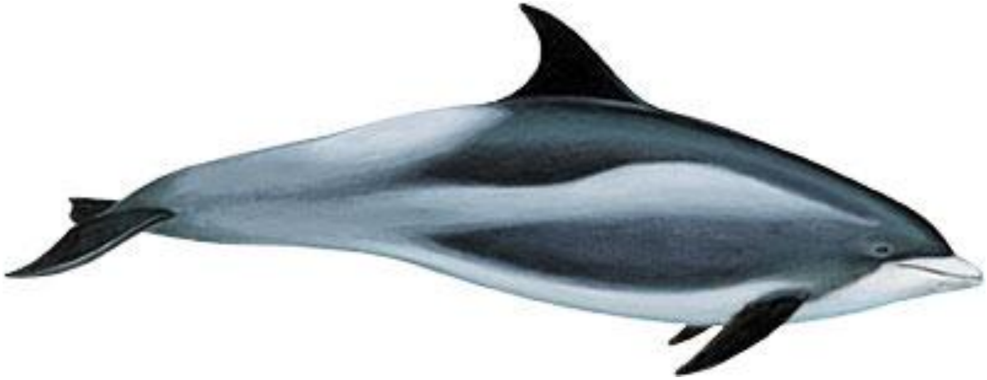

White-beaked dolphin

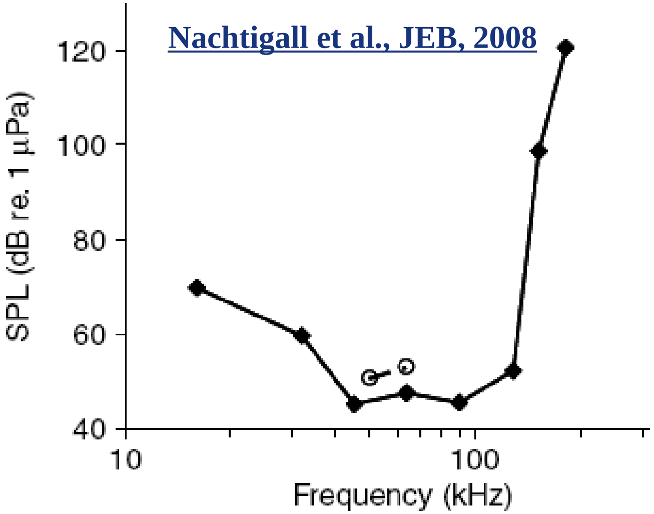

Fig. 9. Partial and entire evoked potential audiogram of two white beaked dolphins, *Lagenorhynchus albirostris*. Female dolphin: broken line with open circles; male dolphin: solid line with black diamonds. The values above 100 kHz are 128 kHz, 152 kHz and 181 kHz.

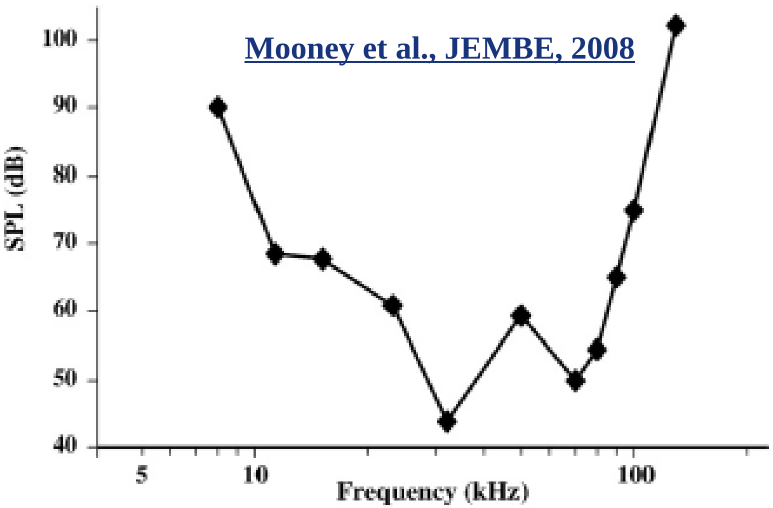

Fig. 3. AEP audiogram of the beluga whale subject stationed at the surface. Thresholds in dB (re: 1 µPa) were measured from 8 to 128 kHz using SAM tones.

Beluga whale



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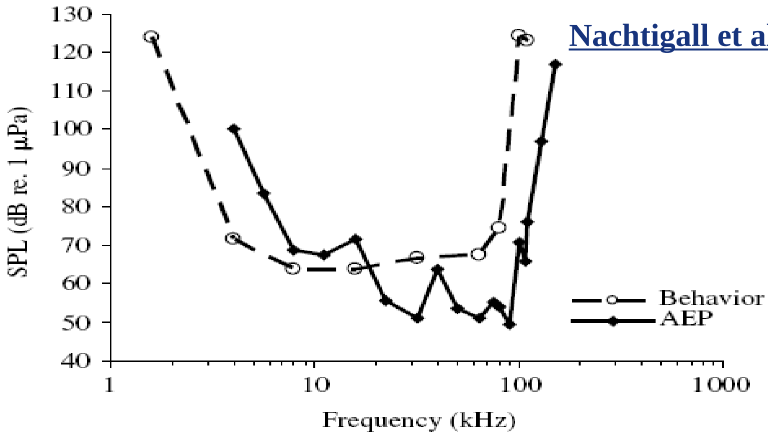
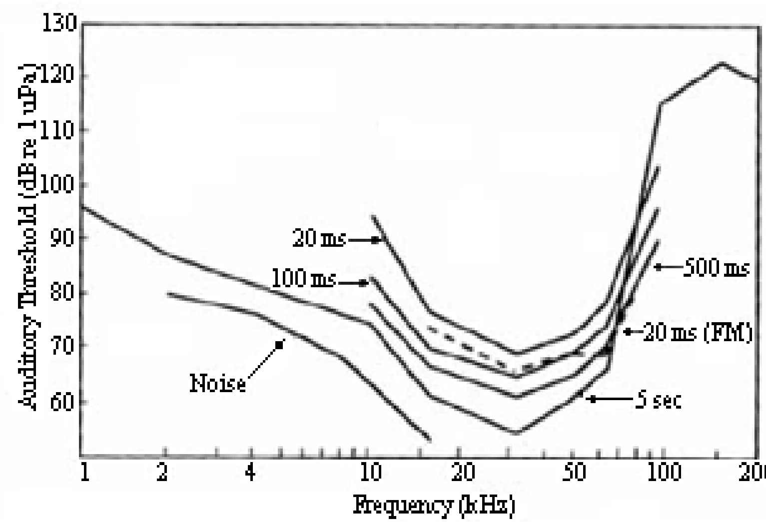


Nachtigall et al., JEB, 2005

Fig. 7. Comparison of an auditory evoked potential (AEP) and behavioral audiogram of two Risso's dolphins. The behavioral threshold was published by Nachtigall et al. (1995). The *y*-axis is intensity of stimulus, or sound pressure level (SPL) in dB. Nachtigall et al. (1995) used a pure-tone, 3 s stimulus; the present study used a 20 ms SAM.

Risso's dolphin

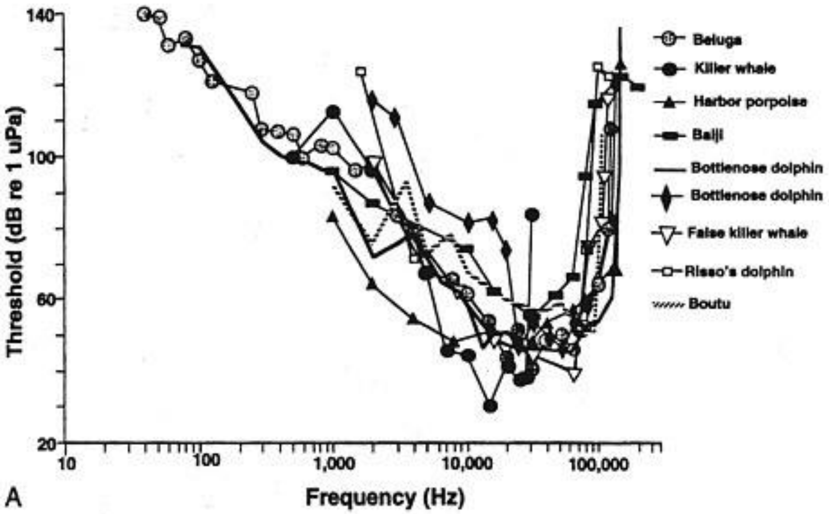
Baiji

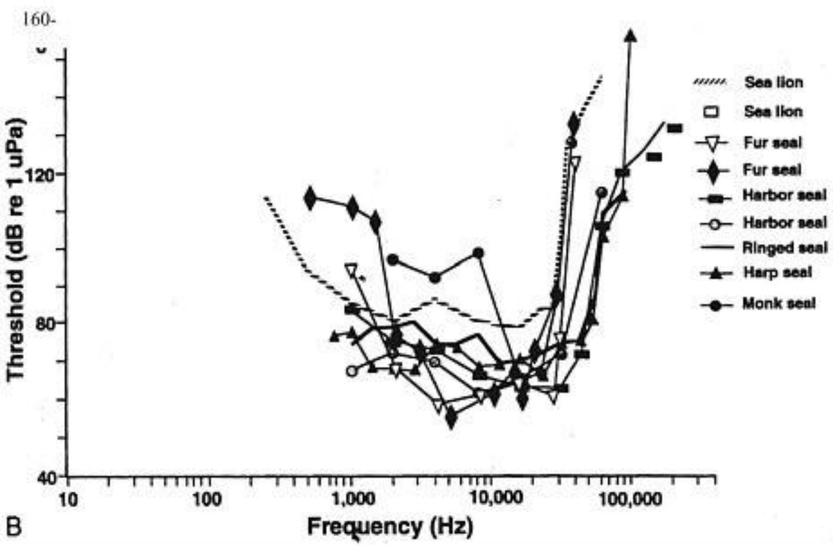


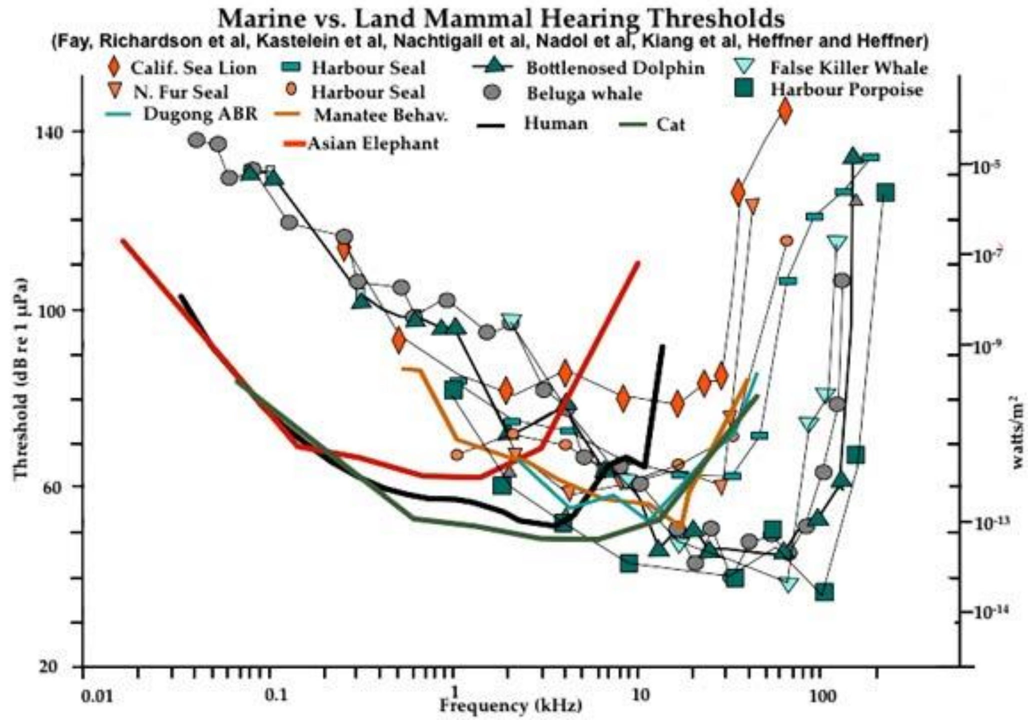
Wang et al.,1992



Bioacoustics of Marine Mammals







- Audiograms of odontocetes and pinnipeds, and comparison of audiograms between marine and land mammals including human being



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Bioacoustics of Marine Mammals

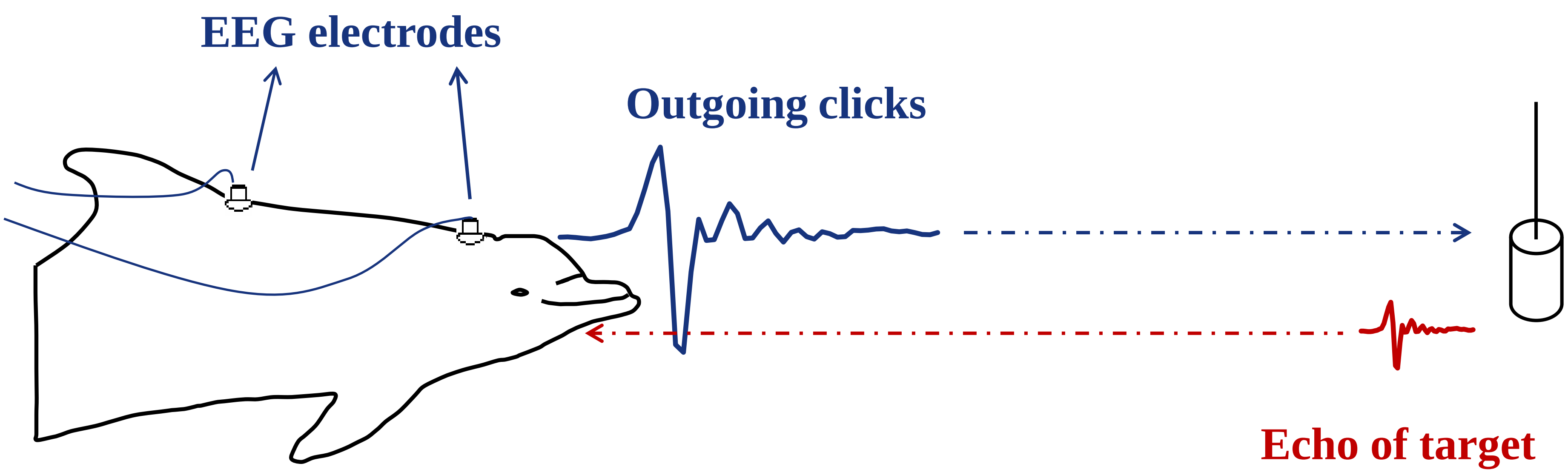
Frequency range of hearing and best sensitivity of odontocete species

