IDENTIFICATION OF ORCINUS ORCA BY UNDERWATER ACOUSTICS IN DABOB BAY

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Abstract

Acoustic vocalizations were recorded from a pod of Orcinus orca under uncontrolled conditions in Dabob Bay, Washington. The animals were not contained, controlled or prompted. This recording was made of wild resident Orcas while they were actively vocalizing in the vicinity of a permanent hydrophone array. The acquisition system is a permanently moored array of omni-phones used by the Naval Undersea Warfare Center Division, Keyport for acquiring and analyzing torpedo and ship radiated noise. Ecology of the Dabob Bay area and information about the acquisition system is included. Orca vocalization and specific examples comparing known vocalizations to the recordings are described. The acoustic output was compared to acoustic vocalizations and compared well with the j-pod known to reside in the Puget Sound area.

I. Introduction

The objective of this paper is to document a winter sighting of Orcinus orca. This occurred in the same area as a government acoustic acquisition equipment combined with winter sighting. Tape recording was made and combined with earlier observation. What follows is a description of the recorded sounds and background documentation. This paper follows the premise that Orcinus orca can be identified through acoustic characterization from work by Dr. John K. B. Ford who has studied these Orcas in the wild using observation and acoustic monitoring over many years.

II. Dabob Bay Habitat

This fjord like area was carved out of bedrock by glaciers 20,000 years ago leaving behind glacial till and clay amongst volcanic rock. As the glaciers receded sediment was deposited. While the walls of the fjord remain hard rock the bottom of the 600 foot deep bay is covered in 30 feet (9.15 m) of mud.[1]

Dabob Bay is an inland waterway connected to the Pacific Ocean by way of the Strait of Juan de Fuca, Admiralty Inlet and Hood Canal. The distance from Dabob Bay to open ocean is a voyage of more than 120 miles (139 nm). Off Dabob Bay is Quilcene Bay which is home to oyster production, light industry, some farming and community and small marina. The waterway is exposed to tidal swings exceeding 15 feet at maximum tide. The weather in the area is moderated by the temperature moderation of the presence of the Hood Canal and Puget Sound as well as by the Olympic mountains to the west topped by Mt. Olympus 7,965 feet (2428.4 m)) and the Cascade mountain range including Mt. Rainier (14,410 feet (4393.3 m)) to the east.

Major rivers into the bay include the Big Quilcene, Little Quilcene and the Dosewallips. Eight major salmon streams and many small streams support fish stocks. Wild runs and a mix of hatchery and wild as wells as runs from other areas are caught in the area. Anadromous members of the Pacific salmon family (Salmonidae) found here include chum salmon (Oncorhynchus keta), coho salmon (Oncorhynchus kisutch); pink salmon (Oncorhynchus gorbuscha) and chinook (Oncorhynchus tshawytscha). Baitfish in Hood Canal consist of Pacific herring (Clupea harengus), surf smelt (Hypomesus pretiosus) and candlefish (Ammodytes hexterus)[2] there are also several kinds of groundfish and shellfish.

Commercial and recreational harvest prohibitions or restrictions have been enacted in the Hood Canal. By 1992 the status of wild coho salmon was a concern and a sharp reduction imposed on ocean fisheries and in 1994 wild coho salmon returned to Quilcene Bay and Hood Canal streams in healthy numbers. Pink salmon stock for the Dosewallips River have fallen since 1960s. Herring stocks are stable. Three counties bordering Hood Canal are the fastest growing in the state. Bulkheads and seawalls diminish marine life habitat interrupting normal migration patterns for juvenile salmon.

The area is home to Harbor seals (Phoca vitulina), River Otters (Lutra canadensis) Dalls' porpoise (Phocoenoides dalli), Gulls (Larus sp.), Murrelets (Synthliboramphus sp.) Great Blue herons (Ardea herodias), Belted King fishers (Ceryle alcyon) , Osprey (Pandion haliaetus), Cormorant (Phalacrocorax sp.) and Bald eagles (Haliaeetus leucocephalus)[3].

A 25% increase has occurred in the harbor seal population. Putting the seal population in Hood Canal at 1500-2000. This fact and an increase in California sea lion population increase fecal coliform problems. Haul out areas have been moved to allow shell fisheries to recover. Several Bald Eagle nests have failed apparently due to PCB. The location of the source is unknown and under study.

