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Research on the vocal culture of *Orcinus orca* in the Loro Parque, Tenerife: a pilot study

TESI DI LAUREA IN:
Evoluzione ed Adattamenti dei Vertebrati Marini

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1. Introduction

1.1 Origin and Evolution

Many people have study the evolution of animals. Darwin is the best example of this. A lot of studies on evolution are based on two basic principles:

1- Anatomical evidence:

- Homologous structures

These types of structures derive from the same ancestor and the same embryonic development. But now they can have different function (Fig. 1.1).

- Analogous structures

Analogous structures derive from different ancestors and have different shapes, but the same function (Fig. 1.1).

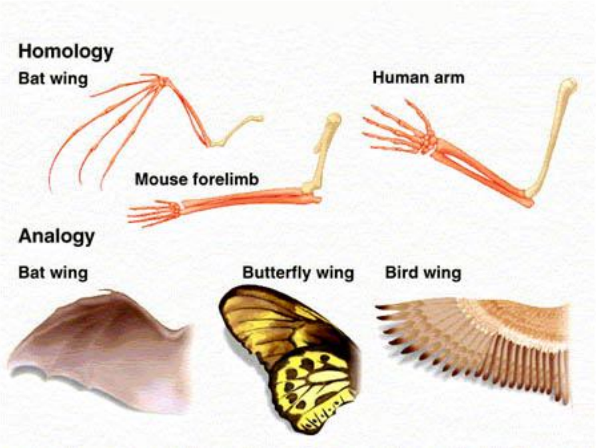

Fig. 1.1 Homology and analogy

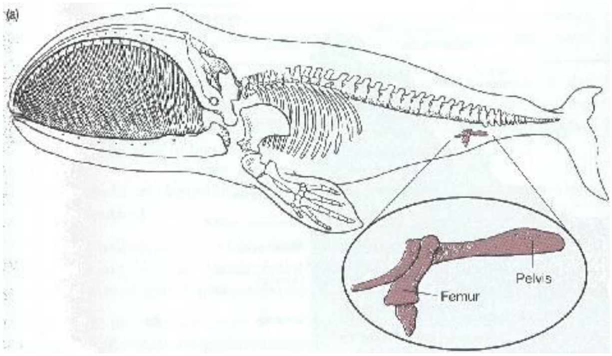

Fig. 1.2 Example of a vestigial structure

- Vestigial structures

These are anatomical structures that are present without any function, or with a limited one (Fig. 1.2). Often they are residual structures such as the human sacrum that presumably was once a tail, like the one of the current primates.

2- Biochemical and molecular evidence:

- Same basis molecules

The DNA is made of a long sequence of smaller units embedded together. There are four basic types of unit: adenine, thymine, guanine, and cytosine. They are normally identified with the initial letter. A, T, G, and C. These molecules are the same for all living beings on the earth.

- Same DNA triplets

The sequence of the four basis molecules encodes instructions. Some parts of our DNA are genes that carry the instructions to make proteins (which are long chains of amino acids). These encoding parts of DNA are based on triplets: sets of three basis molecules that can be specific for an amino acid, or can trigger the end of protein synthesis. These triplets are named codons, and exist in every living being on the earth (Fig. 1.3).

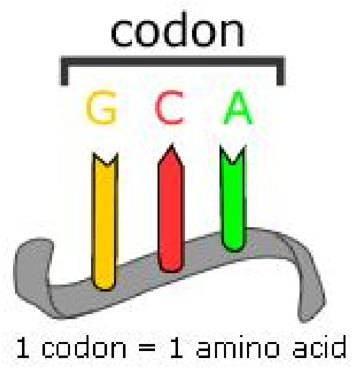

Fig. 1.3 Triplet of nitrogenous bases

- Same 20 amino acids

In all the creatures in the world we can found the same 20 amino acids that are the base to make proteins.

ORIGIN OF MAMMALS

Studies on fossils demonstrate that mammals appeared for the first time on the earth, more or less, 245 million years ago (end of Triassic) (Fig. 1.4).

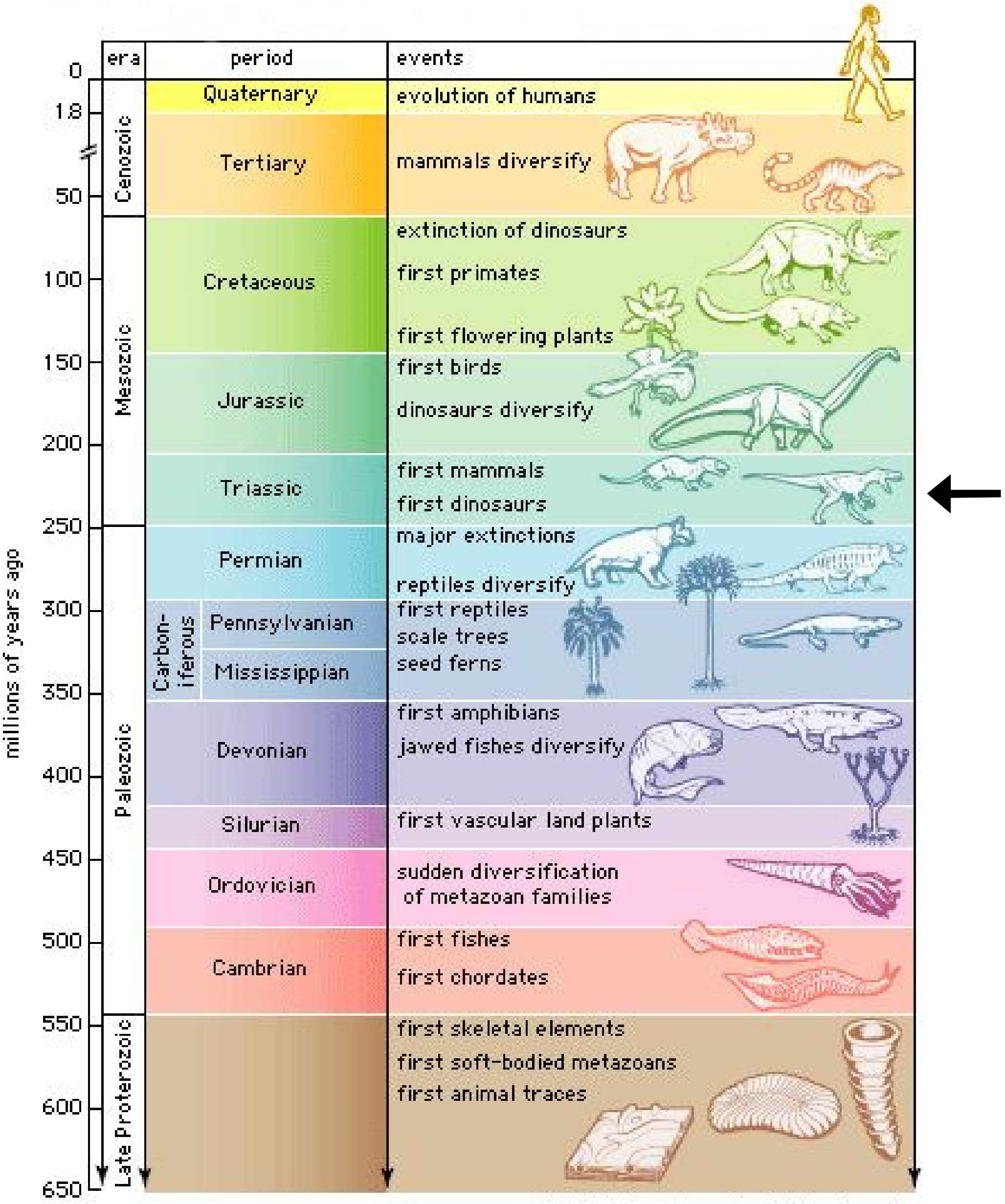

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Fig. 1.4 Geologic time scale, 650 million years ago to the present

They already had the typical characteristics of mammals:

- Udder
- Position of arts
- Size of brain

- Structure and position of teeth
- Complex physiology

Mammals are divided into 3 classes:

- Monotremata (Ornithorhynchidae and Tachyglossidae). They are oviparous mammals
- Marsupials (Macropodidae (Kangaroo), Didelphidae (Opossum) etc…). They protect the little puppies in their addominal pouch.
- Placentalia (Human, Horse, Dolphin etc..). They are the most abundant and possess the placenta which nourishes the embryo in the early stages of its development.

At the beginning they were adapted to night life and to live on insects. Mammals had to defend themselves against large predators, dinosaurs. 65 million years ago, when dinosaurs disappeared, mammals started to increase their number and their species. They started to differentiate themselves from each other, very quickly. In about 10 million years, 4'500 species of mammals can be found. Most of these animals will colonize the terrestrial enviroment. Some will colonize other environments: the sky (for examples: bats) or the sea (for examples: the marine mammals).

Adaptation to aquatic life brought back some animals to the "cradle of life". According to Stanley Miller's theory, indeed, life was originated from the "primordial ooze": that is the primordial conditions of the aquatic environment.

Animals adapted to aquatic life can be divided into two groups: Carnivores and Ungulates. The first group seems to have evolutionary origin in common with the current terrestrial predators: tigers, bears, lions. The second group, probably, has ancestor in common with pigs and hippos, animals that have hooves (that is the meaning of the name Ungulates).

1 Carnivores:
    - Polar Bears
    - Sea Otters
    - Pinnipeds

2 Ungulates:

  - Sirenia
  - Cetaceans

Among these families, marine mammals are Pinnipeds, Sirenia and Cetaceans. Despite their different evolutionary origin, these animals had to develop similar characteristics in order to live in this environment, such as:

- A thick layer of subcutaneous fat that allows them to maintain a constant body temperature.
- The transformation of limbs in fins that allows swimming.
- Resistance to pressure changes allowing diving at various depths.
- Resistance to low concentrations of oxygen that enables long apnoeas.
- The development of a sophisticated echolocation system (biosonar), that allows animals to avoid obstacles or predators.

ORIGIN OF CETACEA

Many parts of the evolutionary reconstruction of Cetaceans are not yet clear. The more that a species is specialized the more is difficult to find its ancestor and marine mammals have experienced great transformation. Despite this, most researchers are inclined to say that their ancestor was a terrestrial animal.

Natural selection favours individuals who have developed morphological and physiological changes that allow them to better adapt to their host environment. For this reason, we can assume that higher specialized animals and less specialized animals lived at the same time. This would also explain the finding of fossils belonging to more modern forms, but dating to geological periods older than others (Würtz and Repetto, 1998).

Studies on the fossil record reveal that the earliest ancestor of cetaceans were Mesonychidae: predatory animals characterized by a large skull with powerful jaws equipped with teeth: incisors, well developed canines, cusped molars. About 55 million years ago, by this group the first cetaceans were originated: the Archaeocete (Fig. 1.5).