Species	*n*	Hearing range (kHz)	Best sensitivity (kHz)	Method	References
T. truncatus	1	0.75–150	7–130	Behaviour	Johnson (1966, 1967)
	42	10–150	10–80[a]	Physiology	Houser and Finneran (2006b)
P. phocoena	1	1–150	2–140	Behaviour	Andersen (1970)
	1	0.250–180	4–150	Behaviour	Kastelein *et al.* (2002)
O. orca	1	0.5–31	5–30	Behaviour	Hall and Johnson (1972)
	2	4–100	12–52	Behaviour	Szymanski *et al.* (1999)
	2[b]	1–100	16–45	Physiology	Szymanski *et al.* (1999)
I. geoffrensis	1	1–105	10–50	Behaviour	Jacobs and Hall (1972)
D. leucas	2	1–130	15–110	Behaviour	White *et al.* (1978)
	4	0.125–8[c]	4–8	Behaviour	Awbrey *et al.* (1988)
	1	8–128	27–107	Physiology	Klishin *et al.* (2000)
	2	2–130	14–90	Behaviour	Finneran *et al.* (2005)
	1	8–128	22–90	Physiology	Mooney *et al.* (2008)
T. truncatus gilli	1	2–135	25–110	Behaviour	Ljungblad *et al.* (1982)
	13	10–150	20–130[a]	Physiology	Houser *et al.* (2008)
P. crassidens	1	2–115	16–64	Behaviour	Thomas *et al.* (1988)
	1	4–45	7–27	Behaviour	Yuen *et al.* (2005)
	1[b]	4–45	6.7–27	Physiology	Yuen *et al.* (2005)
L. vexllifer	1	1–200	10–65	Behaviour	Wang *et al.* (1992)
G. griseus	1	1.6–110	4–80	Behaviour	Nachtigall *et al.* (1995)
	1	4–150	8–108	Physiology	Nachtigall *et al.* (2005)
S. fluviatilis guianensis	1	4–135	16–105	Behaviour	Sauerland and Dehnhardt (1998)
S. coeruleoalba	1	32–120	0.5–160	Behaviour	Kastelein *et al.* (2003)
N. phocaenoides	2	8–152	32–139	Physiology	Popov *et al.* (2005)
M. europaeus	1	10–80	40–80	Physiology	Cook *et al.* (2006)
	1	20–90	20–80	Physiology	Finneran *et al.* (2009)
L. albirostris	2	16–181	32–128	Physiology	Nachtigall *et al.* (2008)
G. melas	1	22.5–50	4–100	Physiology	Pacini *et al.* (2010)
S. bredanensis	14	10–120	Unclear	Physiology	Mann *et al.* (2010)
M. densirostris	1	5.6–160	40–50	Physiology	Pacini *et al.* (2011)
F. attenuata	2	5–120	20–60	Physiology	Montie *et al.* (2011)

Note: Bullock *et al.* (1968) published hearing ranges and relative responses, but not calibrated audiograms.
[a] Greatly varied depending on sex and age.
[b] Same animal tested as preceeding study.
[c] Did not establish upper limit.

Mooney et al., 2012

Hearing and its mechanism during echolocation of odontocetes





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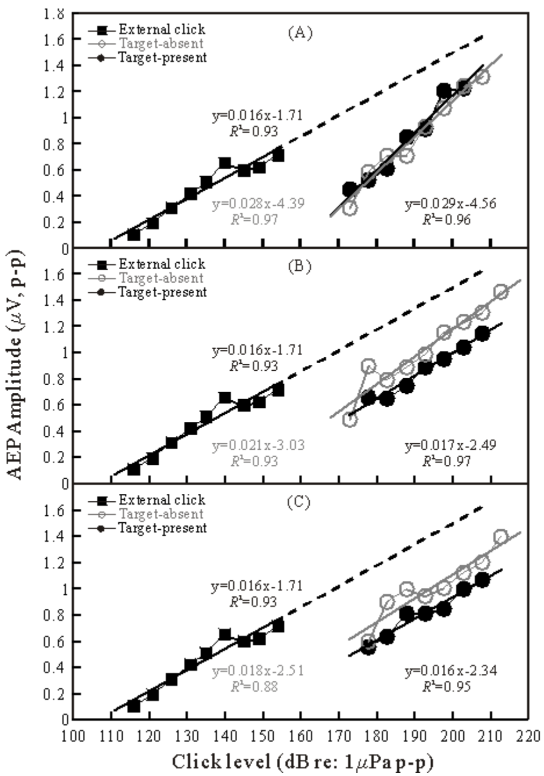
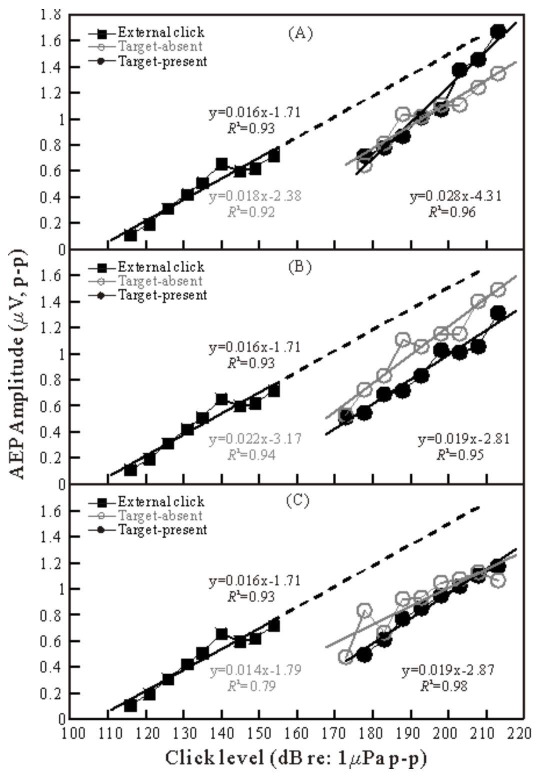
Bioacoustics of Marine Mammals

● Hearing protection

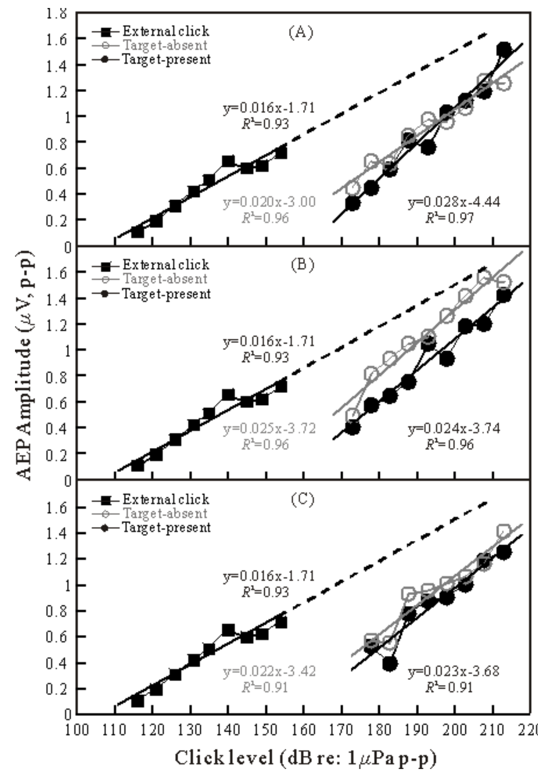
Li et al., PlosONE, 2012



-22 dB target



-28 dB target



-34 dB target

- Dolphin's hearing sensation levels of her own biosonar clicks were 16 to 36 dB lower than the biosonar click source levels;
- Indicating that the dolphin possesses an effective protection system to isolate the self-produced loud biosonar clicks from the animal's ears

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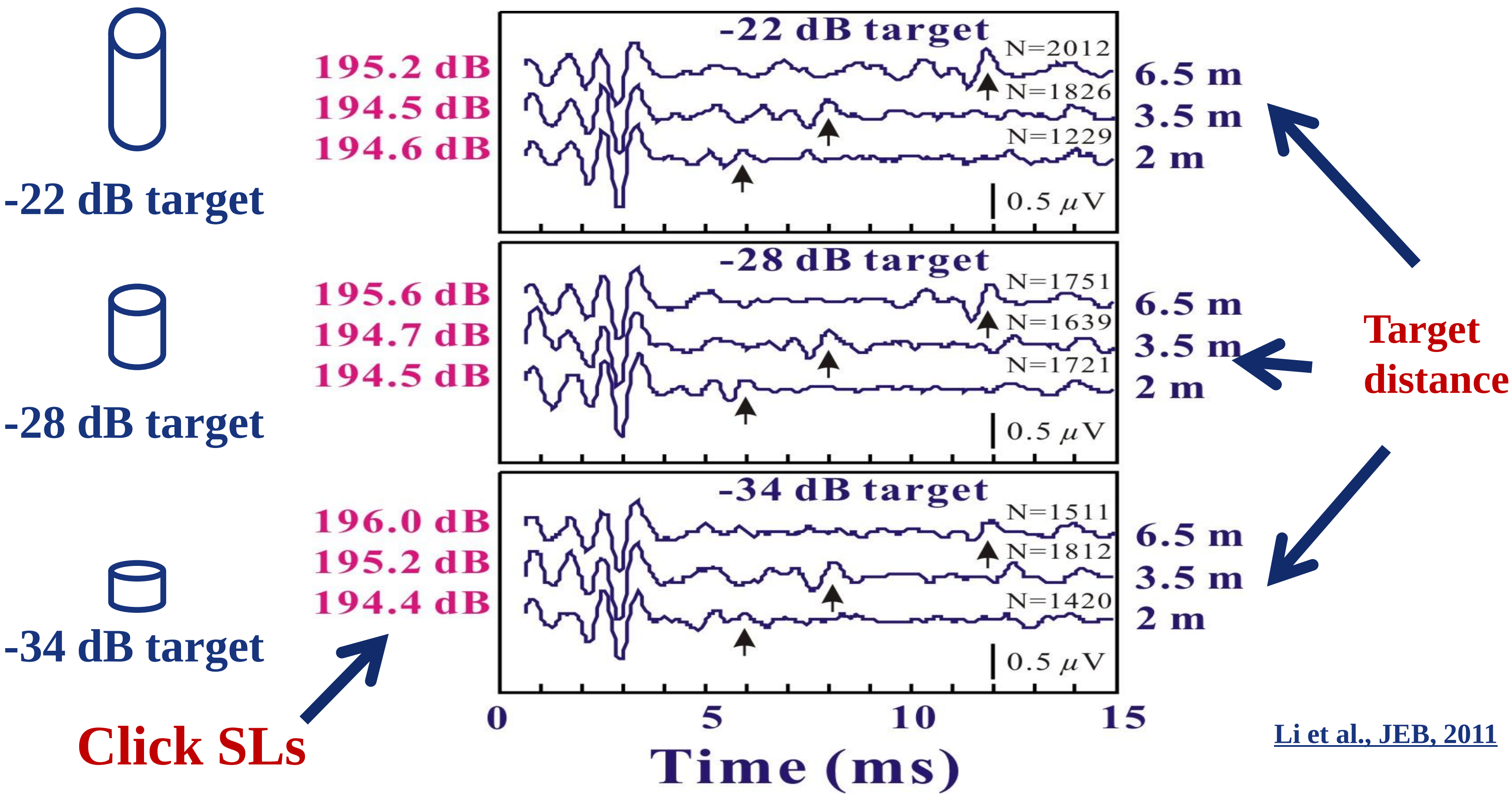
- **Biosonar control**



Li et al., JEB, 2011

– The echo-related AEP response amplitudes increased at further target distances, demonstrating an overcompensation of echo attenuation with target distance

Bioacoustics of Marine Mammals-applications

❑Survey boat



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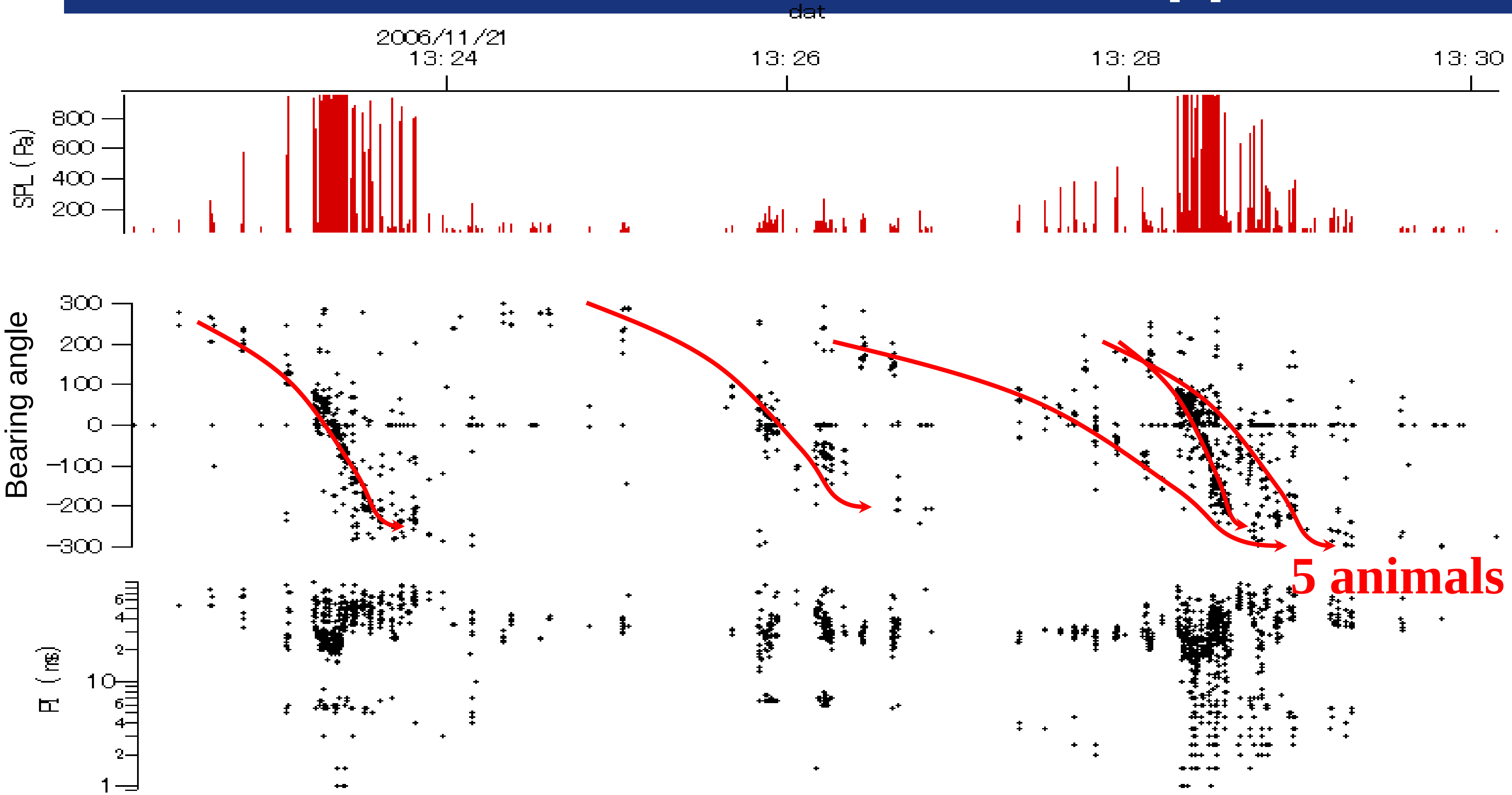
Bioacoustics of Marine Mammals-applications