III. Regulations

Orcas are protected in the USA by the Marine Mammal Protection Act and in Canada by the Fisheries Act of 1970. Permits have been let for the capture of Orcas in US and Canada to groups for display, education and science. The orca is not protected by the Endangered Species Act but by the Marine Mammal Protection Act (MMPA) of 1972 as amended in 1994 and International treaties and the National Environmental Policy Act (NEPA) (1969) with regard to the effect of noise on marine mammals. The MMPA focuses attention on effects of man made noise on marine mammals. Noise related disturbance is considered at least harassment.

IV. Acoustics

A. Environmental Acoustics

The acoustics in this environment are reverberant. Much of the multipath is contributed by the surface and probably the sides. The mud bottom is absorptive.

The sound velocity profile varies throughout the year. It is a semi enclosed bay with limited water circulation. There is a shallow water stratification due to salinity in the winter resulting in upbending in the top layer and a very gradual down bending below. During the summer a strong warm surface layer provides a distinct surface channel. Each fall the water turns over and pockets of warmer less saline water is trapped under a fast surface layer. Transmission loss for Dabob is calculated as

15 log R + 8.7 plus the absorption factor.

Absorption is a function of frequency.

B. Acquisition System

The acquisition system was Bottom Moored Array (BMA) and used by the Naval Undersea Warfare Center Division, Keyport. BMA is permanently moored approximately 2000 yards (1.8 km) from shore located at coordinates 47° 43' 42 " N / 122° 50' 22" W . Data are relayed via cable to the computer site on the eastern bluff of Dabob Bay. The assembly is positioned vertically with shore-controlled winch deployment for range operations, maintenance or stowage. The array is stowed with the center hydrophone at 450 feet (137.2m).The upper and lower hydrophones are spaced vertically 60 and 40 feet (18.3 m and 12.2 m) respectively. The purpose of the BMA is to provide shore based measurement of radiated noise of torpedoes, targets ships and submarines. The three omni directional hydrophones are manufactured by High Tech Incorporated. The hydrophones are calibrated periodically and for normal acquisition a calibration is run along with preoperation ambient noise for later correction and analysis. Analog data are recorded on a one-inch Honeywell 1101 magnetic tape recorder. BMA is provided with autogains which keep data from clipping if the transient ramps up in level.

C. Orca Transmit and Receive Mechanics

Whale eyesight is good but visibility is low and sound underwater travels farther and faster than in air. Sounds are used for communication, echo location and navigation. Echo location sonar is for navigation and detecting obstacles.

Air is forced through structure in the nasal passage beneath the blowhole to produce sound. The melon or forehead is used to focus the high frequency signal. The density of the melon increases gradually from the core through the outer shell and eventually approximates the density of the surrounding water interface (1.03 g/cm^3). Sound transmission in air is highly attenuated because the air medium and the substance of the melon result in a large impedance mismatch. On the other hand it provides a perfect impedance match which ensures that all the acoustic energy will go into the water. Peak spectra of vocalizations correlate with hearing ranges. Audiograms are available for different species show the frequency at

which different species are sensitive or able to hear sounds[4].

Sound is received through the lower jaw. The signal is then conducted to the middle ear. They have special adaptations of the external and middle ear to compensate for rapid dive, deep and long term submersion[5]. These include decoupling of the ear from the skull, specialized soft tissue in the head or middle ear, enlarged inner ear aqueducts and broad Eustachian tubes. The external structure is missing and there is no external ear opening. Sound energy is transported by mechanical transduction to the middle and inner ear parts. They have an air filled middle ear and a similar inner ear parts as a human. The exception is Odontocete inner ears are adapted for ultrasonic perception with narrow basilar membranes and extensive laminae. The middle and inner ear turn these into electrical signals/neural impulses that provide the brain with a view of the world.