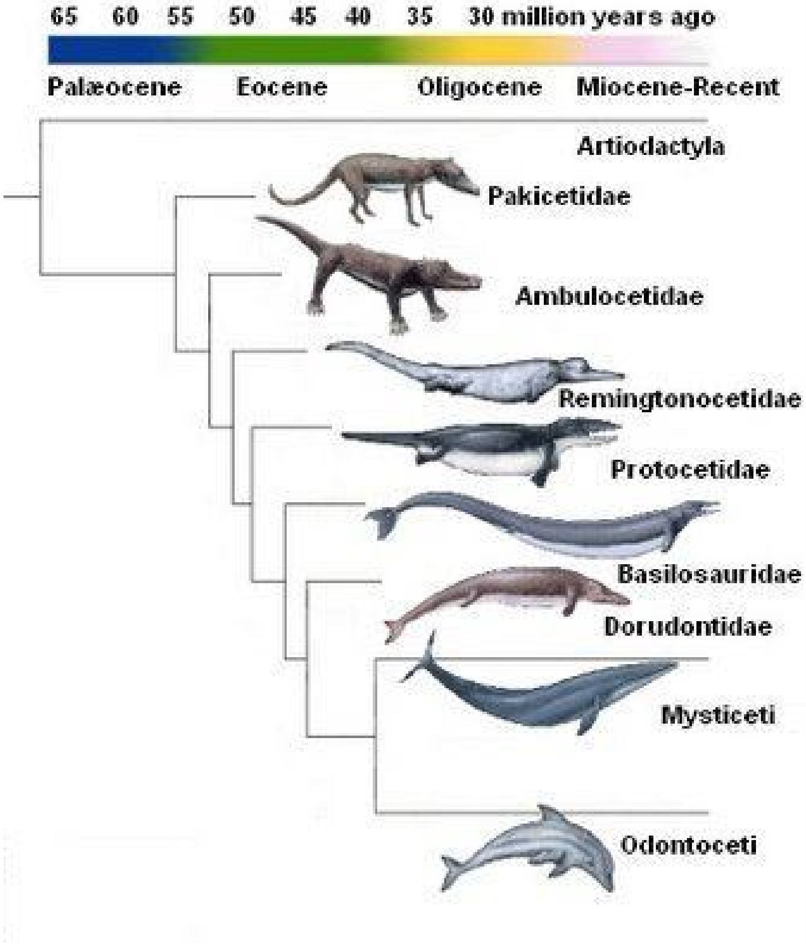


Fig. 1.5 Different shape of Archaeocetes

Pakicetidae: mainly related to terrestrial life except for the characteristics of the ear which already allowed the perception of sound in water (Gingerich and Russell 1990; Thewissen and Hussain 1993).

Ambulocatidae: more similar to current seals and otters for their way of swimming (Thewissen et al. 1994).

Remingtonocetidae: the long and narrow morphology of the jaw, suggests the beginning of a diet consisting of fast aquatic prey; and the middle ear appeared large and adapted for the reception of sound in water (Thewissen and Bajpai 1998)-

Protocetidae: characterized by the reduction of the hind limbs (Thewissen et al. 1996; Uhen 1998; Hulbert et al. 1998)

Basilosauridae: further reduction of the hind limbs (Gingerich and Uhen 1996)

Durodontidae: similar to small dolphins and ecologically distinct from the previous

Mysticeti and Odontoceti: are the two suborder of the order Catacea, which evolved at the same time starting from 25/30 million years ago. The existing Cetacea are, unlike pinnipeds, fully aquatic and have no link with the mainland.

The two suborders: Mysticeti and Odontoceti are identified depending on the presence or the absence of teeth. If they have teeth, can eat the same food: fish or teutofuga, and they are Odontoceti; if they are without teeth, but with corneal structure (dewlap), that allow them to eat plankton. In this case they are Mysticeti.

1.2 The two Cetacea suborders:

Suborder: *Mysticeti*

These Cetaceans have ballen, that are horny plates structure within the mouth, used to filter water in search of food. These mammals have a breather with two orifices, used to breath, and a skull with bilateral symmetry. They have a large or very large size, and are divided in 3 families: Eschrichtiidae; Balaenidae; Balaenopteridae (Fig. 1.6).

***Family**: Eschrichtiidae*

Eschrichtius robustus

***Family**: Balaenidae*

Eubalaena

***Family**:Balaenopteridae*

Megaptera novagliae

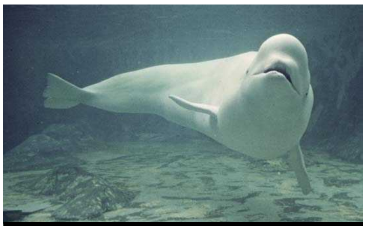
Balaenoptera physalus

Fig. 1.6 pictures of Mysticeti

Suborder: *Odontoceti* (from the Latin: toothed whales)

These Cetaceans haven’t ballen, but own teeth. They are characterized by a breather with a single orifice and an asymmetrical skull. They can have many different sizes, and are divided in various families: Monodontidae, Ziphiidae; Physeteridae; Iniidae; Phocenidae; Platanistidae and Delphinidae. To the last family belongs the species of Orcinus orca (Fig. 1.7).

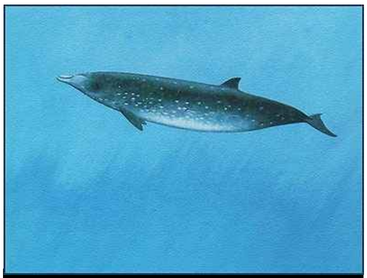
***Family**: Monodontidae*



Delphinapterus leucas

Monodon monoceros

***Family**: Ziphiidae*



Mesoplodon densirostris

Ziphius cavirostris

Fig. 1.7 Pictures of Odontoceti (1)

Family: *Physeteridae*

Physeter macrocephalus

Kogia previceps

Family: *Iniidae*

Family: *Phocoenidae*

Inia geoffrensis

Neophocaena phocaenoides

Family: *Platanistidae*

Orcaella brevirostris

Platanista gangetica

Fig. 1.7 Pictures of Odontoceti (2)

***Family**: Delphinidae*

Stenella coeruleoalba

Delphinus delphis

Grampus griseus

Tursiops truncatus

Orcinus orca

Fig. 1.7 Pictures of Odontoceti (3)

2. Orcinus orca

O. Orcas, or Killer Whales, are marine mammals. They are warm-blooded, air breathing, and bear their calves alive. Killer whales are the largest members of the Delphinid family, and ones of the most powerful predators in the oceans. The name Orcas comes from the latin Orcus: for the Romans it was the god of infernal regions. The Romans took this name from the Greek όρυξ, that generally meant whales or ocean’s monsters.

Orcas can be found in all the oceans throughout the world. They are mainly studied in the costal water of North Pacific Ocean, near British Columbian, Californian and Alaskan coasts. In these studies it is possible to find the description of three groups of killer whales, colloquially known as Transient, Resident and Offshore, discovered in recent years (Ford et al. 2000). The groups differ in coloration, morphological traits, association patterns and diet (Baird et al. 1992).

In the Antarctic waters other three different types of killer whales have been identified, named A, B and C (Pitman and Ensor 2003). These ones differ in morphology, colour and diet from each other (Perrin 2008). They also present an apparent lack of interbreeding, which is confirmed by genetic studies; however, a relatively low level of sequence divergence indicates that these evolutionary changes have occurred recently and in a relatively rapid way (LeDuc et al. 2008). Pitman et al. (2007) with photogrammetry confirmed that the small ice-dwelling fish-eating form (type C) has a modal length of about 5-5.5 m, much smaller than more offshore whales. However, further studies are necessary to ascertain whether these small whales deserve recognition as a separate species or subspecies (Ford 2009).

2.1 Scientific Classification

Domain: Eukaryota
Kingdom: Animalia
Phylum: Cordata
Class: Mammalia
Order: Cetacea
Suborder: Odontoceti
Family: Delphinidae
Genus: Orcinus
Specie: *O. orca*

Scientific name: *Orcinus orca* (Linnaeus, 1758)

Synonyms: *Orcinus glacialis*; *Orcinus nanus*

2.2 Sizes and morphology

Males of killer whales can reach 9.8 metres of length and 9’000-10’000Kg of weight, females are smaller: about 4-8 meters of length and 6’500-7’500Kg of weight. Calves at birth are about 2.4 metres long and their weight is about 150Kg (Fig.2.1).

Fig. 2.1 Size comparison

Their pectoral fins are large and rounded. The dorsal fin is different in males and females. Males have a bigger straight dorsal fin that can reach 2meters of height, and often bends under the heavy weight. Females have a hooked or sickle-shape dorsal fin that can average be about 1meter of height, so usually it doesn’t bend (Fig. 2.2).

While swimming they can reach a speed of 55Km/h, this is the maximum speed that a marine mammal can reach.

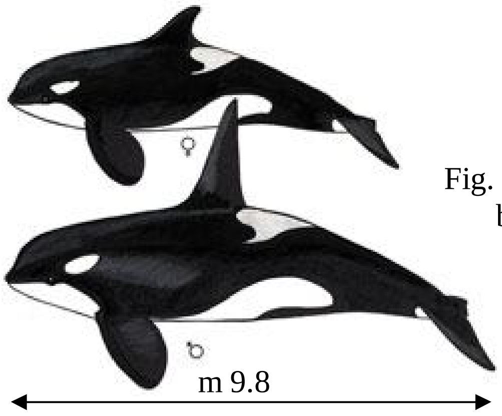


Fig. 2.2 Shape differences between the sexes

They have a large mouth with the lower jaw slightly shorter than the upper. Both the jaws contain from 10 to 13 pairs of powerful, interlocking conical teeth (Fig. 2.3). Usually they have a total of about 40-56 teeth, with a length of about 13 centimetres, and the number of the rings within them may indicate how old an individual is, only in case they are more than 30 years it becomes difficult to distinguish new rings. The teeth are used to grip and tear preys, but not to chew them (Gots and Ronald 2009).

Fig. 2.3 Killer whales' teeth

2.3 Colour

Killer whales bodies have distinctive black and white markings. They have a shining black colour above the body. The white belly extends forward to the end of the lower jaw, and upwards on each side where it forms a large, oblong white area (Gots and

Ronald 2009). Behind the eyes they have an oblong white area, and on the back, behind the dorsal fin, a grey zone with a "saddle" shape.

On the lower abdomen, male killer whales have a distinctive, elongated, almost hourglass-shaped white patch, with a single black central spot overlying a retractable penis. Females have a white genital patch that is stubbier and more oval, with a horizontal row of three smaller black spots, highlighting a central vaginal opening, surrounded by a pair of mammary slits (Gots and Ronald 2009) (Fig. 2.4).