– **Detect the presence, species, individual number**

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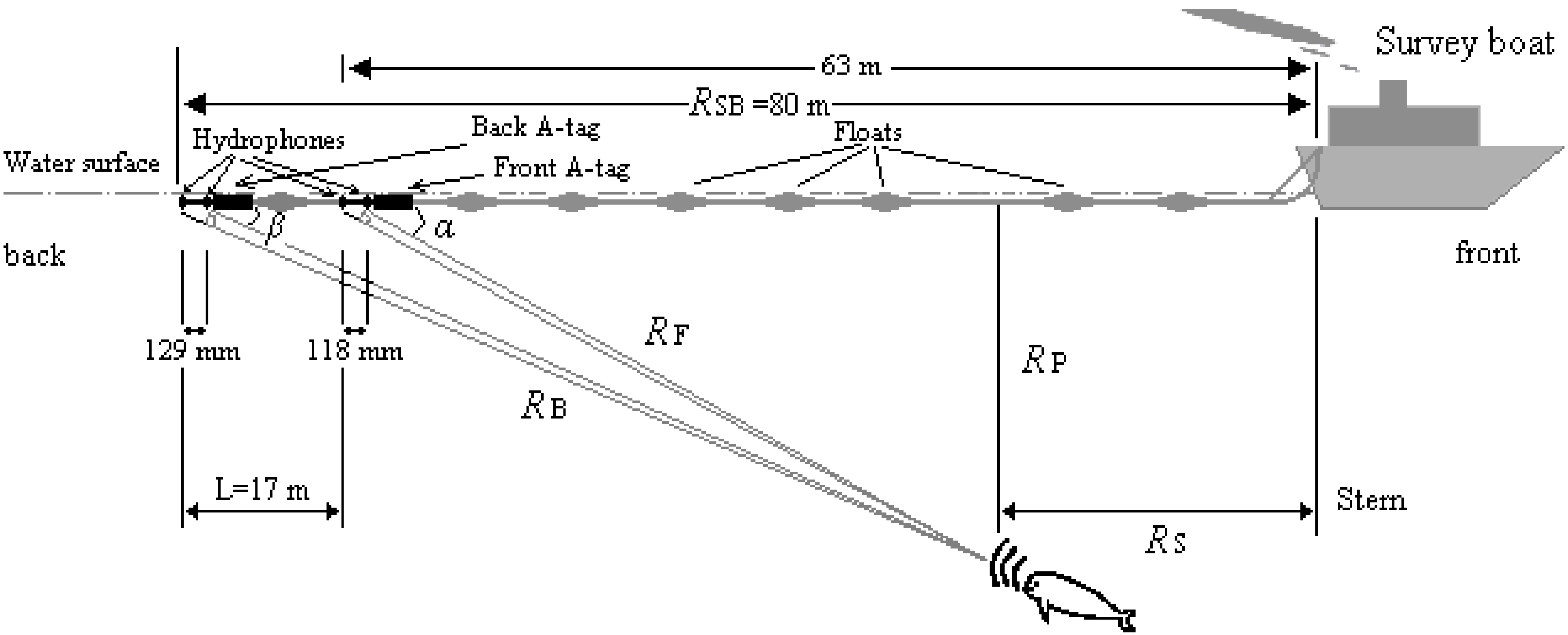
Bioacoustics of Marine Mammals-applications



– **Localization and tracking**

Li et al., JASA, 2009

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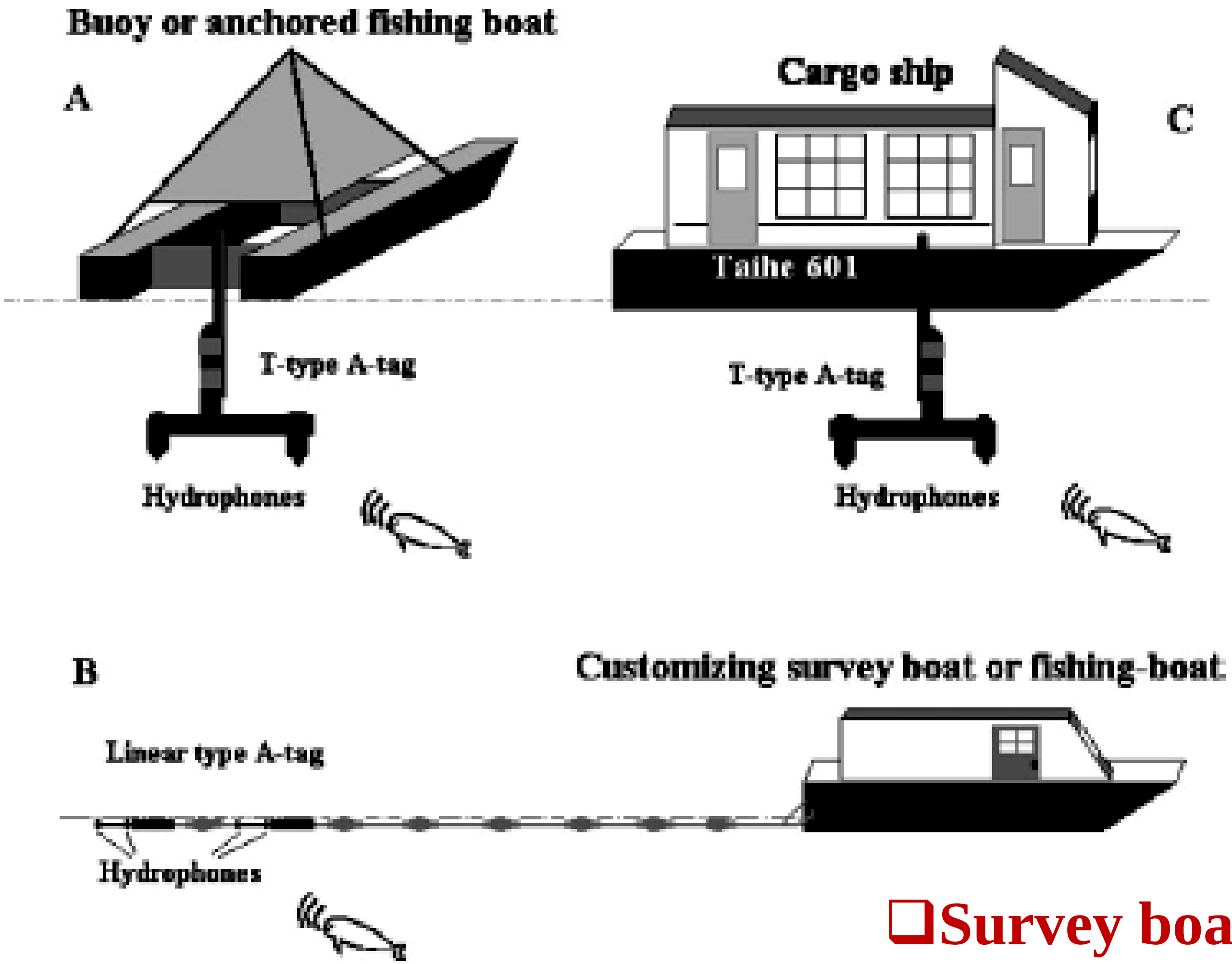
Bioacoustics of Marine Mammals-applications

- ❑Fixed platform
- ❑Cargoship



- Except the survey boat, fixed platform, cargoship can be also applied as passive acoustic monitoring platforms to monitor marine mammals in long-term

❑Survey boat

Li et al., JASA, 2010



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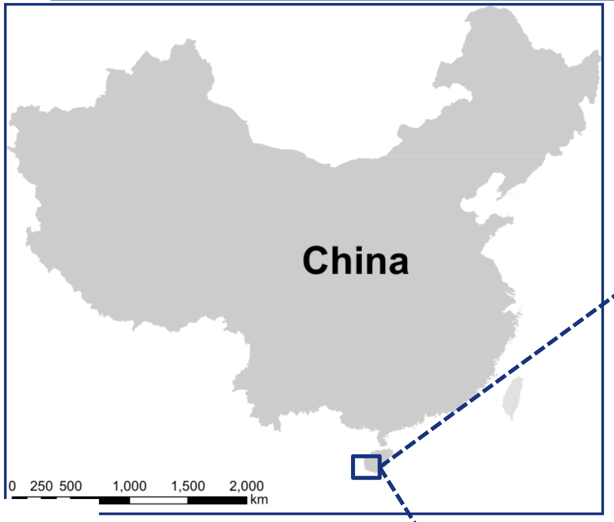
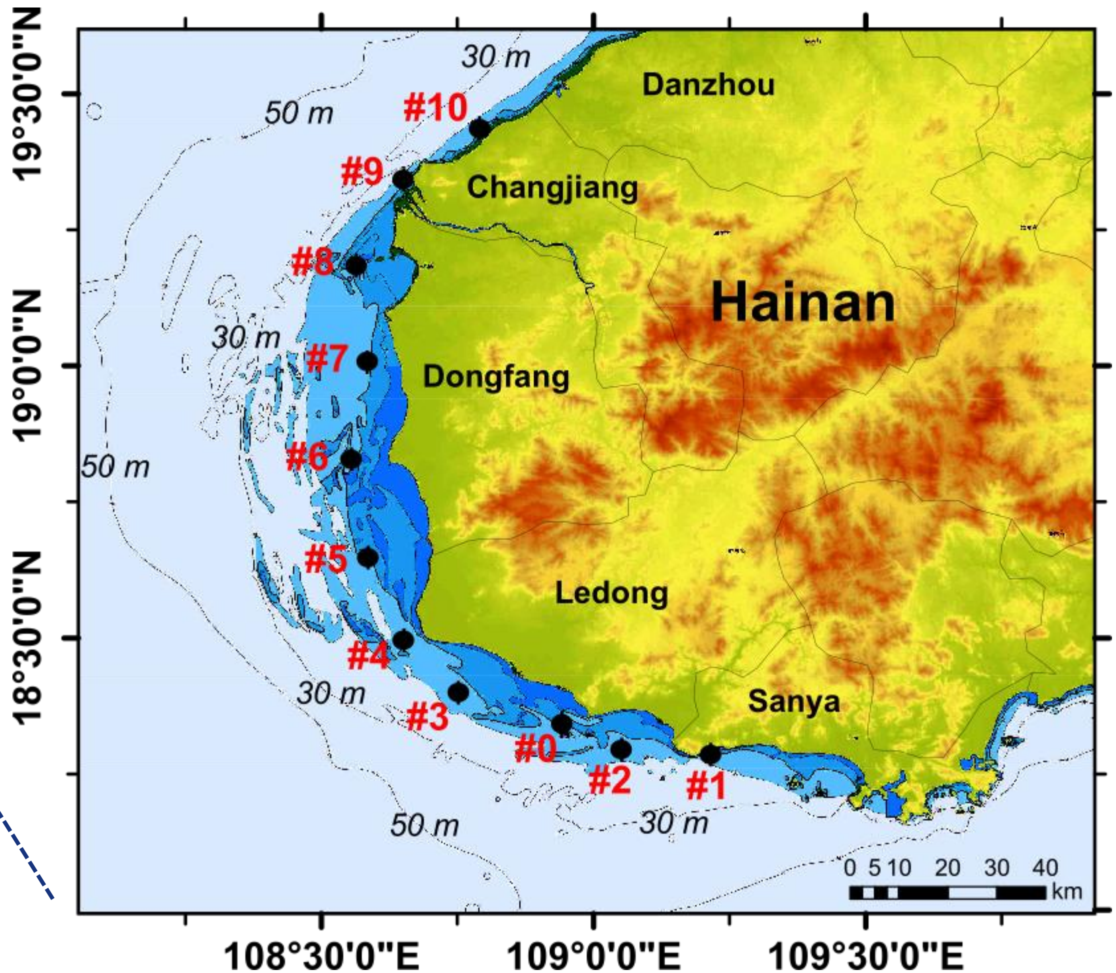
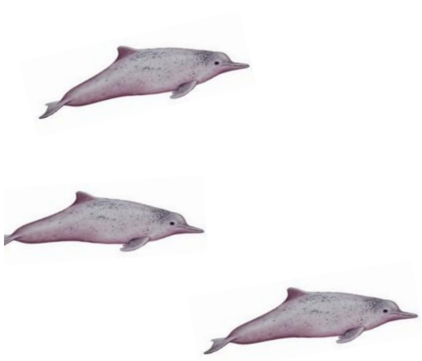
Bioacoustics of Marine Mammals-applications