The types of frequencies which are expected from Orcas are both low and high frequency. Low frequency is described as a fundamental between 250 and 1500 Hz with harmonics to 10 kHz or more. The high frequency fundamental is from 5 to 12 kHz with harmonics to greater than 100 kHz[6]

Low frequency clicks of beluga and Pseudorca echolocation signals have been associated with low amplitude and high frequency clicks with high amplitude signals. The peak frequency may be dependent on the source level frequency. The spectrum of the echolocation signals of Odontocetes may be directly related to signal amplitude[7]

V. Review of Physical Characteristics and Historic Behavior Patterns

Orcinus orca belong to the marine mammal order Cetacea. They belong in the Odontocete family which are toothed including toothed whales and dolphins. Although it is called "killer whale" the orca is the largest dolphin. At birth, calves are about 8 feet (2.4 m). The adult male grows to 27 ft. (8.2 m) and the female reaches an average of 23 ft. (7 m) (maximum 28 ft. (8.5 m)). They are stocky, with a round head, a tall, triangular dorsal fin, and abnormally large flippers, which sometimes grow to 20 percent of body length. They are black above, with a sharply defined white underside. In adults, teeth may be almost 5 inches long (12.7 cm), curving inward and back. The teeth also interlock when the jaws close. A white spot is above the eye. Usually there is a saddle patch behind the dorsal fin. Distinctive coloring, loud breathing and gregarious behavior make them easy to identify in the wild. Orcas are referred to as a is a top level carnivore of the marine ecosystem with a diet that varies regionally or with the pod[8] They primarily eat fish or other cetaceans, pinnipeds and seabirds. Feeding activities depend on group coordination earning them the title "Wolves of the Sea". They are reported to feed on Cod (Gadius sp.), mackerel, striped dolphin, flatfish, Baird's beaked whale (Berardius baindii) sardine, bonito, Harbor seal, salmon, squid & octopus (cephalopods), tuna and Dalls' porpoise[9],[10].

Orcas are found around the globe. including populations described as resident, transient and offshore. These are distinguished by their habitat, forage preference and acoustic dialect. Transient dialect is distinctive from any of the resident pod dialects. It consists of approximately four different calls instead of up to 17 different calls in the resident pods. All transients recorded off the Washington British Columbia coast have the same dialect. They may not have developed sounds depicting lineage. Offshores are highly vocal. Activities include foraging, traveling, resting and socializing. Flipper slaps and breaching are also ways of making noise. Transients forage in silence listening from sounds made by marine mammals, hunting in groups and sharing the meal vocalizing when they are killing or eating prey. Whistles, burst pulse signals constitute discrete calls and a learned dialect. Each pod has a distinct dialect and pods with related dialects are grouped as a clan. As pods grow and split apart dialects diverge[11].

Orcas in this area were not historically the target of commercial whaling. Some were taken incidentally to harvesting of other species. 68 Orcas were removed from the coastal waters of British Columbia and Washington between 1962 and 1977.

Studies of Orcas have been conducted in the coastal waters off British Columbia and Washington State since the early 70's. The two distinct communities of Orcas in this area have been noted for not leaving or gaining new individuals from other communities. Groups congregate in the Johnstone and Haro Straits and were counted annually from July - September from 1973 to 1987. Individuals have

been identified by saddle patch, dorsal fin shape and character of scars and indentations. Pods from each community have also been observed during other times of the year. Pods from the northern and southern communities were rarely sighted in the range of each other.

Residents eat fish and their movement coincides with fish abundance. Transients eat marine mammals and it is not certain what the main diet of Offshores is. The resident Orcas do not migrate great distances but their life is seasonal. Calving occurs between fall and spring with mating occurs May through October. Pods are made up of grandmothers and their offspring and the offspring of the daughters. A generation to an orca is approximately 25 years maturing at about 15 years. The populations are comprised of overlapping generations and there is no evidence of individuals leaving their maternal pods[12].

Matrilineal groups of the resident Orcas include from three to 9 whales of mother and offspring or grandmother and generations of offspring. They are found together all the time and remain next to each other. A subpod is made of several matrilineal groups which travel together and share dialects. A pod is described as up to five subpods (usually ten - 20 whales) traveling together. Some subpods split off and have been observed alone. Multiple pods congregating are described as a clan. The members of the clan have similar dialects and may have common ancestors. Pods that have been seen together once are described as a community. Ranges of clans may overlap. Two resident communities exist separately in coastal waters of British Columbia and Washington. The northern community ranges from the mid Vancouver Island to Southeast Alaska and the southern community ranges from southern Vancouver Island to Puget Sound.[13]

VI. Observations and Recordings

A. Observations

On 19 December 1995 a pod of Orcas entered Dabob Bay. Observers watched the whales feed and interacting. Not much sound was detected above ambient. Whales were observed throughout the day. The group stayed together most of the day moving from one area to another, feeding, resting but not vocalizing a great deal. They were observed feeding in a cooperative manner and resting. Sometimes several males lined up shoulder to shoulder moving in the same direction at a steady slow pace coming up to breathe synchronously. At other times all the individuals would gather at the mouth of Quilcene Bay and alternately surface not moving far from each other with infrequent vocalizations. At approximately 0500 on 20 December the vocalizing began continuously and a tape was made. No observations of behavior were possible at this time due to darkness. By dawn the vocalization had subsided. The Orcas progressed southward out of the bay.