Male ***Female***

Fig. 2.4 Genital organs

2.4 Social structure

Killer whales are social mammals that live in highly complex social systems (Norris 2002). They live in groups called "pods". Every pod is a matriarchal group, with an adult female with her children. The group can be as large as 50 animals, but usually the number varies from 5 to 20 individuals. Members of a pod can disperse each other during the foraging for food, but don't remain separated for more than a couple of hours. They maintain the group together using the acoustic exchange. Each studied pod has a slightly different acoustic repertoire or dialect, which facilitates pod integrity. A pod can remain together for life, and is typically composed of 20% adult males, 20% juveniles and calves and 60% of female and immature males (Gots and Ronald 2009) . When an adult female of the pod, has her owns child, can swim separated from her own group, but normally, not so far away. When a mother overlives her sons, she can go swimming with her Daughters and grandchildres.

Several killer whales pods can form clans. This is possible when they share the same ancestors and have the same pulsed call signals (Yurk et al. 2002).

In the North Pacific, different groups of killer whale have different behaviours, for examples:

Resident killer whales tend to travel along predictable routes, and don't change direction abruptly except in pursuit of preys. They have a regular diving pattern of about 3-4 15-second diving, followed by a longer 3-4-minute diving (Gots and Ronald 2009).

Transient killer whales normally enter small bays not visited by the residents. They often change direction suddenly, and during the diving, they often remain underwater for more than 5 minutes; occasionally more than 15 minutes (Gots and Ronald 2009).

The behaviour of riding the waves has been reported for killer whales (Dahlheim 1980). During a study in the northern gulf of Mexico, there were orcas riding the bow and quarter waves of the survey ship; once there were more than 10 individuals riding the bow wave in a chorus-like fashion (O'Sullivan and Mullin 1997).

In general killer whales make the same activities of other delphinids: breaching; jumping; spy-hopping; tail-lobbing. Aerial displays can be more commonly seen during socializing episodes (Gots and Ronald 2009).

2.5 Growth and Reproduction

Females of *O. orca* start reproducing before males. Normally they become sexually mature at the age of about 11/13 years; although in a controlled environment they usually reach the sexual maturity before.

The youngest killer whale known to have given birth was 8 years old.

Some studies demonstrate that females are polyestrus and cycle independent from one another (Duffield et al. 1995).

In nature females near to sexual maturity may stay with an adult female that has just had a calf. This is to learn what she will have to do in future. A female of killer whale can normally give birth 4-6 times in her reproductive life (about 25 years). The pregnancy rate is of about 1 calf every 8 years. But it can occur to have an interval of only three years between two pregnancies. Birth are usually single, though there are two records of twin births. The gestation period is of about 17 months, with successful pregnancies ranging from 16 to 18 month (Duffield et al. 1995). After the birth calves are supposed to remain dependent from their mother for approximately 1 or 2 years. When a female has her last offspring, often at a age not older than 40 years, it is supposed to live other 20 years. Like in every marine mammals if a female doesn't recognise her calf, or if the calf dies after few days of life, she becomes ready to have another baby immediately. In nature, if a calf isn't recognised by his/her mother, it will die. After a few years, especially if a young sibling is born, calves don't stay with their mother any more, but with a non-breeding female or "aunt", which is usually a close associate of their mother.

Matings take presumably place quickly between partners from different pods. But, males stay with their own pod, making paternity difficult to trace (Knudtson 1996).

Males reach the sexual maturity at about 14 years of age.

The average size of males at sexual maturity ranges from 5.2 to 6.2 m (Christensen 1984), while females become sexually mature between a length of 4.6 to 5.4 m (Perrin and Reilly 1984).

In British Columbia and Washington State, males start maturing at about 14 years of age, but don't reach the full size until when they are about 20 years old (Gots and Ronald 2009).

Another important thing is that when a male reaches the sexual maturity, also the dorsal fin grows and becomes more straight on. The dorsal fin loses the curve that characterises young males.

Calves are about 2.4 meters long with a weight of approximately 180 kilograms at the birth. Births normally occur in Autumn or Spring.

2.6 Some physiological characteristics

When they go underwater, dive time is usually less than 5 minutes. The maximum time recorded was 15 minutes in British Columbia, for a killer whale in a transient pod. The maximum depth of dive is unknown. In British Columbia killer whales' prey is usually found in the top 100m of water, so they do not have to dive deeply (Ford et al. 1994).

The core body temperature is about 36.4ºC.

The brain of an adult killer whale is the focal point of the Central Nervous System, and can weigh up to 6Kg (Gots and Ronald 2009).

SENSE ORGANS

(http://www.seaworld.org/animal-info/info-books/killer-whale/senses.htm)
(http://www.whalesbc.com/orca_killer_whales.html)

EYESIGHT

All the Delphinids have surprisingly good vision. Killer whales, given the position of the eyes, likely possess binocular vision, at least in a downward position (Knudtson 1996). Like other delphinids, killer whales have well-developed eyesight both above and below the water.

Glands at the inner corners of the eye sockets secrete oily, jellylike mucus that lubricates the eyes, washes away debris, and probably helps streamline the eyes as an orca swims. This tear like film may also protect the eyes from infective organisms.

DNA from several other species of toothed whales indicates that their eyes do not develop pigment cells called "S-cones," which are sensitive to blue light. As a result researchers theorize that all modern cetaceans, including killer whales, lack these visual pigments and therefore aren't able to discriminate colour in the blue wavelengths. Their colour vision is thought to be comparable to the ones of colourblind people.

There are some studies at SeaWorld about the discrimination among similar objects by killer whales. For example, if the task was to match an object to another and the *O. orca* was given two possible choices, the *O. orca* chose the right matching object with 92%

accuracy, and when three choices were presented the killer whale's accuracy was about 82%. Researchers did not determine whether the whale was responding to shape, size, or colour. Future studies may provide more detailed information on the visual abilities of killer whales.

TACTILE

O. orcas are known to be sensitive to touch. Anatomical studies and observations of behaviour indicate that killer whale’s sense of touch is well developed. The skin is rich with nerve endings, in particular around the eyes, face, snout and blowhole, as well as in the area of the male and female genital openings.

TASTE

Little is known about killer whales’ sense of taste. They have taste buds, although they haven’t been well studied. In zoological parks, killer whales show strong preferences for specific food fishes. It is also known that *O. orcas* rely on sensors on the tongue to detect certain chemicals dissolved in sea water (possibly providing information on location, prey, another individual, etc.).

SMELL

Olfactory lobes of the brain and olfactory nerves are absent in all toothed whales, indicating that they have no sense of smell. A sense of smell would go largely unused in killer whales, that are air-breathing mammals that spend the majority of time underwater.

HEARING

Killer whales have a well-developed, acute sense of hearing. They are sensitive to a wide range of frequencies between 0.5 and 100 kHz. Recent studies on younger killer whales discovered that them could hear sounds at frequencies as high as 100 kHz, but anyway the greatest sensitivity is at about 15 kHz.

The toothed whales have small external ear openings. Some scientists believe that killer whales receive sound through these openings; other scientists believe these to be non-functional. Foam surrounds the ear bone on all sides. This foam contains air. Air stops sound waves travelling through water and living tissues. Many scientists believe that this foam acoustically isolates the ears; enabling a killer whale to tell which direction a sound comes from.

In toothed whales, ears aren’t attached to the skull. Ligaments hold each ear in a foam-filled cavity outside the skull. These auditory nerve fibres tend to be large in diameter, enabling them to transmit signals more rapidly in the killer whale nervous system than in the human one. So other scientist believe that this separation of the ears allows a killer whale to localize sound (important for echolocation).

Most sound reception probably takes place through the lower jaw. The fat-filled lower jawbone appears to conduct sound waves through the jaw to bones in the middle ears. The lower jawbone of toothed whales broadens and is hollow at the base, where it hinges with the skull. Within this very thin hollow bone there is a fat deposit that extends itself back toward the auditory ear bone complex. Sounds are received and conducted through the lower jaw to the middle ear, and then to hearing centers in the brain through the auditory nerve.

2.7 Food and Feeding

In a controlled environment a typical adult male of killer whale eats about 79kg of herring a day, while adult females eat 63kg. Newly-weaned calves eat 16kg daily.

In the wild they spend up to 60% of their time searching to get food. It is clear that wild killer whales consume more energy than the once in captivity, so they need to eat more.

Killer whales are known to feed on a wide array of prey, including most marine mammal species (except river dolphins and manatees), seabirds, sea turtles, many species of fish (including sharks and rays) and cephalopods (Dahlheim and Heyning 1999; Ford and Ellis 1999; Ford 2002).

Some subpopulations are specialized on particular types of prey (Bigg et al. 1990). Local subpopulations can exhibit remarkable specialisations with respect to their food preferences.

RESIDENTS

The northeastern Pacific resident population is salmon-specialized and has a strong preference for one species, the chinook salmon (*Oncorhynchus tshawytscha)* (Ford and Ellis 2006). These salmon-eating killer whales show seasonal movements synchronised to their main prey.

TRANSIENTS

Transients in coastal waters of the northeastern Pacific appear to focus their foraging on pinnipeds and small cetaceans and occasionally take baleen whales. These mammal-eating live more or less in the same area of the residents , without undergoing seasonal because their main prey, harbour seals (*Phoca vitulina*), harbour porpoises (*Phocoena phocoena*) and Dall's porpoises (*Phocoenoides dalli*) are present year round. These transient whales have never been observed to eat any species of fish (Ford et al. 1998).

In the eastern Aleutian Islands, Alaska, the diet of transient killer whales in spring was primarily grey whales (*Eschrichtius robustus*) and in summer primarily northern fur seals (*Callorhinus ursinus*). Steller sea lions (*Eumetopias jubatus*) did not appear to be a preferred prey or major prey item during spring and summer (Matkin et al. 2007).

In the Gulf of Alaska, transient killer whales feed on Steller sea lions (Maniscalco et al. 2007).

OFFSHORES

The Offshores are seldom encountered in the inshore waters of Washington and British Columbia and seem to prey on fish, including halibuts and sharks (Ford 2009). Chemical tracers show that offshores consume prey species that are different from those of sympatric resident and transient killer whales. These offshores forage as far south as California (Krahn et al. 2007).

ANTARTIC Type A; B; C

In Antarctic, type "C" killer whale population profiles of individual chemical tracers are consistent with a fish diet (Krahn et al. 2008). While type "B" killer whales feed on pinnipeds in loose pack-ice, the larger type "A" killer whales are open water marine mammal hunters specialized on minke whales (*Balaenoptera bonaerensis*) (Pitman and Ensor 2003).

NORWAY and STRAIT OF GIBRALTAR

Killer whales in coastal Norway are specialized on herring (Similä et al. 1996).