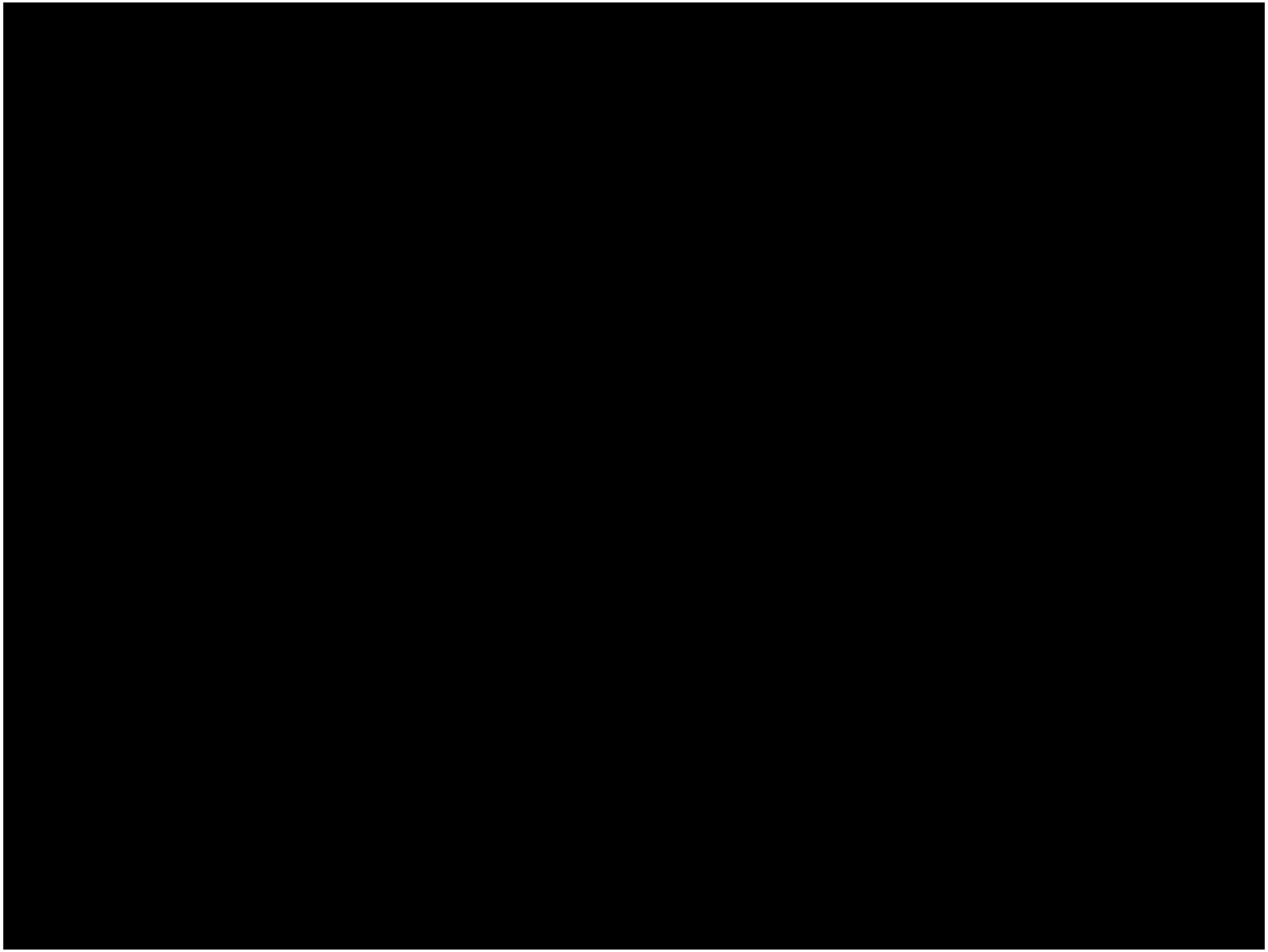
*South-western coast of **Hainan Island***







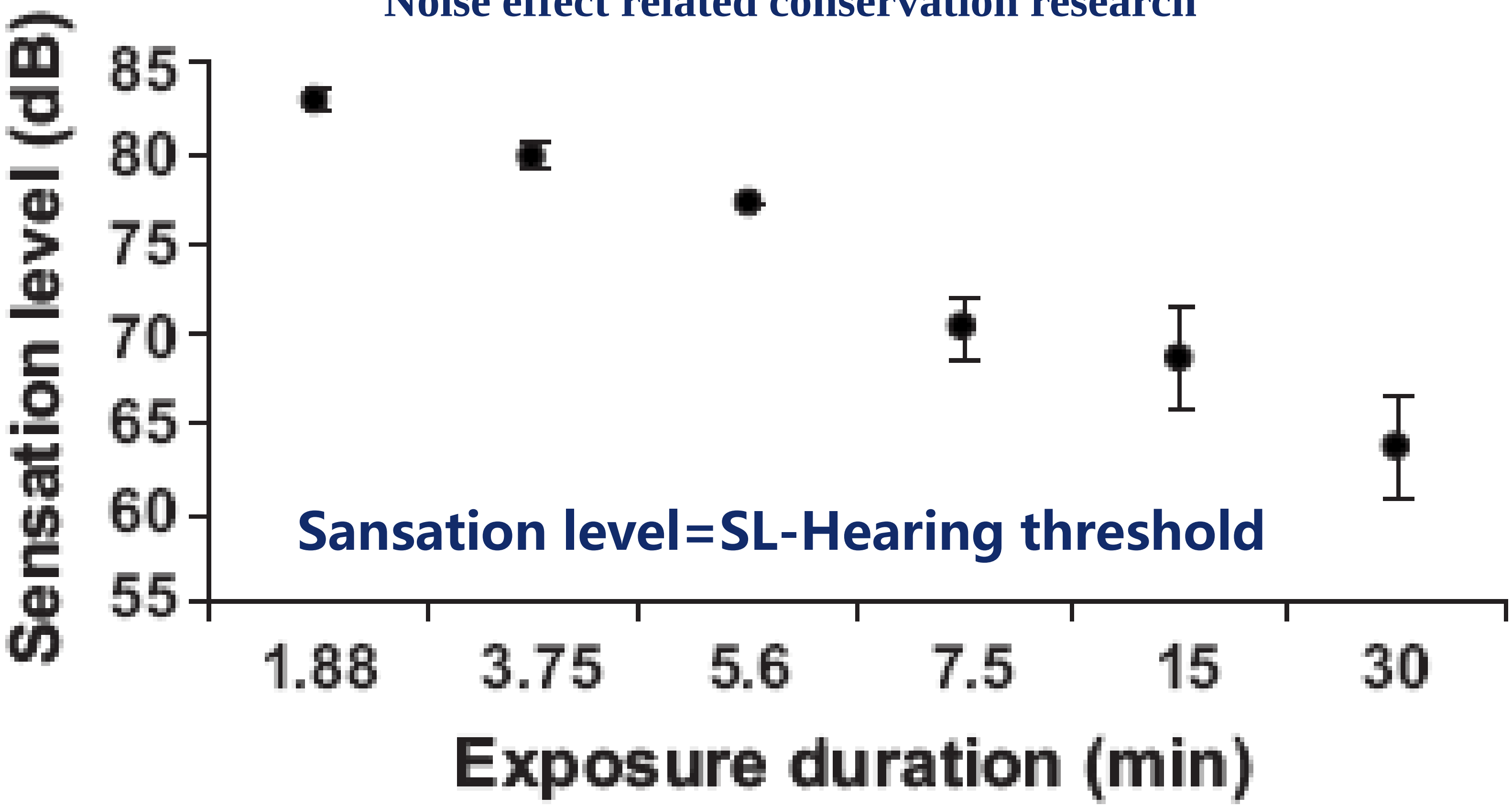
Bioacoustics of Marine Mammals-applications





Bioacoustics of Marine Mammals-applications

Noise effect related conservation research



- **Higher sensation level, higher effect of noise on the animals**

Mooney et al., JASA, 2009

Recent Bioacoustics Researches on the Indo-Pacific Humpback Dolphin (IPHD, Chinese White Dolphin): Apply to Noise Effect Evaluation



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Case study on Indo-Pacific humpback dolphins

Indo-Pacific humpback dolphin (IPHD)

- Nearshore small odontocete
- Tropical coastal waters of Southeast Asia Region
- Coastal waters of southeast China.

Jefferson and Rosenbaum, 2014

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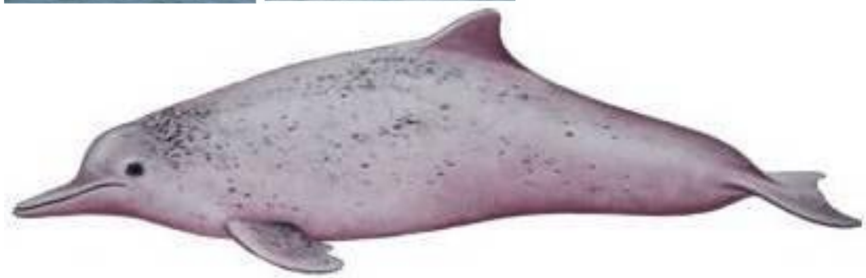
Case study on Indo-Pacific humpback dolphins

Aquatic Mammals 2004, *30*(1), 149-158, DOI 10.1578/AM.30.1.2004.149

A Review of the Status of the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) in Chinese Waters

Thomas A. Jefferson[1] and Samuel K. Hung[2]

a Jolla Shores Drive, La Jolla, CA 92037 USA
iu Village, Tai Wai, New Territories, Hong Kong



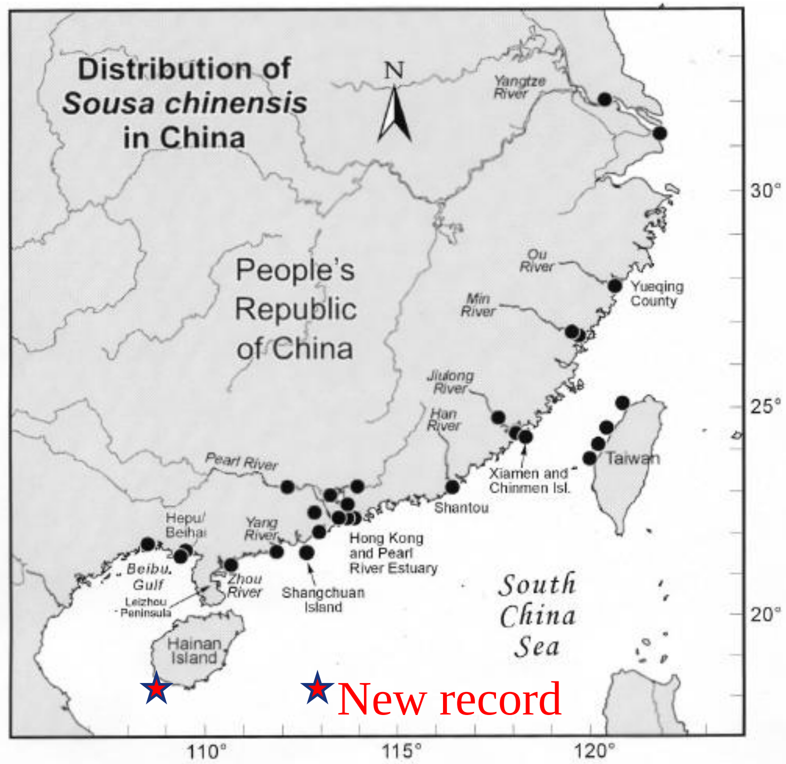


Figure 1. Reliable records of occurrence of *Sousa chinensis* in Chinese waters; updated from Jefferson (2000).

Jefferson and Hung, 2004

- **Observed from the Beibu Gulf, near the border of Vietnam, to the mouth of the Yangtze River**
- **Have been recently recorded in southwest of Hainan Island.**

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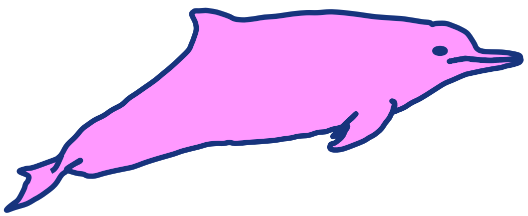
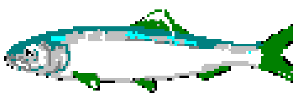
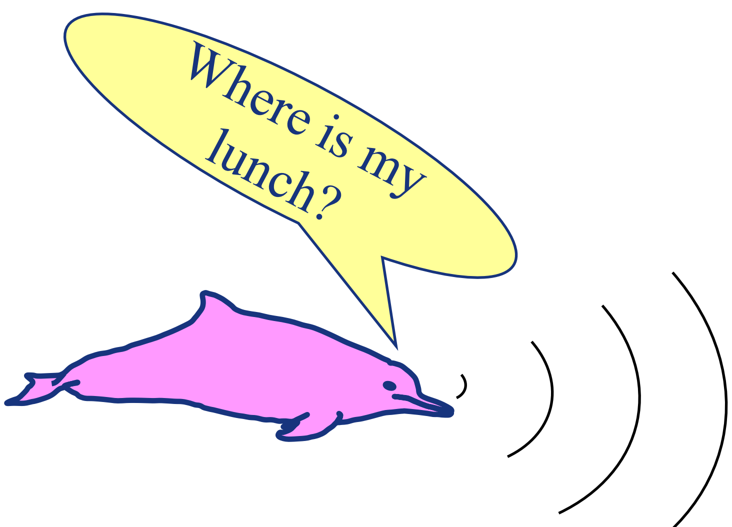
Case study on Indo-Pacific humpback dolphins

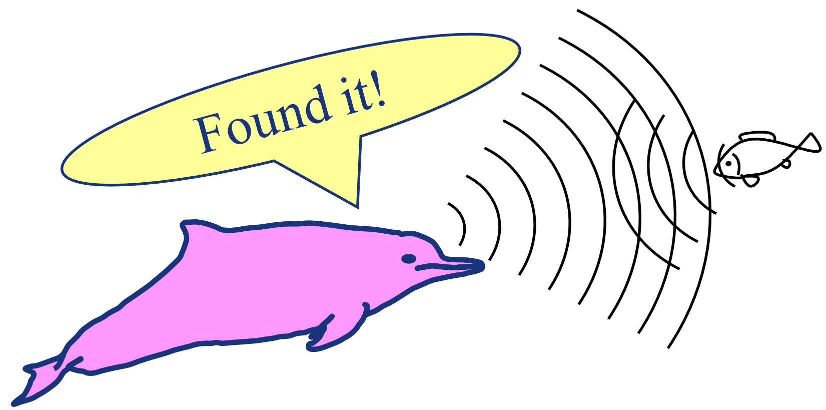
Highly developed sound production system and hearing capabilities