B. Recordings

Ambient and background noise was below 250 Hz and generally did not interfere with the signal to noise ratio of the orca vocalizations. The vocalizations can be described in three groups. High whistles (6-8 kHz), tonals with frequency modulated sweeps including grunts, zips and snorts and third crackle popping of short duration and relatively low frequency. The higher tones are directional and used for communication while the last form is used for navigation[14,15].

Ship noise such as propulsion and other machinery noise generated by naval vessels in the area did not significantly increase the background noise level above 1 kHz. Ambient and background noise were below 250 Hz and did not interfere with orca vocalizations. Characteristics of whale calls included transients, short broad band zip, narrow band frequency sweeps, snorting or grunting. Calls often had reverberation due to multipath propagation effects. They produced staccato snap pop click trains (200 clicks/sec) almost continually for navigation and identification of objects and other whales. Repetition rates are thought to increase as objects get closer. Whistles were up to one and a half to two seconds long. Calls contain frequency shifts and frequency modulated sweeps. These have distinctive qualities and were easily recognized above ambient noise.

One whale would emit a call and others would respond with the same call followed by a different call or by some variation on the call. Many individuals were vocalizing at the same time and responding to each other. Calls were overlapping. One did not wait to start the call before the first one was finished. The same call sometimes varied by increasing duration or change in pitch.

Whistling was between 8 and 10 kHz. Some tones would star at 2 kHz with harmonics up beyond 10 kHz. Low frequency "zip" would start below 100 Hz with multiple harmonics followed by multiple repetitions of higher frequency variable "washa" sound.

VII. Conclusions and Recommendations

The tape was sent to John K. B. Ford at the Vancouver aquarium and the group was instantly identified as the j-pod. A comparison was made to previously recorded j-pod tones as well as vocalizations from other pods most of the signature calls were present and similar enough to the sample of individual sound clips for a positive identification. A cursory check was made of other resident and transient pods but it became obvious that the j-pod matched these vocalizations.

The recording provides further evidence of the use of signature calls among Orcas. Information of the pattern and character of their calls and a wintering location for this specific group is an important data point. In addition to being able to characterize the pod we were able to record the acoustic interaction between individuals.

There was no attempt to correlate sound production with behavior or signal levels. Actual sound levels from individuals were not determined for several reasons (1) the animals were not tracked tagged either visually (it was dark) or tagged. (2) The hydrophones were not spatially distributed for triangulation on a specific tone.

The use of passive seafloor arrays to track and monitor calls of whales are better than other methods such as radio tracking or visual observation. Seafloor arrays are unobtrusive. Acquisition systems of opportunity can be available 24 hours each day and in any weather. Ships or aircraft as observing platforms may interfere with whale behavior. A stealth recording can help scientists determine what "normal" behavior is. Few animals outside of several families of birds have been shown to modify their vocal repertoire based upon the sounds they hear. Will increase in marine noise cause Orcas modify their vocal repertoire?
Often studies have been limited to toothed whales and dolphins in captivity as a basis for information of effects of noise on marine mammals. Behavioral and acoustic output may vary in the wild. Calls of the ranging marine mammals provide a fuller more representative repertoire than can be documented with captive animals[16]. Recommend a hearing study be conducted on free ranging Orcas as was done with gray whales (Eschrichtus robustus)[17].

VIII. Related Reading

Altes, Richard A. (1980)" Detection, estimation and classification with spectrograms" JASA 67(4):1232-1246

Au, Whitlow W. The Sonar of Dolphins, publisher Springer Verlag

Au, W.W.L., R.W. Floyd, RH Penner and AE Murchison (1974) "Measurement of echolocation" JASA 56:1280

Buck and Tyak (1993) "A quantitative tech...compare and classify humpback sounds..."Ethology 77:89-102

Dahlheim, M. E., F. Awbry (1982) A classification and comparison of vocalizations of captive orcas (Orcinus orca) J. Acoust. Soc. Am. 72:661-670