In the Strait of Gibraltar, killer whales prey on migrating bluefin tuna (*Thunnus thynnus*) between February and November. Their diet in other months is completely unknown (Reeves and Notarbartolo di Sciara 2006).

ZEW ZELAND

Some killer whales in New Zealand may forage selectively on rays and other elasmobranchs (Visser 1999). They were found to capturing and eating thresher (*Alopias vulpinus*) and smooth-hammer-head (*Sphyrna zygaena*) sharks; ten species of elasmobranchs are now recorded as prey for this population (Visser 2005).

There are also evidences (remains in some liller whales' stomach) that *O. orcas* prey on marine turtles, specifically the olive ridley turtle, *Lepidochelys olivacea* (Esquivel et al. 1993); and the leatherback turtle, *Dermochelys coriacea* (Caldwell and Caldwell 1969; Sarti et al. 1994).

The pursuit of prey is a group effort. They hunt in deadly pods (Fig. 2.5). Every pod uses effective cooperative hunting techniques similar to the behaviour of wolf packs.

Fig. 2.5 Pod of Orcas

They have a great diversity of foraging tactics, also depending from the prey they want to attack. The tactics include intentional beaching to gain access to seals onshore; orl ramming ice floes from beneath to break the ice and make the prey spill into the water.

TACTICS:

Sea Lions

Argentine killer whales gather in February in front of the beaches where sea lions breed puppies, to hunt the still inexperienced ones. The hunting technique generally consists in the cooperation of at least two animals. One who swims on the sea surface not far from the coast and another swimming underwater from the opposite direction towards the beach. Pups closer to the sea are easily unable to escape. The *O. orca* is beaching intentionally to catch its prey (usually a pup swimming in the shallows) and then using the tail movements, to go back safely into the sea, with any captured puppies (Fig. 2.6). It is calculated that killer whales catch a sea lion one out of three times they slide onto the beach (Gots and Ronald 2009).

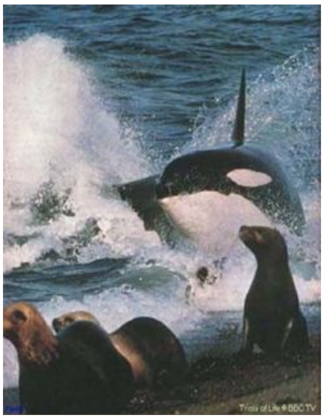

Trials of Life ® BBC TV

Fig. 2.6 Beaching to hunt


Fig. 2.7 Hunting Sea Lions

Killer whales can kill adult sea lions with considerable effort and caution, since they are tough and dangerous prey. One after another, the killer whales charge the sea lion. The attack can continue for one or two hours until the sea lion is barely conscious (Fig. 2.7). Then it is drowned and eaten.

Baleen whales

Killer whales will attack also larger whales without hesitation (Fig. 2.8). Probably they hunt on calves on their first migration from low-latitude breeding and calving areas to high-latitude feeding grounds. Their results imply that adult baleen whales are not an important prey source for killer whales in high latitudes. (Mehta et al. 2007) They could bite them on the lips and throat trying to separate the young ones from their mothers.

Killer whales were filmed in 1979 off Baja California attacking a blue whale (first documentation of predation against the largest specimen of balaenopteridae from BBC). About 30 killer whales, working together, assaulted a young, 18m blue whale, stripping away flesh and blubber, piece by piece, as it tried to flee. After more than 5 hours, they broke off the attack suddenly, leaving the blue whale mortally wounded (Tarpy 1979).

Some researchers claim that along the coast of southern California, killer whales wait for the arrival of the gray whales and prey on calves and juveniles, rather than adults.

Off the southern coast of Alaska, *O. orcas* were seen “molesting” a pair of humpback whales. The humpbacks were “twisting and turning in the water” and were attacked from behind by a second group of killer whales, “who were taking bites at their bellies”.

Fig. 2.8 Attack on a Ballen Whale

Baleen whales tend to stay clear of *O. orcas*. A “pack of hungry killer whales can tear a whale to pieces” - taking just tasty bits - the skin, blubber, dorsal fin, tongue, and flesh of the lower jaw (Bright 1991).

Herrings

Fig. 2.9 Hunting on a herring's shoal

Off the coast of Norway, hundreds of killer whales congregate seasonally to feed on overwintering herring in the fiords, using a feeding strategy that researchers call “carousel feeding”. Basically, some *O. orca* surround a shoal of herring, to keep it together, and drive the compact ball of herring towards the surface (Fig. 2.9). Individual whales, then, take turns to swim into the herring, deliver a quick blow to the fish with their tail flukes, and then eat the dead and stunned herring (Knudtson 1996). Killer whales are not capable of catching these fishes unless they have stunned them first with tail slaps. In general *O. orca* prefer to search out small patches of herring in the early morning, in shallow waters and near underwater seamounts, which aids in herding their prey. However, whales have also learned to follow the fishing fleet and feed on herring that fall from the nets while the catch is being hoisted (Similae 2005).

Icelandic killer whales have developed another strategy. They can emit a 3-s, 680-Hz call that ends 1 s before the tail slap. The frequency of the call falls within the herring audiogram, but outside that of killer whales. This call seems suited for herding the herring into tighter groups, making it possible to debilitate more fish. However, herring are not defenceless. The school can produce a flatulent bubble net that could hinder detection by killer whale biosonar (Miller et al. 2006).

Near vessels

In the waters between northern Scotland and Norway, killer whales are frequently observed in the vicinity of the Scottish pelagic fleet targeting mackerel (*Scomber scombrus*) and herring. They approach the vessels during retrieval of the net, and remain there until this is completed (Fig. 2.10). There is no evidence that killer whales have ever become entangled in the nets (Luque et al. 2006). Killer whales are known to follow fish-processing vessels for many miles, feeding of discarded fish. In the Bering Sea, the same pod of whales was reported to follow a vessel for 31 days for approximately 1,600 km (Dahlheim and Heyning 1999 and refs. therein).

Fig. 2.10 Pod following a vessel

Longlines

Off southern Brazil (Secchi and Vaske 1998; Rosa and Secchi 2007) and in many other areas world wide, killer whales have learned to prey on fish hooked to longlines. In the Southern Ocean e.g., longline fisheries for Patagonian toothfish (*Dissostichus eleginoides*) suffer catch rate decreases of more than 50% when killer whales occurr close to longline vessels (Kock et al. 2006).

Tuna

Their strategy is to chase their prey for up to 30 min at a relatively high sustained speed (3.7 m/s) prior to capture, pushing medium-sized tuna (< 1,5 m long) beyond their aerobic limits until exhaustion. Larger tuna may be inaccessible to killer whales unless they use cooperative hunting techniques or benefit through depredation of fish caught on long lines, drop lines or trap nets (Guinet et al. 2007).

Sharks

The observation of the ocean is not easy, therefore there are not enough data to develop reliable statistics. Based on the data collected so far we can say that in most cases killer whales and white sharks (the two large predators of the oceans) tend to avoid each other. But there are some records of killer whales attacking a great white shark:

- October 8, 1997 near the Farallon Islands, an attack of this type was filmed: a killer whale of about 6meters of length against a half-length great white shark.
- End of 2009 several photos documenting the attack on a white shark. Ingrid Vissen was present.


Fig. 2.11 Attacking a Shark

Ingrid Visser is a marine biologist who lives and works in Tutukaka, New Zealand. For more than 17 years has studied the hunting strategies of killer whales. These animals take hunting strategies that allow them to prevail even against mako sharks or white sharks. In an article by Ketty Areddia (28 Nov. 2009) there is an explanation of the strategy. In this article Ingrid Visser says: "They use a winning combination of great skill, intelligence and brute force, capture and eat those that are unreachable for many predators of the ocean. The most impressive technique is the backlash: the killer whale turning quickly creates very strong currents that do not allow the shark to escape, so the animal will rise to the surface water and at this point the *O. orca* will raise up its back hitting the shark and throwing it violently out of water. At this point the killer whale can eat the stunned shark” (Fig. 2.11).

Another strategy that dott. Visser describes in the article is called " to enclose ": “A group of killer whales have a circle around the shark and push or attack him from below in turn. After this attack they turn it up and down to disorient it, so then they can eat it.”

2.8 Distribution, Habitat and Population's dimensions

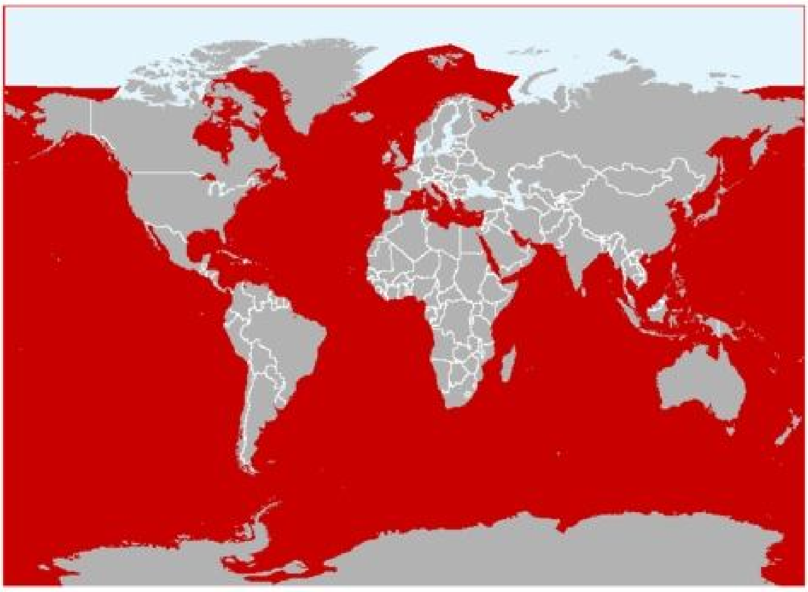


Fig. 2.12 Distribution of *Orcinus orca*: this species is found in all regions of the world (map mod. From Taylor et al. 2008; © IUCN).

Orcinus orca occurs throughout all oceans and contiguous seas, from equatorial regions to the polar pack-ice zones, and may even ascend rivers (Fig. 2.12). However, they can be found in larger number in coastal waters and cooler regions where productivity is high (Jefferson et al.1993; Dahlheim and Heining 1999 and refs. therein).

Data from the central Pacific are scarce. Killer whales have been reported off Hawaii but do not appear to be abundant in these waters (Barlow 2003).

Killer whales in the Mediterranean were not assessed and are included in the "Visitor species" section (Reeves band Notarbartolo di Sciara 2006).

Although the available data are far from being complete, and the widespread nature of killer whales distribution, makes the global estimate of the population size difficult to estimate, it is possible to say that abundance estimates for the areas that have been sampled provide a minimum worldwide abundance estimate of about 50,000 killer whales (Taylor et al. 2008).