Navigation



Foraging

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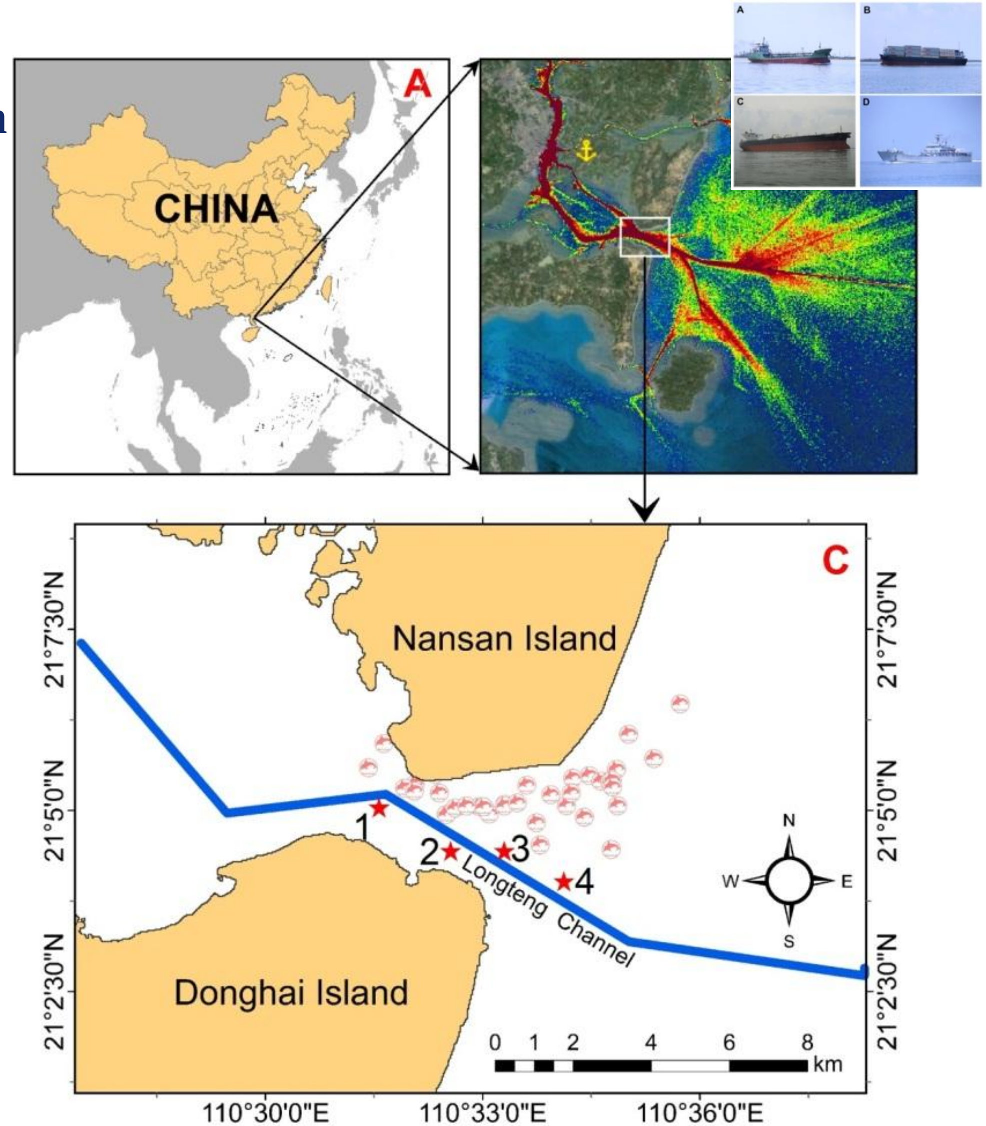
Case study on Indo-Pacific humpback dolphins

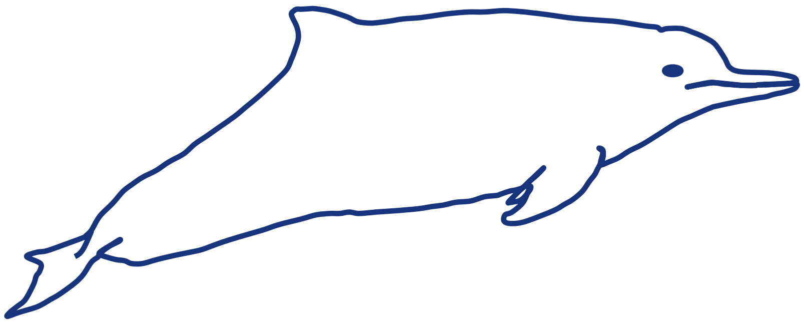
- **Most Indo-Pacific humpback dolphin habitats are heavily occupied by human activities**
  - **Shipping**
  - **Fishing**
  - **Underwater engineering**

  Significantly increase the underwater noise
- **Man-made underwater noise may interfere with both communication and biosonar systems of the dolphins in many ways**
  - **hearing damage, such as auditory masking and temporary or permanent hearing loss**
  - **altered behavior**
  - **habitat avoidance, or even death.**
- **In recent decades, the effects of underwater noise on Indo-Pacific humpback dolphins have been of increasing concern**





Case study on Indo-Pacific humpback dolphins



IPHD

- **To increase knowledge and understanding of the effects of underwater noise on Indo-Pacific humpback dolphins with the hope of facilitating protection and management for these dolphins, bioacoustics researches on the dolphins were recently carried out at:**
  - **The sound production and hearing**
  - **Characteristics of typical noise in their habitats**
  - **Potential impacts of the noises on the dolphins.**

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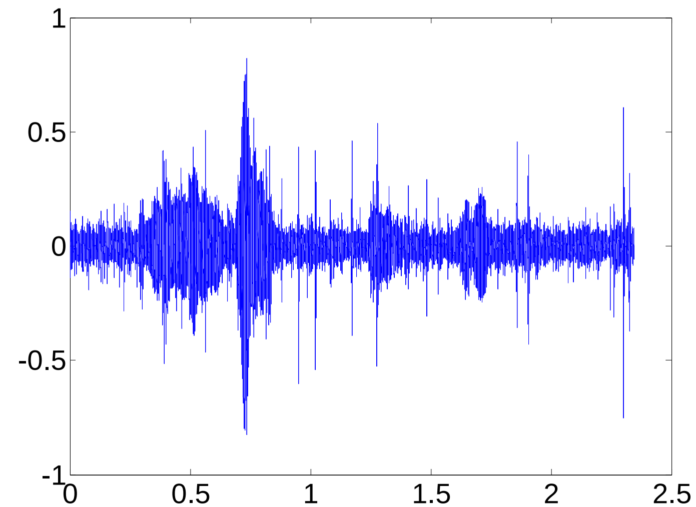
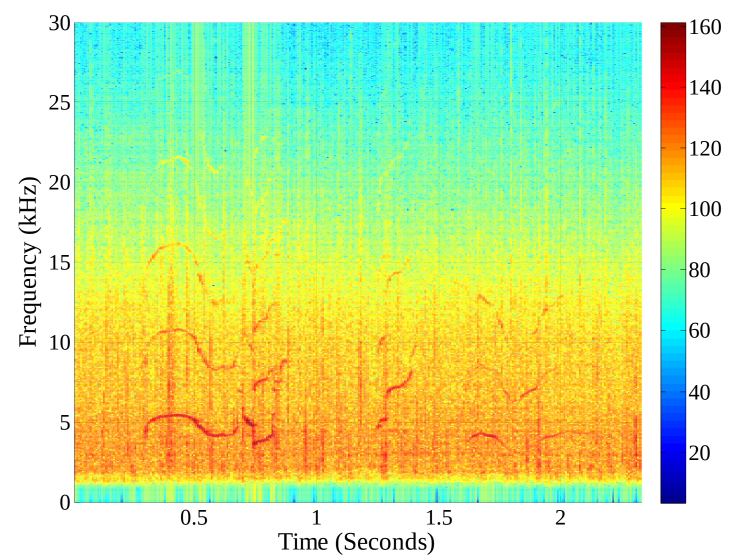
Case study on Indo-Pacific humpback dolphins

Sound production of IPHD

- **Sounds of humpback dolphins (*Sousa* sp.) were first described in 1977** (Zbinden et al., 1977)
- **Broadband click trains, burst pulses, and whistles** (Sims et al., 2012b)
- **Frequency of the whistle fundamental contour ranges from approximately 0.5 to 30 kHz** (Wang et al., 2013)
- **Significant differences were found in parameters of whistles in different populations** (Hoffman et al., 2015)





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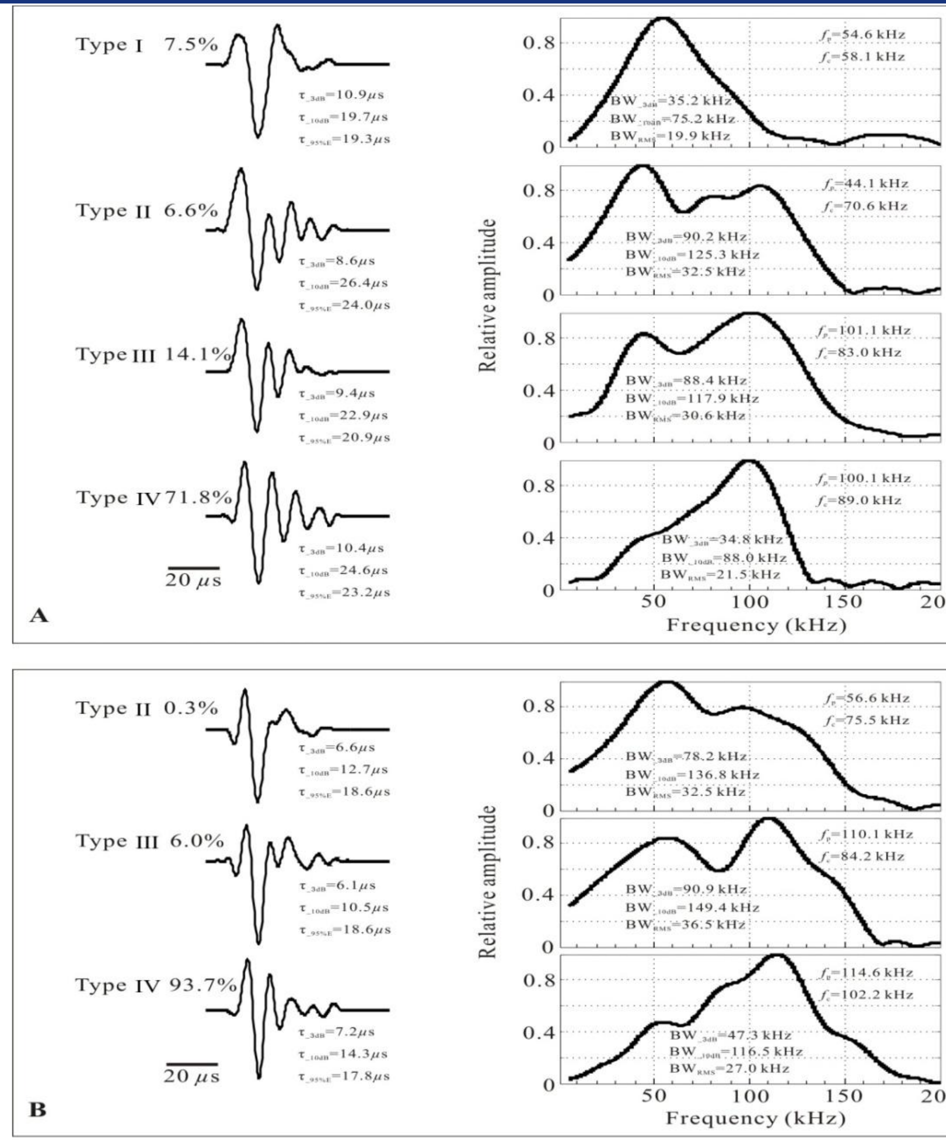
Case study on Indo-Pacific humpback dolphins

Sound production of IPHD

- Clicks of the IPHD in captivity are similar to those of other small dolphins
- high-frequency, broadband short signals with peak frequencies > 100 kHz
- Could be sorted into four types (types I–IV) by spectrum shape
- likely age-related differences in frequency characteristics



Li et al. 2013



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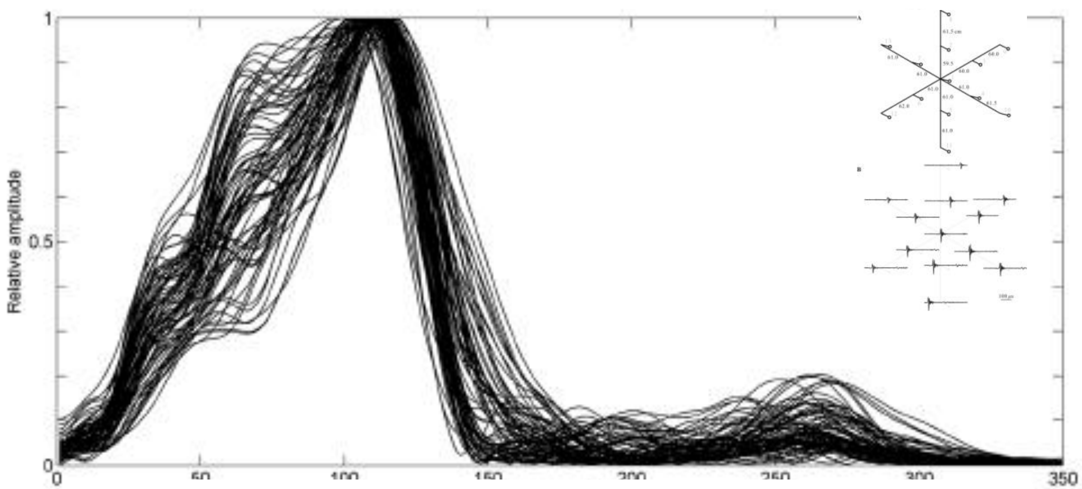
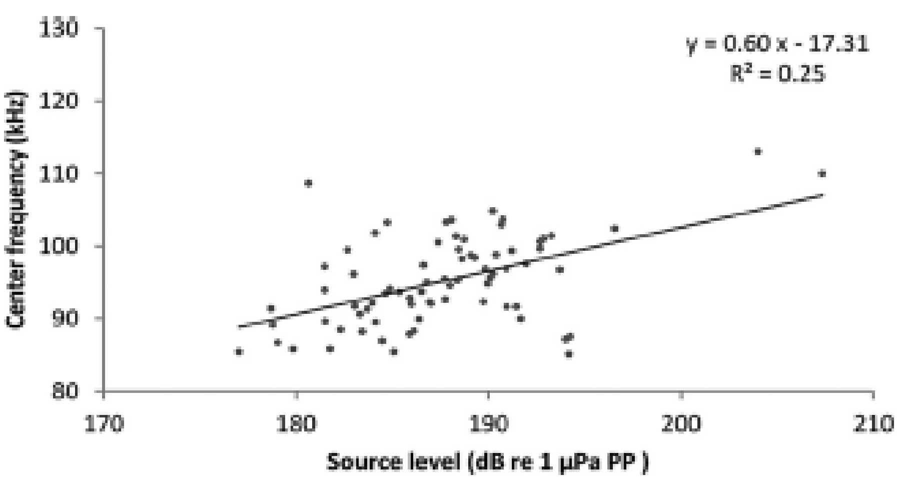
Case study on Indo-Pacific humpback dolphins