Fristrup, Kurt, M, and William Watkins (1994) Marine animal sound classifications" Tech Report Woods Hole WHOI-94-13

Mellinger & Weisburn et al (1994) "Measuring... whale calls...autocorrelation" JASA 95(5):2881(A)

Stafford Kathleen M. (1995) Characterization of Blue Whale calls for the NE Pacific and Development of a Matched Filter to Locate Blue Whales on US Navy SOSUS (Sound Surveillance System) Arrays. Masters Thesis, Oregon State University, Corvallis OR

Whitehead, Hal and Linda Weilgart (1990)" Click rates from Sperm Whales" JASA 87(4):1798-1806

M. A. McDonald, J. A. Hildebrand, & S. C. Webb(August 1995) "Blue and fin whales observed on a seafloor array in the Northeast Pacific", SCRIPPS J. Acoust. Soc. Am. 98(2), Pt1 p 712-20

Acknowledgement

I'd like to thank Mr. Stan Howell,
Dr. John K. B. Ford and Dr. Marilyn Dahlheim, for their time and insight in support of this project.

References

[1] Terich, T. (1987)"Living at the Shore of Puget Sound and the Georgia Strait" 161 pp.

[2] Hood Canal Coordinating Council Technical Working Group, (1995) "Shellfish and Finfish, Resources at Risk in the Hood Canal Watershed, June

[3] McConnaughey, B. and E. McConnaughey,(1985) "The Audubon Society nature guides. Pacific Coast", 633 pp.

[4] Richardson, W. J., C. Greene, Jr., C. Malme, D. Thomson (1995) "Marine Mammals and Noise", 576 pp.

[5] Ketten, D. (12-13 Dec 1995) "Marine Mammal Auditory Anatomy, Frequency Correlates, and Hearing Loss" presented in ASA Marine Mammal Bioacoustics Short Course,

[6] Bain, D. and M. Dahlheim "Effects of Masking Noise on Detection Thresholds of Orcas" pp. 243-256 Marine Mammals and the Exxon Valdez, Academic Press

[7] Au, W., J. L. Pawloski, P. E. Nachtigall, M. Blonz, R. C. Gisiner "Echolocation signals and transmission beam pattern of a false killer whale (Pseudorca crassidens)"

[8] Yano, K. and M. E. Dahlheim, (1995) "Killer whale, Orcinus orca, depredation on longline catches of bottomfish in the southeastern Bering Sea and adjacent waters" Fishery Bulletin 93:355-372

[9] Yano, K. and M. E. Dahlheim (1995) "Killer whale, Orcinus orca, depredation on longline catches of bottomfish in the southeastern Bering Sea and adjacent waters", Fishery Bulletin 93:355-372

[10] Leatherwood, J. S. and M. E. Dahlheim "World wide distribution of pilot whales and killer whales" Naval Ocean Systems Center, Tech. Report 4431-39

[11] John K. B. Ford, Graeme M. Ellis, Kenneth Balcomb (1994) " Killer Whales" 102 pp.

[12] Olesiuk, P., M, Bigg and G, Ellis "Life History and Population Dynamics of Resident Killer Whales (Orcinus orca) in the Coastal Waters of British Columbia and Washington State" SC/A88/ID3 from the REP. INT. WHAL. COMMN (SPECIAL ISSUE 12) pp. 209-243

[13] John K. B. Ford, Graeme M. Ellis, Kenneth Balcomb, (1994) " Killer Whales" 102 pp.

[14] John K. B. Ford, Graeme M. Ellis, Kenneth Balcomb, (1994)" Killer Whales" 102 pp.

[15] Dahlheim, M. E. and D. K. Ljungblad "Preliminary Hearing Study on Gray Whales (Eschrichtus robustus) in the Field" p.335-346 of Sensory Abilities of Cetaceans edited by J. Thomas and R. Kastelein, Plenum Press, NY 1990 in Baja California Sur, Mexico. Laguna San Ignacio

[16] John K. B. Ford, Graeme M. Ellis, Kenneth Balcomb " Killer Whales" 1994 102 pp.

[17] Dahlheim, M. E. and D. K. Ljungblad "Preliminary Hearing Study on Gray Whales (Eschrichtus robustus) in the Field" p.335-346 of Sensory Abilities of Cetaceans edited by J. Thomas and R. Kastelein, Plenum Press, NY 1990 in Baja California Sur, Mexico. Laguna San Ignacio