Abundance estimates are only available on a regional basis:

- North-eastern Pacific:

Fig. 2.13 Sites of photo identification in the NE Pacific

Many photo identification were made in the North-eastern Pacific (Fig. 2.13). Photo-identification studies recorded at least 850 individual killer whales in Alaska. It should be noted that photo-identification techniques result in a minimum count of animals (Dahlheim and Heyning 1999).

More recent estimates in coastal waters of the western Gulf of Alaska and the Aleutian Islands, estimate an abundance of 991 and 1’587 resident killers specimens, respectively; and of 200 and 251 transient killer whales, respectively (Zerbini et al. 2007).

The eastern North Pacific Northern Resident stock numbered 216 in 1998 (Ford et al. 2000). The Transient stock in British Columbia and south-eastern Alaska is of about 219 catalogued whales (Ford and Ellis 1999). The eastern North Pacific Southern Resident stock numbered 86 whales in 2007, 79 in 2001 and 99 in 1995 (Carretta et al. 2009). The population fluctuated considerably over the past 35 years, due to a variety of reasons (Krahn et al. 2004). More or less in the same area (off the Californian coast) 105 ‘transients’ were identified (Black et al. 1997).

Surveys conducted in 2001 (Barlow and Forney 2007) and 2005 (Forney 2007), estimated the total number of offshore killer whales within 300 specimens on the coasts of California and Oregon.

A 2002 shipboard line-transect survey referring to the entire Hawaiian Islands EEZ (Fig. 2.14) resulted in an abundance estimate of 430 killer whales (Barlow 2003).

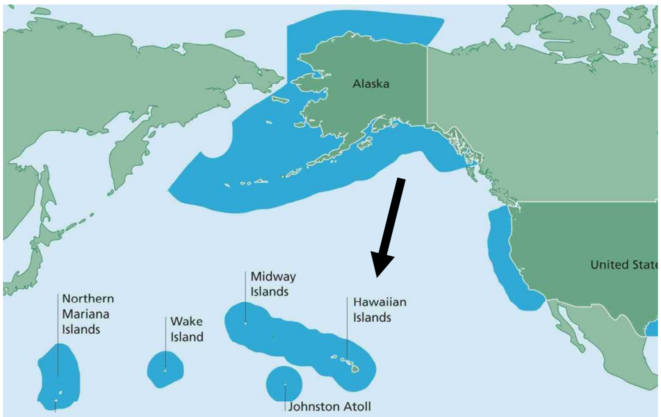


Fig. 2.14 Exclusive Economic Zone (the part in blue)

- North Atlantic:

  In Norwegian coastal waters questionnaire surveys yielded the estimate between 483 and 1507 killer whales (Dahlheim and Heyning 1999). Sightings in the eastern North Atlantic gave rough estimates of around 3100 killer whales for the area comprising the Norwegian and Barents Seas, and the Norwegian coastal waters. The estimate is 6600 killer whales for Icelandic and Faroese waters (Reyes 1991 and refs. therein).

  Offshore killer whales near Washington are estimated to be 1’014.

  On the Atlantic coast of the USA, the estimate (in 2003-2004) of abundance for killer whales in oceanic waters of the northern Gulf of Mexico was 49 (Mullin 2007).

- North-western Pacific:

  Off the Japanese coast the estimate is 1’200 killer whales north of 35° N, and 700 animals south of 35° N (Dahlheim and Heyning 1999).

- Antarctic waters:

  Around Antarctica, the most recent estimate is 25’000 killer whales south of 60°S (Branch and Butterworth 2001).

- Southern Indian Ocean:

  Estimates are not available for this region, however, Poncelet and colleagues (2002) reported a strong decline of killer whales in the coastal waters of Possession Island between 1988 and 2000. Several factors which may have contributed to the decline were identified (like decreasing fecundity; decline of the main prey or dispersion of individuals from the costal waters).

  Williams et al. (2009) considered the conservation status of fish-eating killer whales in southern African waters to be 'vulnerable', because populations are very small and are subject to both short and long-term impacts from longline fisheries.

2.9 Threatened and Endangered

O. orca are seen as dangerous animals. Their English name (killer whales) fully expresses this feeling of danger. In the ancient cultures from Pliny the Elder up to 1960 killer whales were seen as “bloodthirsty wolves of the sea” (Gots and Ronald 2009).

Direct attacks by free-running killer whales on humans resulting in death have not been recorded (Dahlheim and Heyning 1999). However lists of some close approaches by killer whales to divers exist. Many cases are reported in the Diver magazine (August 1999) from New Zealand. Aggressive behaviours are noted towards boats, probably provoked by attempts to capture, harpoon or harass the killer whales (Notarbartolo di Sciara 1978).

In fact, if today we analyze the danger *O. orca* represent for human beings and how much men can be dangerous for killer whales, it can be surprising to discover that we constitute a very big problem for the survival of *O. orca*.

Hunting

Historically, killer whales have never been the primary target of whale hunters. They were commercially harvested by Japan, Norway, Russia, South Africa, Iceland, but the numbers that were taken, were generally small, less than hundreds (Gots and Ronald 2009).

The fishery on killer whales in Norway, for oil and animal food (a single killer whale can yield 1,5 t of oil and up to 2 t of meat), was subsidized and justified as a control measure to protect inshore herring stocks (Gots and Ronald 2009).

Norwegian whalers in the eastern North Atlantic took an average of 56 killer whales per year from 1938 to 1981. The Japaneses took an average of 43 killer whales per year along their coastal waters from 1946 to 1981. The Soviets, whaling primarily in the Antarctic, took an average of 26 animals annually from 1935 to 1979 and then took 916 animals in the 1979/80 Antarctic season (Dahlheim and Heyning 1999 and refs. therein). During the period 1976-1988, 59 whales were captured alive off Iceland, out of which 8 were released, 3 died and 48 (an average 3.7 per year) were exported to aquaria. Live-captures of several killer whales have also taken place in Japanese waters (Reyes 1991). Between 1953 and 1980, about 6’000 were taken off Japan, Norway, and Antarctica, and were usually a by-catch during other whaling operations (Gots and Ronald 2009).

It seems that the hunting against killer whale increased after the ban on harvesting sperm whales issued by the International Whaling Commission (IWC) in 1979. The species won a measure of protection thanks to the IWC recommendation about extending the safeguard to all cetaceans. In 1980, IWC added killer whales to the factory ship moratorium. No specimen has been taken in commercial whaling operations anywhere in the world since 1981, and in 1982, IWC recommended against further killing of this species until more data are known about impact on populations (Gots and Ronald 2009).

Killer whales are still taken for food in small numbers in coastal fisheries in Japan, Greenland, Indonesia, and the Caribbean islands (Reeves et al. 2003) by native people and other small-scale traditional whaling operations. There are no reports of subsistence taking (killing) of killer whales in Alaska or Canada (Gots and Ronald 2009). By-catch in trawl and driftnet fishing operations occurs, but is considered rare (Dahlheim and Heyning 1999)

Contaminants

Persistent bio-accumulating contaminants have recently been found as a serious potential risk to some killer whale subpopulations. In a study blubber biopsies were collected for contaminant analysis from 47 killer whales of both sexes, various known ages, and two distinct populations that frequent the waters of British Columbia, Canada, and adjacent areas (i.e. northern and southern residents; transients). These biopsies were collected between 1993 and 1996. The results report that total PCB (PolyChlorinated Biphenyl) concentrations were very high in three killer whale subpopulations. As a long-lived and a top predator, it could be quite susceptible to accumulation of high levels of heavy metals and organochlorines. PCB levels in most sampled killer whales were higher than the ones established for harbor seals; these high levels put this species at risk of adverse effects and this suggests that the majority of free-ranging killer whales in this region are at risk of toxic effects as well. Southern resident and transient killer whales of British Columbia and Washington can be considered among the most contaminated cetaceans in the world (Ross et al. 2000).

A preliminary toxicological study indicates that PCB levels are considerably lower in the Southern-Indian Ocean than those found in British Columbian transient killer whales (Ross et al. 2006a). The effects of PCBs on killer whales, at the observed concentrations, are unknown.

Disturbance

The concern about the effects on marine mammals produced by the increasing human maritime activities, and consequently increasing of noise levels in the water is rising (Dahlheim and Heyning 1999). Moving boats can disrupt activities such as foraging and resting, and underwater boat noise could affect social and echolocation signals of the killer whales or otherwise interfere with foraging. For example, close approaches by whale-watching vessels have been shown to result in escape responses by resident killer whales in British Columbia. This causes an energy loss for whales frequently subjected to whale watching activity (Williams 2002).

In assessing the impact of noise produced by vessels on killer whale hearing ability, it was concluded that noise reduces the ability to detect signals of similar frequencies.

However, the ability to detect broadband signals such as other killer whale calls and clicks, it isn’t substantially affected by low levels of vessel noise (Bain et al. 1993). Acoustic investigations (Bain and Dahlheim 1994) on captive *O. orcas* concluded that:

- Vessel noise can reduce the whale’s ability to detect pure tones
- Noise has the strongest effect when it comes from the side or behind the animal
- The killer whale’s ability to detect broad-band signals is not substantially affected by low levels of vessel noise

In the middle of 1960s, killer whales from waters off British Columbia and Washington State suddenly became a "hot item" on display in public aquariums. Now killer whales are a big attraction in the aquariums and in the wild.

Near Telegraph Cove, on northeast Vancouver Island, is the world's most reliable killer whale-watching territory, attracting about 10’000 people a year (Gots and Ronald 2009).

The concentration of killer whales following the herring stocks in a few fjords along Norway’s northern coast each autumn has attracted whale-watching tourists, to the benefits of the local community (Kemf and Phillips 1994).

The growing numbers of whale watchers (and recreational boats and kayaks) may unintentionally be responsible for short-term disturbances of killer whales (Gots and Ronald 2009).

Fast-moving boats in the proximity of killer whales can also represent a risk of collision or injury from propellers. Visser (1999) reports on propeller scars observed on killer whales in New Zealand and their possible causes of mortality.

Oil Spills

Large-scale catastrophic oil spills have the potential to cause significant mortality of killer whales. The Exxon Valdez oil spill on the 24 of March 1989 in Prince William Sound, Alaska was strongly correlated with the loss between 1989 and 1991 of 14 killer whales from a pod. That pod was seen swimming through the area of the spill, covered with a light sheen of oil. It Seems that no attempts were made by the killer whales to avoid contaminated waters(Dahlheim and Matkin 1994; Harvey and Dahlheim 1994; Matkin et al. 1994;). Oil spills may also have an indirect effect by reducing prey abundance.