Sound production of IPHD





- Clicks of the wild IPHD are short-duration, broadband, ultrasonic pulses, similar to those produced by the dolphins in captivity and by other whistling dolphins of similar size
- Source level was 187.7 dB re: 1 µPa in average, lower than those of other whistling dolphins, which are up to 220 dB re: 1 µPa

Fang et al., 2015



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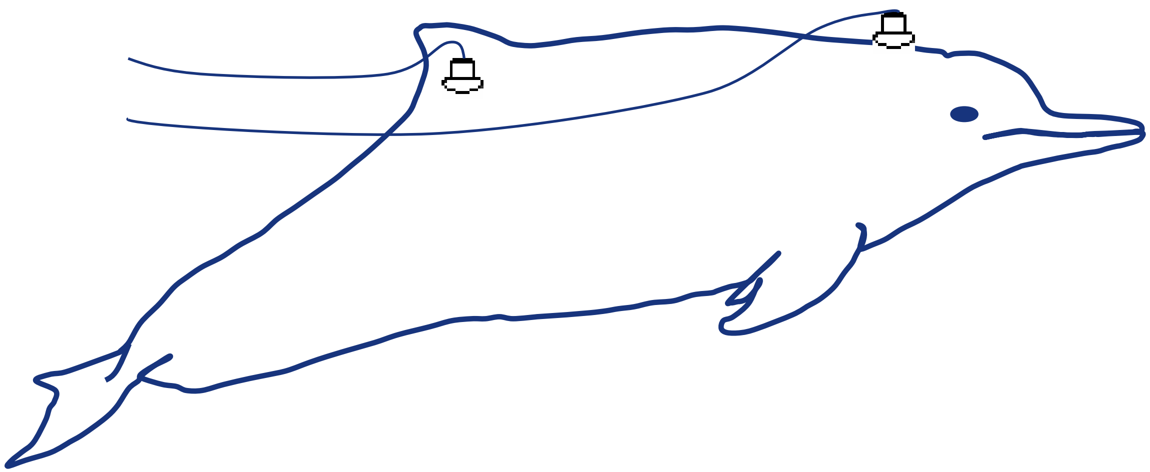
Case study on Indo-Pacific humpback dolphins

Hearing of IPHD

Electrophysiological method (ABR method)



- A non-invasive method;
- A recording suction-cup EEG was worn on the skin of animal brain, and a reference suction-cup EEG was worn on its back, to record Auditory Brainstem Response (ABR) of the animal to the sound stimulus;
- By using this method, a hearing audiogram of the animal could be measured within one to two hours, and the results are comparable to those acquired by Behavioral method.



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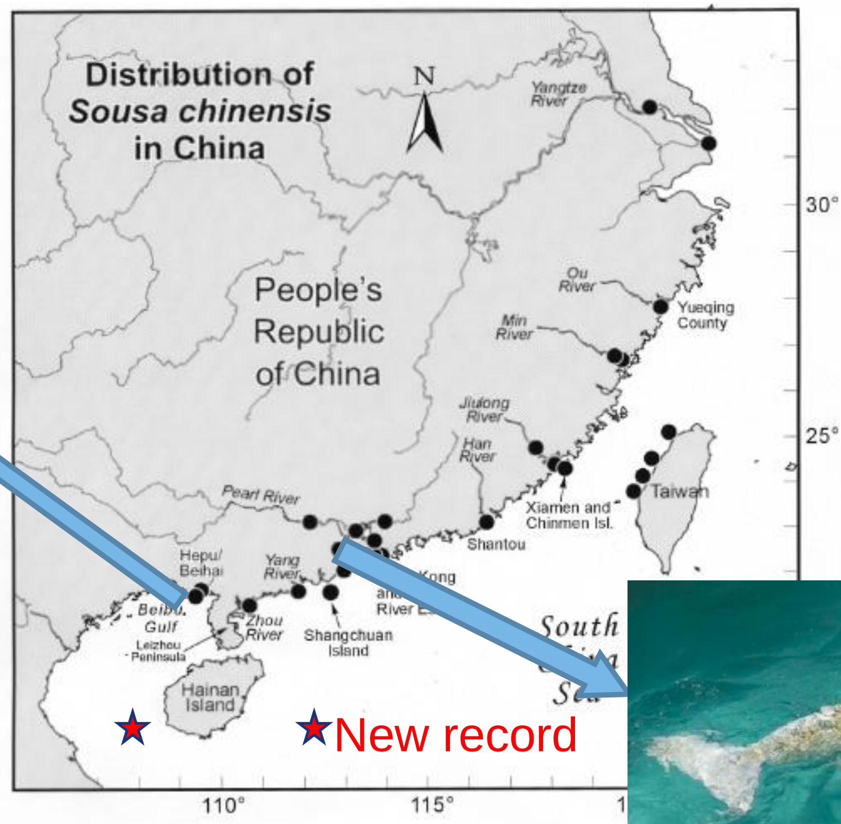
Case study on Indo-Pacific humpback dolphins

Hearing of IPHD

13 years old（Young dolphin）



Li *et al*., 2012, 2013

Figure 1. Reliable records of occurrence of *Sousa chinensis* in Chin
from Jefferson (2000).

Jefferson and Hung., 2004


About 40 years old（Old dolphin）

- **Hearing of two stranded IPHD were measured**
  - **One young dolphin from Sanniang Bay;**
  - **One old dolphin from Pearl River Estuary.**

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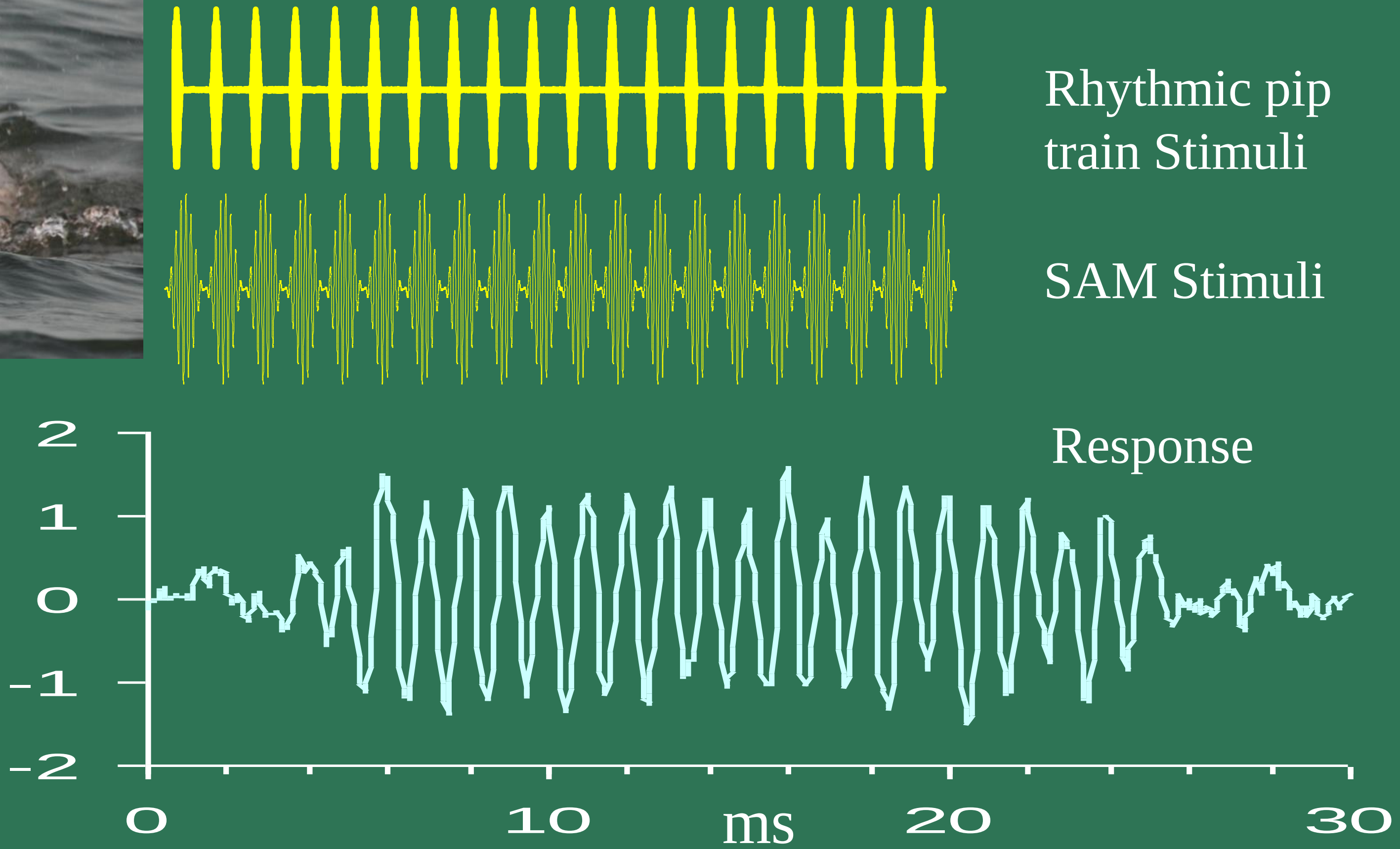
Experimental protocol



Odontocete ABR envelope following response to the Rhythmic pip trains/Sinusoidal Amplitude Modulation (SAM) stimuli



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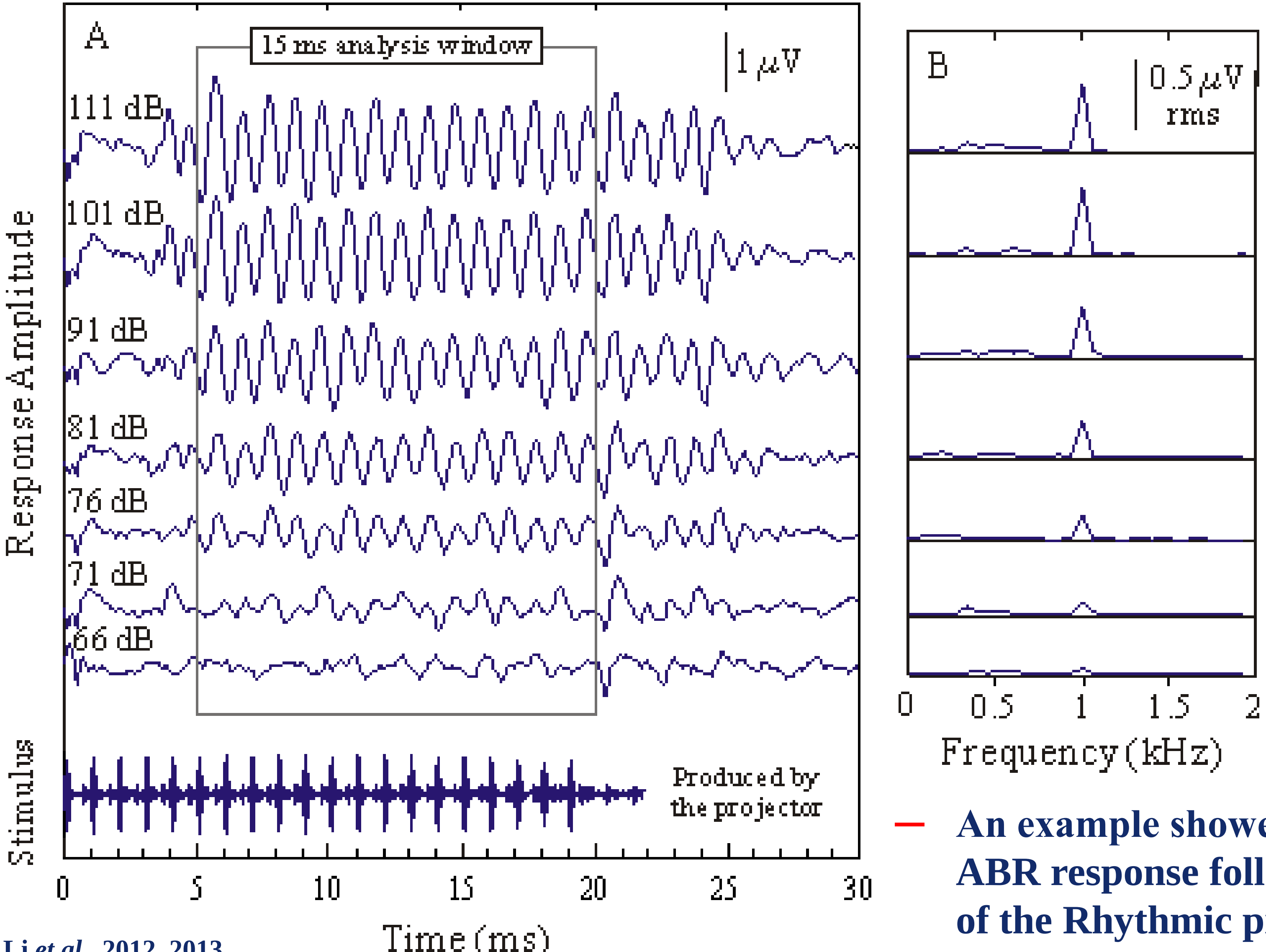

- An example showed the animal's ABR response followed the envelope of the Rhythmic pip train