Overfishing

A study dated 2003 estimated, with the use of meta-analytic systems, that the large predatory fish biomass now is only about 10% left if compared to pre-industrial levels.

The analysis shows that the global ocean has lost more than 90% of large predatory fishes. Although it is now widely accepted that single populations can be fished to low levels, this analysis shows a general, pronounced decline of entire communities across several ecosystems (Myers and Worm 2003).

In the study it also emerges a decline in “prey” fish stocks worldwide and some studies demonstrate that the ecological extinction caused by overfishing, precedes all other kinds of pervasive human disturbance to costal ecosystems (Jackson et al. 2001). There have also been dramatic declines in marine mammal populations throughout the world. The effects of such reductions in prey populations (both fish and marine mammals) and subsequent ecosystem changes on world-wide populations of killer whales are unknown but could result in population declines.

Due to their dietary specialization, some populations of killer whales could be especially vulnerable to a reduction of their food supply. For example in British Columbia and Washington State the changes in the abundance of Chinook salmon (the major prey of the resident killer whales of that area) is reported in a strong correlation with the changes in the abundance of killer whale in the same area (Ford et al. 2005). Mammal-hunting killer whales in British Columbia have experienced periods of reduced prey availability since 1970 due to depletion of pinniped populations (Ford and Ellis 1999).

The depletion of the Mediterranean bluefin tuna stock is considered a source of concern for the survival of the Gibraltar killer whales (Cañadas and de Stephanis 2006).

Fisheries interactions

Fishermen in many areas see *O. orca* as competitors, and it is known that sometimes intentional shooting against killer whales occurs. Surveys conducted in 1992 in the Bering Sea and western Gulf of Alaska showed that, 9 out of 182 individual whales in 7 out of the 12 pods encountered had evidence of bullet wounds (Dahlheim and Waite 1993)

In the 1950s, the U.S. Navy was enlisted to destroy killer whales off the Iceland Coast with machine guns, rockets and depth charges; such control measures are still contemplated in Iceland to protect the herring fishery. In 1961, the Canadian Department of Fisheries mounted a machine gun on the east shore of Vancouver Island, with the intent of deterring whales from entering the Strait of Georgia. The gun was never used.(Gots and Ronald 2009).

Also in Australia, there are reliable reports of fishers shooting killer whales plundering their catch. They have become entangled in drift-nets and in lost or discarded netting (Banister et al. 1996).

Since 1990 there has been only one report about an killer whale that had had a contact with a salmon gillnet, but did not become entangled. So it could be said that no mortality has been attributed to fishery interactions in Canadian waters since 1990 (Guenther et al. 1995).

From 1990 until 1995 the mortality rate about incidents linked to commercial fishery was monitored in Bering sea/ Aleutian islands (Alaska). The estimated minimum mortality related to groundfish trawl and longline fisheries, is 1.4 animals per year (Hill et al. 1997).

Climate changing

The global climate change will have negative effects on the marine ecosystem. These effects will lead to changes in prey availability, and then to negative consequences for those on the highest steps of the food chain. For what concerns killer whales, some subpopulations will definitely be more penalized than other ones.

UICN Red List

In the 2008 IUCN Red List of threatened species about Cetaceans, *O. orca* are considered a Data Deficient (DD) specie.

The IUCN Red List of Threatened Species provides taxonomic, conservation status and distribution information on plants and animals that have been globally evaluated using the IUCN Red List Categories and Criteria. This system is designed to determine the relative risk of extinction, and the main purpose of the IUCN Red List is to catalogue and highlight those plants and animals that are facing a higher risk of global extinction (i.e. those listed as Critically Endangered, Endangered and Vulnerable). The IUCN Red List also includes information on plants and animals that are categorized as Extinct or Extinct in the Wild; on taxa that cannot be evaluated because of insufficient information like for killer whales (Data Deficient); and on plants and animals that are either close to meeting the threatened thresholds or that would be threatened were it not for an ongoing taxon-specific conservation programme (i.e., are Near Threatened) (Fig. 2.15) (http://www.iucnredlist.org/about)

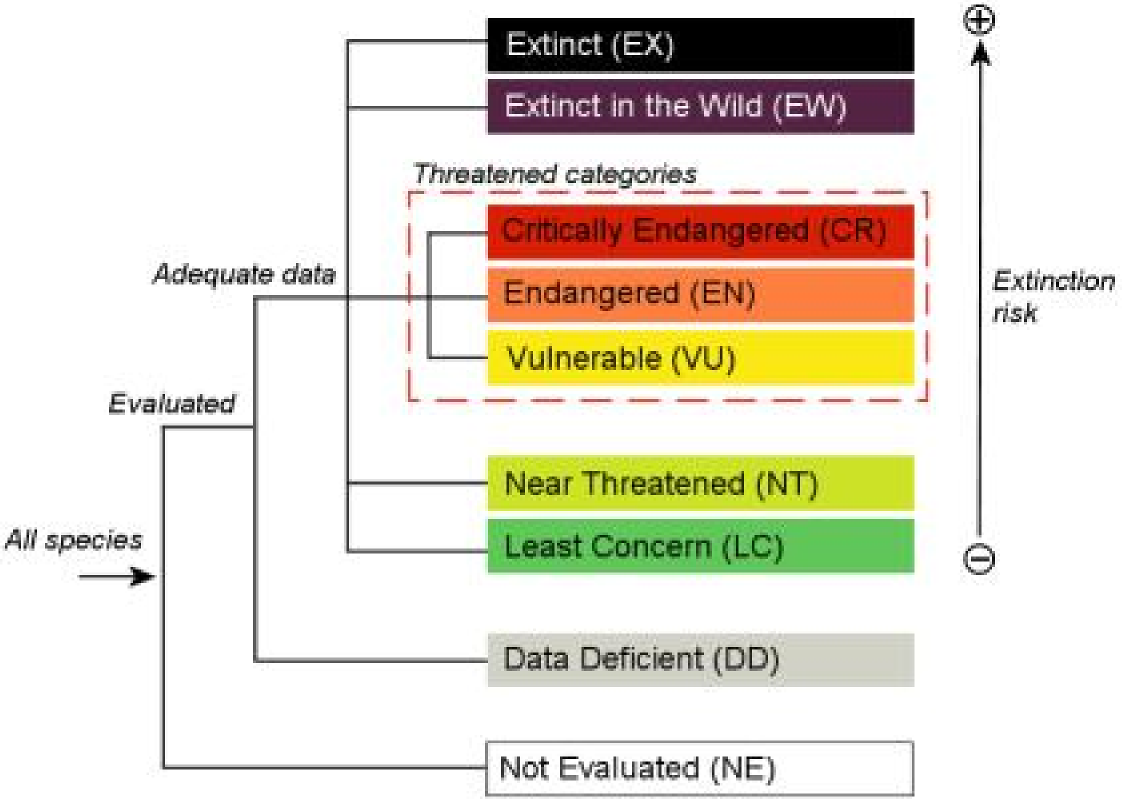


Fig. 2.15 The IUCN Red List categories

2.10 Mantaining in a controlled environment

In 1964, a collecting team from the Vancouver Public Aquarium captured unintentionally an alive killer whale and decided to display it. The *O. orca*, named "Moby Doll", proved to be intelligent and docile. Although it survived less than three months in a controlled environment, it didn’t show to be equal to the reputation until then attributed to killer whales for ferocity and aggressiveness (Gots and Ronald 2009).

In 1965, a large male, accidentally netted by fishermen at Namu, (British Columbia), was purchased by the Seattle Marine Aquarium (for $8,000), where it delighted thousands of spectators (Griffin 1966).

As a result, live capture of killer whales became a lucrative commercial enterprise. From 1964 to 1973, 22 were captured off southwest British Columbia and sold to oceanaria. Entire pods were taken by encirclement of gillnets, and the majority then released after sorting. The continued capture of killer whales led to "a public outcry". For this reason in 1971 Canadian authorities and the State of Washington imposed new regulations and permit requirements for capturing killer whales. In 1976, there was a ban on capturing killer whales in Washington State. Although killer whales could still be taken in British Columbia under permit, local public opposition discouraged capture attempts since 1977. In 1990, British Columbia officially banned killer whale captures (Gots and Ronald 2009).

In February 1991, a killer whale at the Vancouver Public Aquarium died. Then there were some incidents in relation to trainers in several parks, some of them unfortunately finished with the death of the trainer. All these incidents gave prominence to the issue of killer whales in captivity. It is suggested that confinement causes psychological stress; that it is a condition of sensory deprivation. But there is no firm proof that confinement is physiologically harmful (Gots and Ronald 2009).

There was, anyway, a strong opposition to keep wild killer whales in a controlled environment; and perplexity about keeping whales for pure entertainment and profit (Knudtson 1996).

Over time, an intense "free-the-whales" campaign has developed.

The most famous case is that of Keiko, star of the “Free Willy” film. He was captured in Eskifjordur, in the east of Iceland, in 1979 at about two-years of age. After his Hollywood fame the “Free Willy Keiko Foundation” was founded (Oregon), with the main intent of making Keiko return back home. In June 1998, the Prime Minister of Iceland agreed that Keiko could be brought to Iceland, where the Iceland Ministry of Agriculture gave him a clean bill of health. After placing new satellite and VHF (Very High Frequency) tags on Keiko’s dorsal fin, so he could be tracked, he was released in the ocean (July 2002). Thanks to the satellite system, it was possible to verify that he had travelled with wild whales off the coast of Iceland and dives were tracked as deep as 100 m (Gots and Ronald 2009).

Fig. 2.16 Keiko in the Skaalvik fjord

After an extended absence, Keiko showed up in the Skaalvik fjord in western Norway at the end of August (Anonymous 2002) (Fig. 2.16). Keiko had not been fed since he had left Iceland in the hope that he would have hunt on his own. Since there was concern about his health, Keiko got a good meal, and Norwegian authorities pledged the best of care for Keiko.

In December 2003, Keiko moved to Taknes Bay where he could come and go as he chose. The staff continued to feed and work with him. However on December 12 he died, apparently from pneumonia, and was buried beside Taknes Bay (Free Willy-Keiko Foundation 2003).

For animals born and raised in a controlled environment the return to their original environment is always something delicate and dangerous. This step leads to risk the lives of released animals (any type of animals). About killer whales problems could be:

- *O. orcas* speak different dialects in different pods. The dialects of whales in oceanaria have been used to determine the identity of the pods from which they were originally captured. This is essential if you want killer whales to be freed with success.
- Captive *O. orca* can spread disease to wild animals if released: introduction of new organisms from one marine environment (controlled environment) to another (wild).
- The chance that microorganisms harmless in their environment could have serious effects if moved to a new one.
- Animals grown in a controlled environment may not be immune to microorganisms present in wild.
- *O. orca* grown in oceanaria will not probably have propensity for hunting, and could therefore starve to death.

At this point we have some killer whales in parks worldwide (that it is dangerous to return to wild), and bans on the capture of other *O. orca* in oceans. An idea comes really fast to mind: Captive breeding.

There have been successful births in aquaria; Sea World has had 6 births between the 1985 and the 1990 (5 still alive in 1990). On the basis of its breeding record, Sea World has been granted permits to import whales from aquaria of other countries (Gots B.A. and Ronald K. 2009).

In North American facilities, in a 1994 census, 43.3% of killer whales were found to be captive-born (Duffield 1994). Worldwide records of 2007 indicate that 64.4% of *O. orca* surviving in oceanaria or parks were born in captivity (Jacobs 2007, web source).

There are currently at least 45 killer whales in oceanaria and parks around the world. This number includes the ones born in captivity. The countries holding killer whales are (Gots B.A. and Ronald K. 2009) :

- USA: three Sea World parks, Six Flags Marine World, and the Miami Seaquarium;
- Canada: Marineland Ontario;
- France: Marineland Antibes;
- Spain: Loro Parque Tenerife (Fig. 2.17);
- Japan: Kamogowa Sea World, Taiji Whale Museum, and Port of Nagoya Public Aquarium;
- Argentina: Acuario Mundo Marino

Thanks to oceanaria millions of people have the opportunity to watch killer whales at a close range, to know them and to feel themselves more responsible for their survival. In addition, researchers have more opportunities to study these animals in depth.(Dahlheim and Heyning 1999).

Fig. 2.17 Kohana with Adán in the Loro Parque

3. LORO PARQUE

The Loro Parque was founded in 1972 by Mr. Wolfgang Kiessling.

The park was designed with the idea of the integration of every kind of animal species in a perfect reproduction of their wild environment.

It is thought as a tribute to the natural world and an aid to the preservation of the planet.

The park is the home for many different species of animals.

Several species of parrots in great quantity (the park is named after this bird Parrot=Loro in Spanish) from many different places around the world: from Africa, Asia and tropical countries; from Australia and Indonesia. The park has got the largest collection of parrots in the world.

In Loro Parque there are also many different kinds of monkeys ranging from the great primates, like gorillas and chimpanzees (Fig. 3.1); to the little ones like titís.

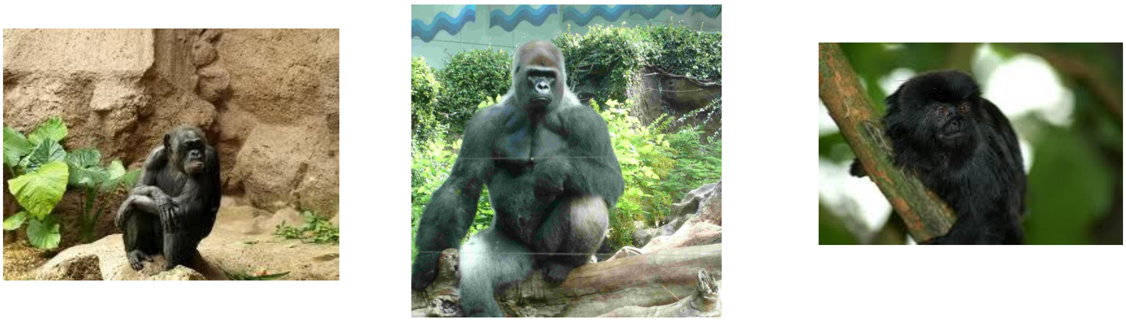


Fig. 3.1 Monkeys in Loro Parque

There is a big Pinguinarium with 5 different species of penguins, including the Humboldt penguin who lives in the Pacific coast of Chile and Peru, but can't be found in the cold Antartica like all the other penguins (Fig. 3.2). The King Penguins that are in the park come to life from the "eggs out of seasons", eggs that are deposed but about which parents do not take care. In nature from these eggs chicks don't born. The others penguins were born in captivity.

Fig. 3.2 Penguins in Loro Parque

Then there are Jaguars and Tigers in pair; Turtles from Galapagos and from Africa; Suricata; Pink flamingos; American Alligator; Iguanas; a pair of Crowned Cranes (Fig. 3.3). In the aquarium there are both freshwater and saltwater animals.


Fig. 3.3 A Crowned Cranes

The species of marine mammals that live in the park are: Californian Sea Lions; Atlantic Bottlenose Dolphins and killer whales.

There is at least a pair of animals for every species, they live together and can reproduce the species.

The park is on good terms with other parks and oceanaria in the world. Thanks to this exchanges of animals are possible.

In addition to animals also flora is held in high regard. The whole park is surrounded by greenery. There is a greenhouse with orchids; an area with Dracaena draco trees (trees endemic to the Canary Islands) of different ages; a ficus forest and a wonderful forest of palms (Fig. 3.4) immediately after the entrance through the Pueblo Thai (built in a perfect Thai-style, thanks to the good relationship with the Thailand rulers).

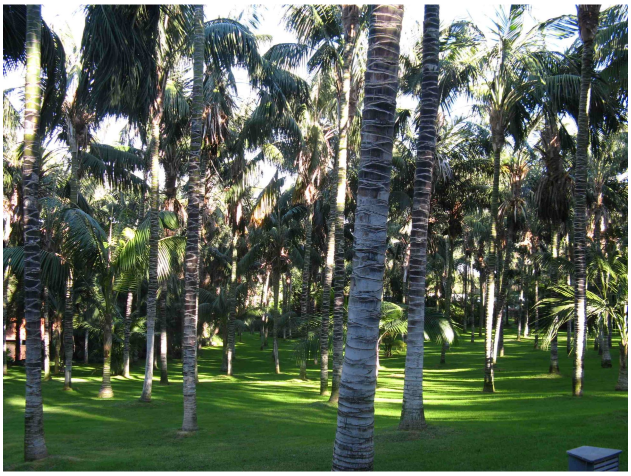


Fig. 3.4
Palm's forest

The Park is certificated by ISO 14000, EMAS III and Biosphere Parks Animal Embassy:

TÜVRheinland®
ISO 14001:2004
Nº 3.00.04056

EMAS

BIOSPHERE
RESPONSIBLE
TOURISM

3.1 Loro Parque Fundación

Loro Parque Fundación is a non-governmental organization legally registered with the Ministry of Education and Science of the Government of Spain since 1994.

The Fundación works in the following three main fields:

- Education

In the educational field, the Fundación organises a lot of activities in the park: videoconferences with schools, in order to teach about the animals in the park, how they live, their status of being preserved, and, eventually, what we can do to help their preservation status. As educational activities Guided tours for schools are carried out, with the aim of giving further information over the animals or activities in order to keep the animals active (i.e. how to collect fruit in leaves and close them has a package so that the parrots have to study a way to reach the food). In the final side of the park there is a classroom with computers that allow children to learn a lot of things about animals playing games.

- Research

What concerns research several projects are carried out (the topic of this thesis is an example) concerning the animals in the park, but there are also some studies in the wild worldwide.

- Conservation

Conservation is primarily based on highly endangered animals. Responsible breeding programmes and conservation activities are developed using certain species as ambassadors for nature.

The Fundación has its headquarters in Loro Parque, Tenerife, but operates at international level, with the mission to conserve species threatened by extinction and their habitats.

To our knowledge, it is the only foundation with all administration costs covered by its principal supporter: Loro Parque. Thus all donations are invested 100% in the protection of the environment, that is concentrated on parrots and terrestrial ecosystems and cetaceans in the marine environment. Parrots are found in all tropical regions where there is the greatest biodiversity, but also a severe environmental destruction. No other group of birds contains such a high number of threatened species. In addition, due to their beautiful colours and appealing behaviour, parrots can be a flagship species that serves to increase the support of local communities and to attract the aid vital for carrying out economic and environmental improvements.

We can report two examples:

- The Yellow-eared Parrot of the Central Cordillera (Columbia) had 81 individuals in 1999 when the Loro Parque Fundación started the conservation project on the species and in 2010 there were more than 1000 individuals (Fig. 3.5).

Fig. 3.5 Yellow-eared Parrot

- The Lear's Macaw of Serra Branca (Brasil) had 250 individuals in 2001 when the Loro Parque Fundación started the conservation project on the species and in 2010 their number had increased to more than 1000 individuals (Fig.3.6).

Fig. 3.6 Lear's Macaw

The two species have gone from a "Critically Endangered" condition to a "Endangered" condition.

In the marine environment, cetaceans occupy the last link in the food chain and therefore suffer the consequences of all the problems that today affect our oceans. In addition, their singular intelligence has always fascinated man since remote times. In addition, the collection of dolphins and killer whales that live in Loro Parque gives the opportunity to obtain a great amount of information complementary to field projects.

3.2 Orca ocean

This facility was inaugurated in 2006 after the arrival of 4 killer whales. Two females from the Orlando SeaWorld (Florida), and two males from San Antonio SeaWorld (Texas).

The two females, Kohana and Skyla, and the youngest of the two males, Tekoa are half-brothers by his father.

Keto, the oldest of two males, and also the oldest of the group, is the half brother of the mother of Kohana. Kohana is the oldest of the females.

Finally we can say that Keto and Skyla are half-brothers by his mother.

These animals belong to the second generation of killer whales born in a controlled environment.

On October the 12, 2010, in Orca ocean, was born Adán (Fig. 3.7), the son of Kohana and presumably Keto, but the fatherhood has not been confirmed by DNA analysis yet.

Kohana being a mother very young and inexperienced, so Adán was raised by the trainers who have taken care of him with all the necessary precaution (Fig. 3.8).

Fig. 3.7 Birth of Adán

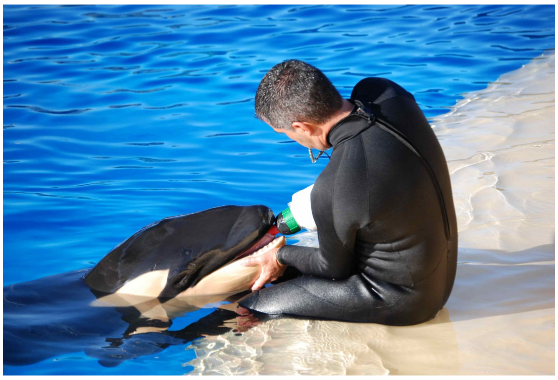


Fig. 3.8 Nursing

Finally in November the 29th, 2011, came Morgan a young killer whale of about four years. Morgan was rescued in shallow waters off the Dutch North Sea in June 2010. Has been rescued and placed in the Harderwijk Dolphinarium in Holland. Here has been treated and cared for 17 months.