Li *et al.*, 2012, 2013



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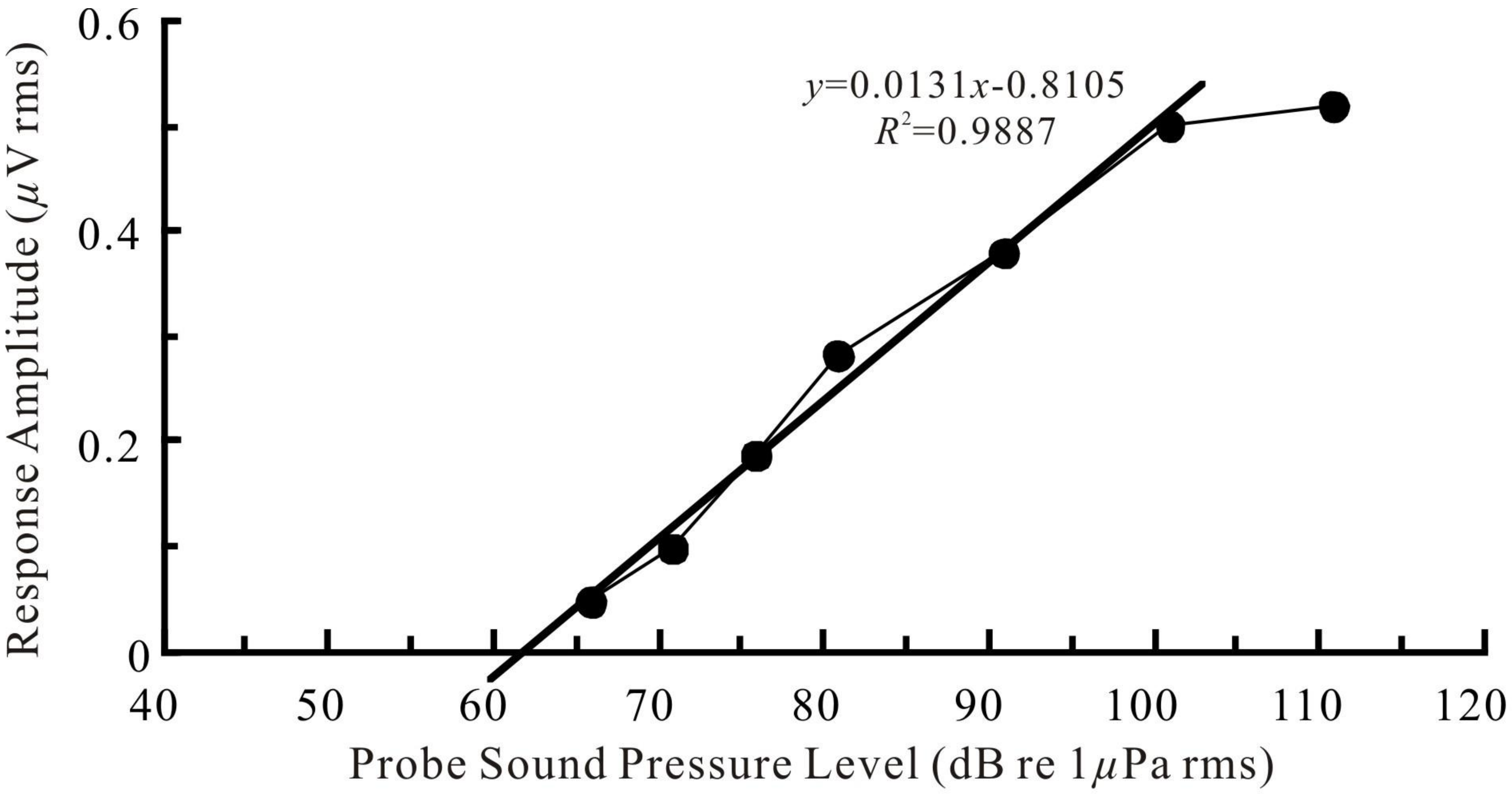

The intersection of the regression line with the zero crossing point of the response input-output function was defined as a threshold estimate

<u>Li *et al.*, 2012, 2013</u>



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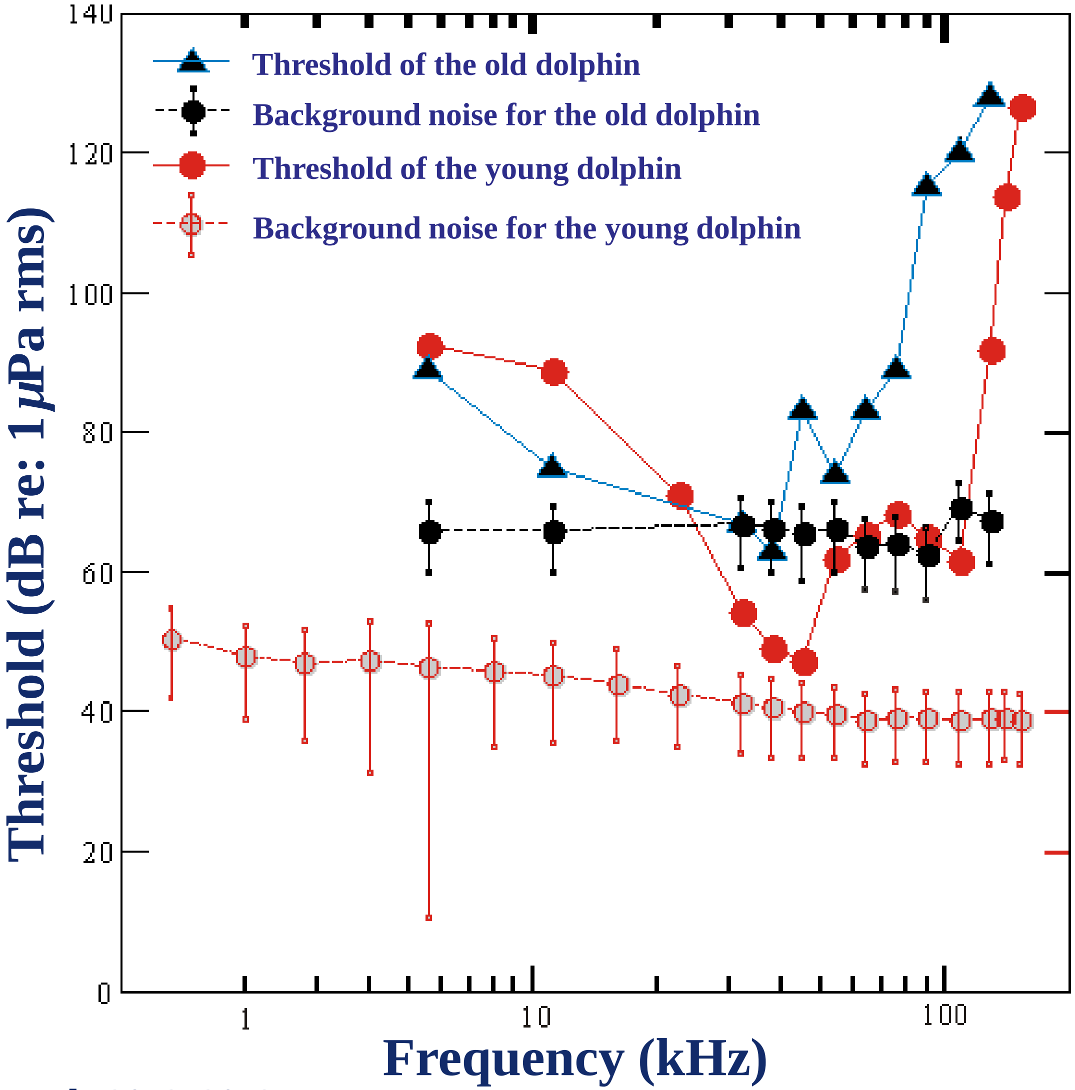

Li et al., 2012, 2013

- U-shape audiograms
- Similar to those of other odontocete species
- the hearing sensitive frequency range of the IPHD is higher than 5 kHz and lower than 120 kHz, with possible age-related hearing loss in old dolphin
- The old dolphin seemed to demonstrate a high-frequency hearing loss relative to the young dolphin

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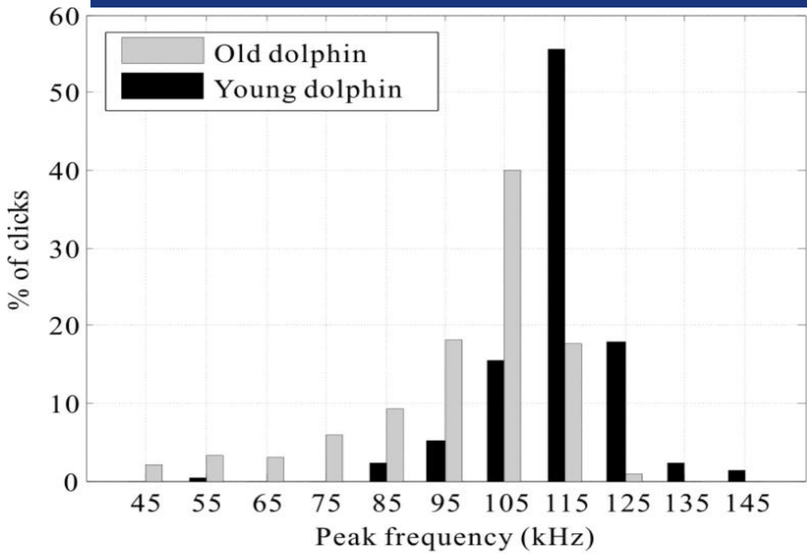

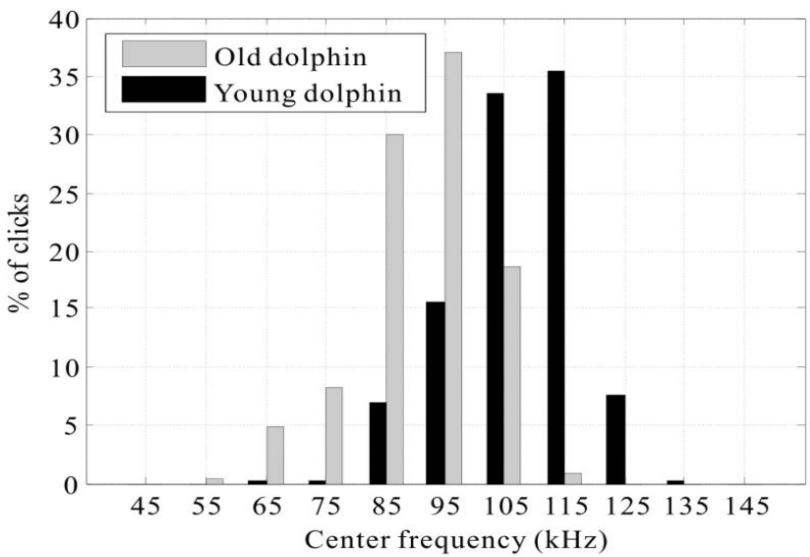

- **Histograms of the peak frequency and center frequency of all the measured clicks for both the old and young dolphins.**
  - **Both the peak frequency and center frequency for the old dolphin were lower than those for the young dolphin;**
  - **Suggest that the old dolphin tended to shift the spectral content of its echolocation clicks downwards to where the animal's hearing is more sensitive to partially compensate for its high-frequency hearing loss.**

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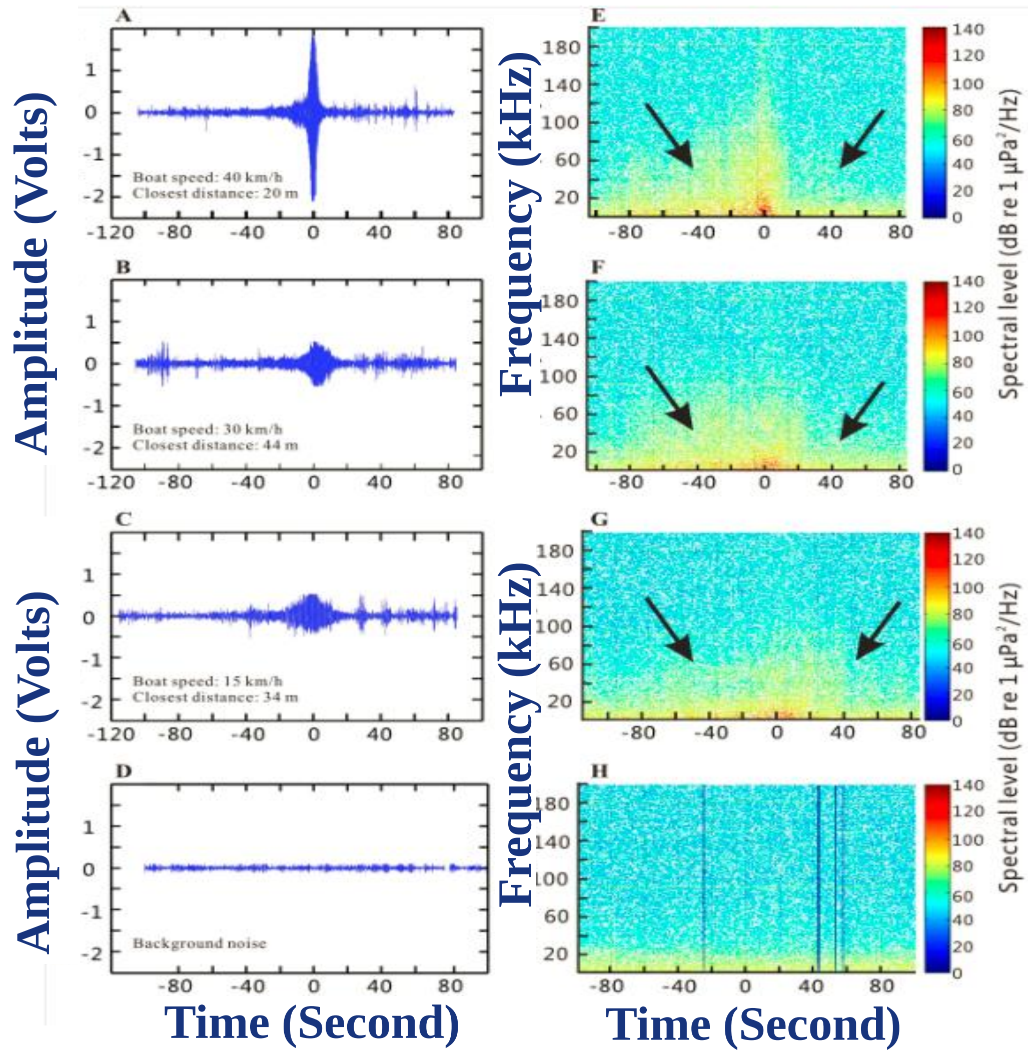
Case study on Indo-Pacific humpback dolphins

<u>Typical noise in IPHD habitats</u>

- Only a few researchers have investigated underwater noise in relation to protecting IPHD <u>(Würsig & Greene, 2002; Sims et al., 2012a; Li et al., 2015)</u>
- Loud sounds from vessels significantly affect the IPHD habitat <u>(Würsig & Greene, 2002; Sims et al., 2012a)</u>
- Broadband noise characteristics of small high-speed boats, commercial ships and underwater constructure in IPHD habitat were investigated only in recent years



<u>Li et al., 2015</u>

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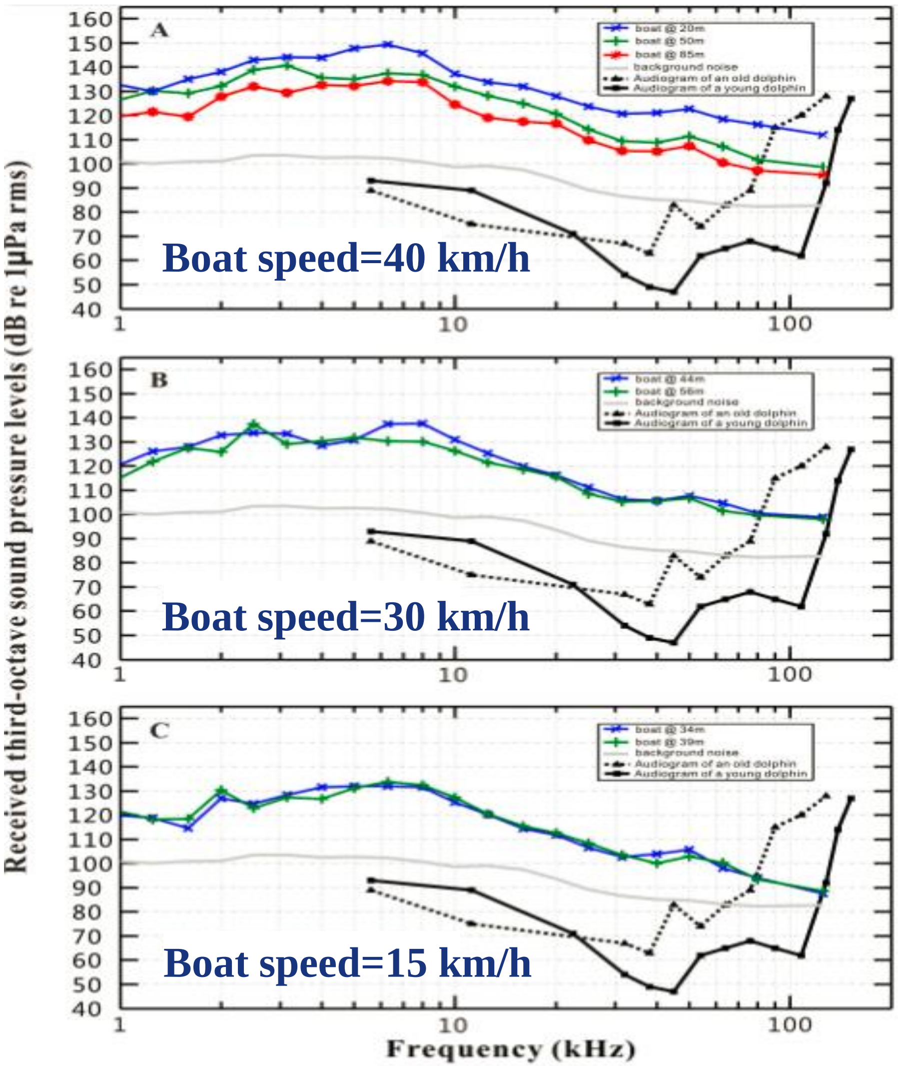
Case study on Indo-Pacific humpback dolphins

Typical noise in IPHD habitats



- The noise from the high-speed boats raised the ambient noise level from ~5 to 47 decibels across frequency bands ranging from 1 to 125 kHz at a distance of 20 to 85 m, with louder levels recorded at higher speeds and closer distances
- The noise produced by the high-speed boat can be heard by IPHD in most of their hearing sensitive frequency range

Li et al., 2015

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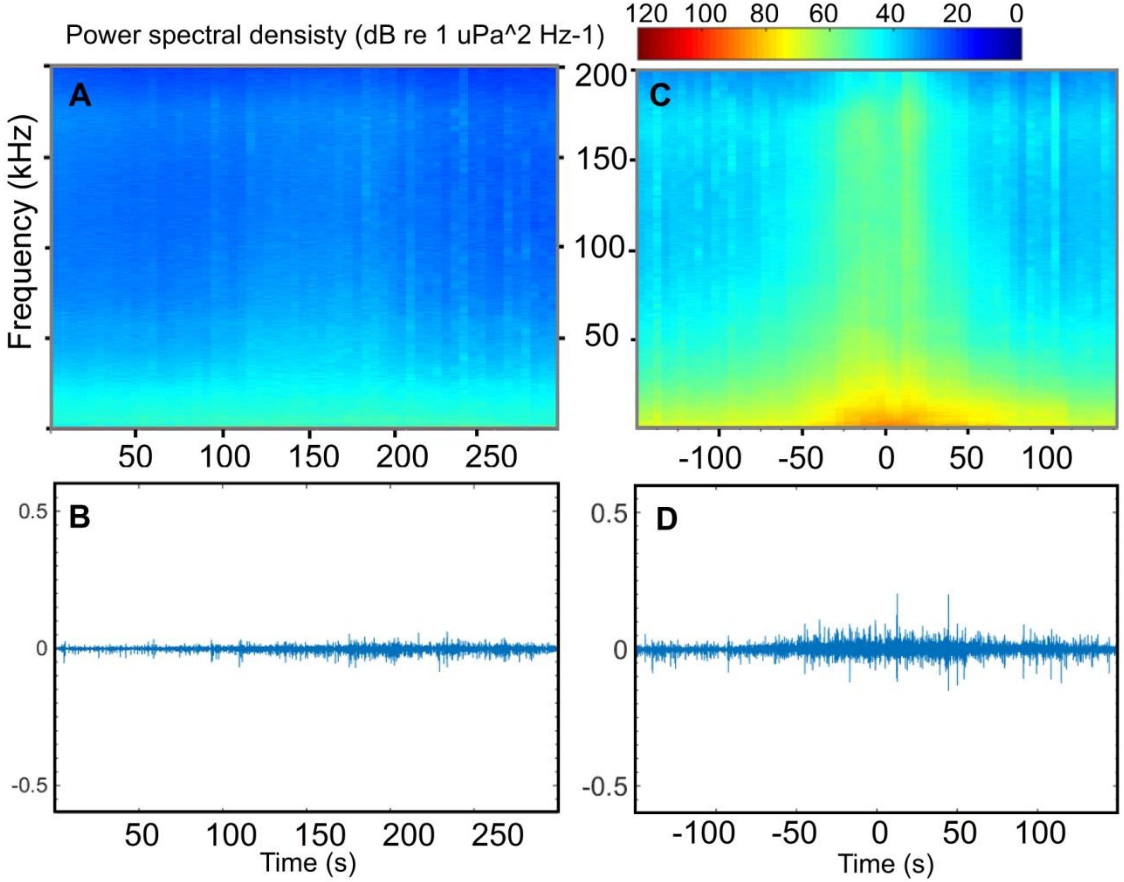

– Commercial ships produce noise comprised of mid-to-high-frequency components with frequencies > 100 kHz

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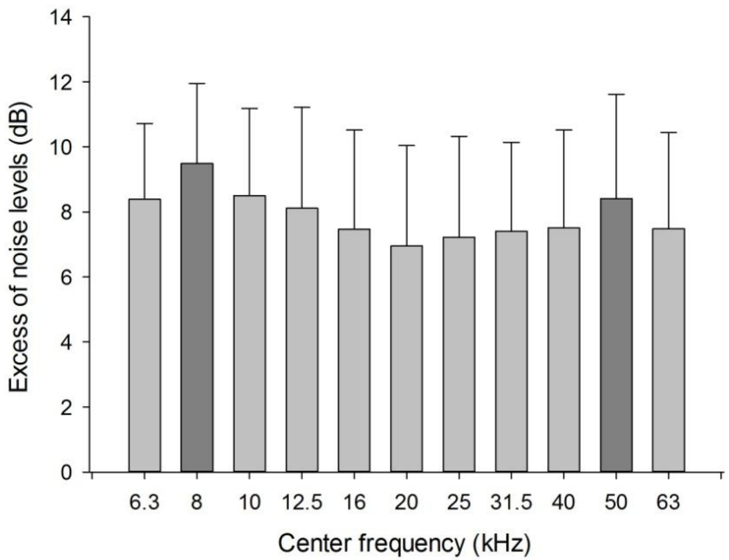

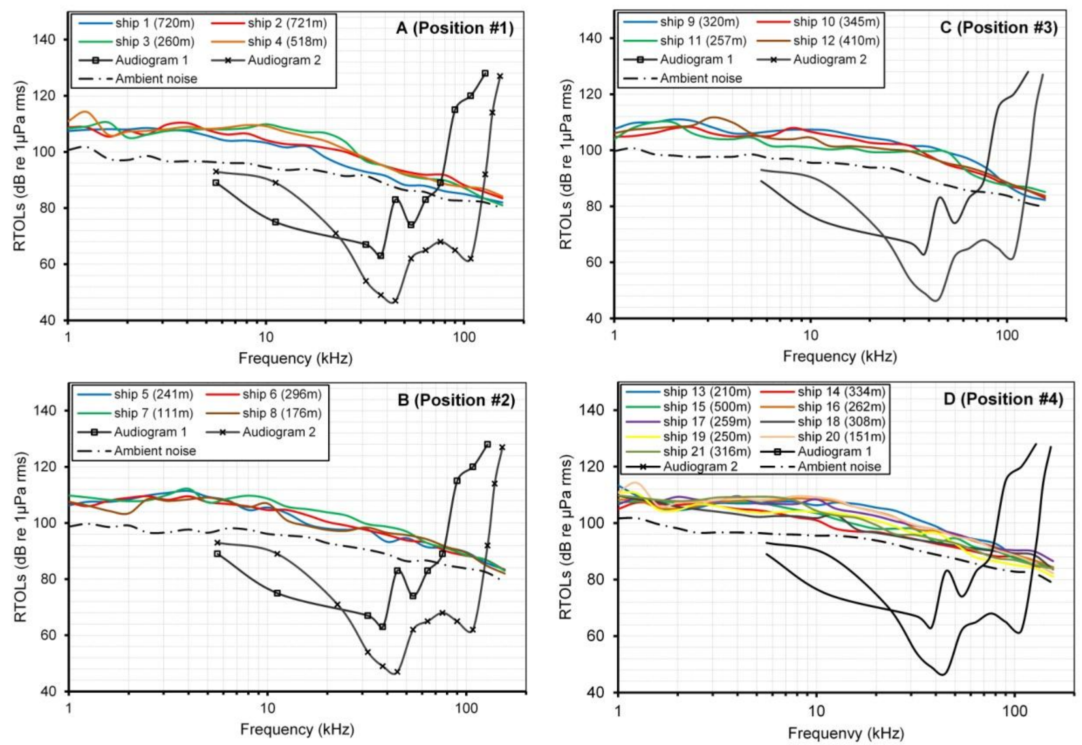

- The noise from commercial ships can be sensed by the hearing system of IPHDs within most of their sensitive frequency range
- Noise from commercial ships in the third-octave band with a center frequency value of 8 and 50 kHz was estimated to be able to be sensed by the dolphins at distances of approximately 2,000 and 1,000 m, respectively

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Potential Impacts

The investigated noise generally raises the ambient noise level and is audible to Indo-Pacific humpback dolphins in a broadband frequency range. It may interfere with IPHDs in various ways, including

– **Hearing masking**
  - **Both the communication and echolocation systems of humpback dolphins could be masked by various shipping noises at distances of 1,000 m** (Li et al. 2015)
  - **Noise from small high-speed boats at a close distance would likely mask echoes of the dolphin target at target distances of 10–20 m** (Li et al. 2015)

– **Temporary or permanent damage to the auditory system**
  - **No TTS data exist for the Indo-Pacific humpback dolphin**
  - **TTS onset was assumed in mid-frequency cetaceans when the animals were exposed to single or multiple pulses with sound exposure levels (SELs) > 183 dB re: 1 µPa2 s and nonpulses with SELs > 195 dB re: 1 µPa2 s** (Southall et al. 2007)

– **Altering behavior**

– **Habitat avoidance or death**

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Regulation and Mitigation Implications

– **Modify sound sources to reduce overall noise levels**
- **Equipped with quieter engines**
- **changing shipping routes**
- **reducing ship speed**

– **Set marine protected areas (MPAs) in Indo-Pacific humpback dolphin habitats, within which shipping activities would be restricted**
- **Few identified "hot spots" of the Indo-Pacific humpback dolphin have been managed as MPAs in Chinese waters**
- **More "hot spots" of this animal need to be identified, to determine the location of more suitable MPAs**

– **Seasonal and geographical restrictions to avoid ensonification of shipping noise to the humpback dolphins and their habitats**

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Future research focus

While man-made noise is increasingly recognized as a significant and pervasive pollutant with the potential to have adverse effects on Indo-Pacific humpback dolphins, relevant researches are rather scarce

- Baseline ecological research needs to be undertaken to identify more "hot spots"
- Long-term, systematic research should be performed to gain in-depth information on sound production and hearing capabilities at the population level, as well as the behavior and stress hormone levels
- Research should be carried out to develop effective passive acoustic monitoring methods to monitor various underwater noises and background ambient noise at large space and time scales, and with more human activities
- The stranding network of the Indo-Pacific humpback dolphin should be established and expanded to its entire distribution range



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Marine Mammals

↓ Bioacoustics ↕

↓ Ecology ↕

↓ Evolution and Conservation ↕

Conservation of marine mammals and their habitats



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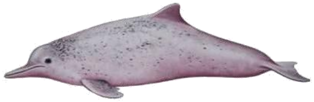



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Our research team and facilities

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The 4th Program of China-ASEAN Academy on Ocean Law and Governance

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