When she was rescued was estimated to be about 3 years old and she weighed only 400Kg. The Dutch government permit that originally approved the capture said to the dolphinarium could hold her and restore her health so she could be release. Once she was healed, the park consulted a team of experts to advise on the feasibility to release Morgan back to the sea, and they agreed she had little chance of survival in the wild unless her natal pod could be identified. Analysis of her vocal patterns showed only that she was from Norwegian waters (Samarra et al. 2010)

Finally the court decided to transfer her to Orca ocean, where she immediately adapted very well and has been integrated in the group (Fig. 3.10).

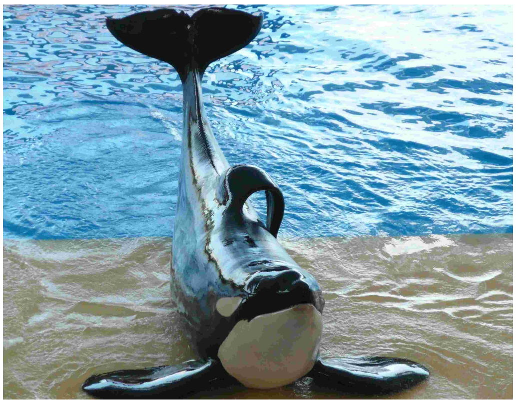
Fig.3.9 Morgan arrived at the Orca ocean

Fig. 3.10 Morgan with Kohana and Skyla (integration with the group)

Now in Orca Ocean there are six killer whales (Table 3.1; Fig. 3.11)

Table 3.1 The 6 killer whales of Orca ocean

Name	**Sex**	**Date of birth**
Keto	Male	17 June 1995
Tekoa	Male	8 November 2000
Kohana	Female	3 May 2002
Skyla	Female	9 February 2004
Adán	Male	12 October 2010
Morgan	Female	Unknown



Keto

Kohana

Skyla

Tekoa

Adán

Morgan

Fig. 3.11 The killer whales in Orca ocean

The structure of Orca Ocean consist in 4 pools (Fig. 3.12):

Pool M: is the Medical one, large 7,1x12,4 m and 4,2m deep. The floor of this pool can be raised to bring the animal out of the water. In this way can be assured the necessary medical care and other routine controls (for example take the measures of the body of the animal).

Pool C and Pool B are respectively 20,5x36,5m and 30,5x44,8m large; and have the same deep of 8,1m.

Pool A: is the largest one and is the pool where the show are made. Has a deep of 12m and is large 24,5x50,5.

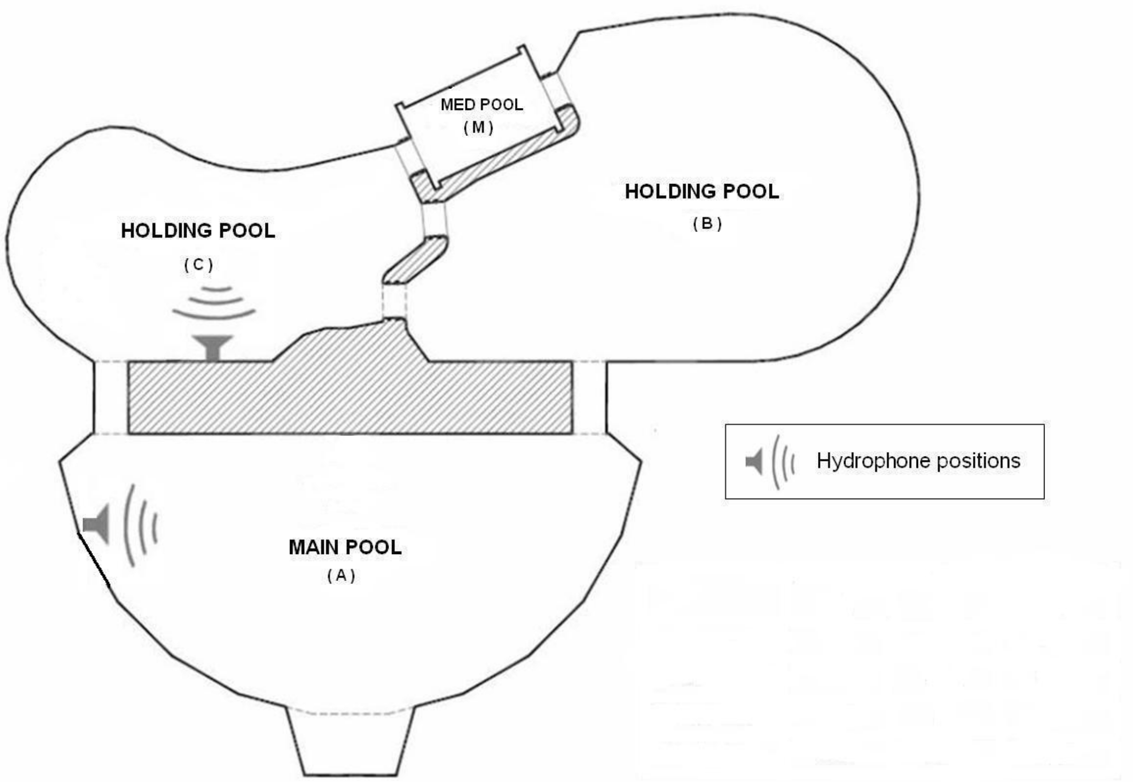


Fig. 3.12 Scheme of the pools of *O. orca* ocean in the Loro Parque

The water in the pools is continuously monitored, as regards temperature and ozone in the morning; chloride, nitrite, nitrate and aluminium in the afternoon. These checks are performed every day.

In the field of veterinary control, are carried out blood and urine test volunteers, especially once a month and once a week respectively. Are also performed ultrasound scans both in males and females, for control of internal organs. The ultrasound scans are made every one or two months.

Each veterinary check could be performed with greater frequency if there is the need.
For example if a female were to get pregnant, the ultrasound scan will be made weekly to ensure the smooth growth of the fetus.
The animals are often measured in weight and length, in order to ensure a good growth.

The weight is measured on the scale, for the adult (Fig. 3.13), and can change during the year (Fig. 3.14). The killer whales are weighted weekly to establish a diet based on their activity and their weight.

Fig. 3.13 The weight is measured on the scale for the adult

The weight of Adán is controlled by another system, because he is still to young to be able to get on the scale. Adán was weighted every two days during his first year of life; only after the arrival of Morgan, has slowed this rate measurement of his weight (Table 3.2).

Table 3.2 Morphometric parameters of the killer whales in the Loro Parque

	Weight (kg) 11-1-2012	Weight (kg) 19-2-2012	Lenght (m)	Width (m)
Keto	3'331.633	3'342.9730	5.90	3.32
Tekoa	2'129.6144	2'125.0785	5.33	3.08
Kohana	2'025.2883	2'000.3407	5.00	2.84
Skyla	1'585.3040	1'585.3040	4.84	2.79
Morgan	1'131.7120	1'170.2673	4.08	
Adán		630.4929		

Lenght: is from the nostrum tip to fluke match (total lenght)

Width: is the girth at the axilla (immediate posterior of pectoral flippers)

Length and width are from 25-1-2012.

Weight are from 11-1-2012 and from 19-2 2012.

Herring, Capelin and Spratt are the kind of fish that they eat (Table 3.3).

Table 3.3 Example of quantity of fish ate in a day

	Food (kg) 4-11-2011	Food (kg) 23-2-2012
Keto	54.43	58.98
Tekoa	45.36	43.10
Kohana	38.56	40.84
Skyla	43.09	43.10
Morgan	-	43.10
Adán	20.41	22.68

During a day the food is distributed in various meals (Table 3.4). They used the weight measures (to weight fish and to weight animals) in pounds (libbra), because, only like this they are comparable with the data continuously exchanging with the Sea World in the USA. For this reason the data in kilograms aren't round.

Table 3.4 Distribution of fish to the different killer whales during the various meals of the day in Kg (23-02-2012).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	*****	**Tot**
Keto	4.54	4.54	4.54	9.07	4.54	9.07	4.54	9.07	9.07	**58.98**
Tekoa	4.54	2.27	4.54	9.07	2.27	6.80	2.27	6.80	4.54	**43.10**
Kohana	4.54	2.27	4.54	6.80	2.27	4.54	4.54	4.54	6.80	**40.84**
Skyla	4.54	2.27	4.54	6.80	2.27	6.80	4.54	6.80	4.54	**43.10**
Morgan	4.54	6.80	4.54	4.53	4.54	4.54	4.53	4.54	4.54	**43.10**
Adán	2.72	2.72	2.27	2.72	2.27	2.27	2.72	2.27	2.72	**22.68**

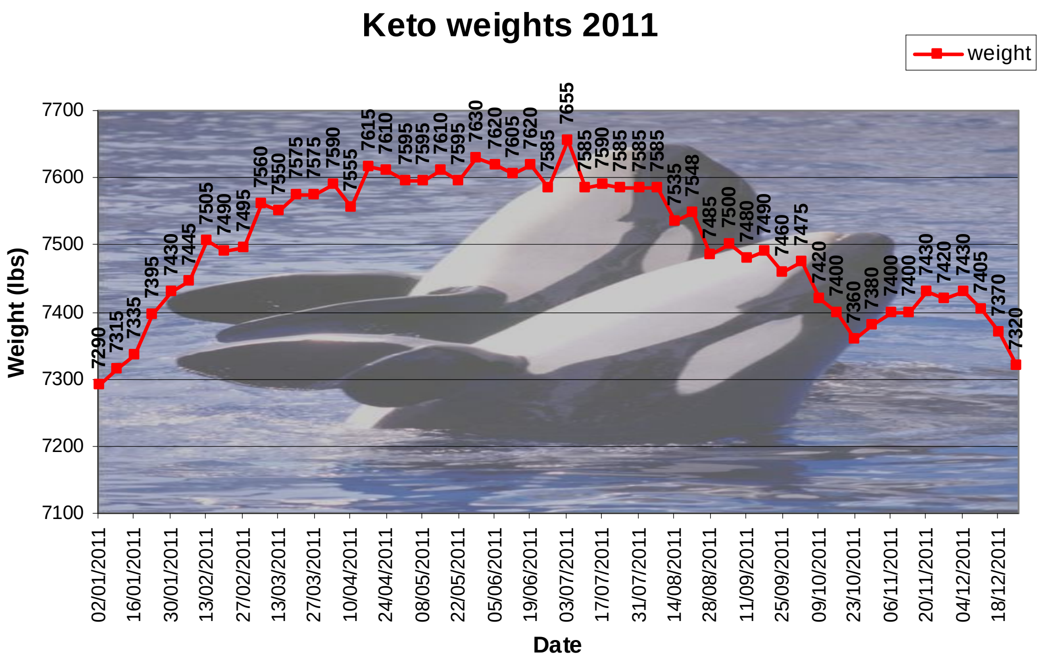


Fig. 3.14 Trend of Keto's weight during 2011

4. STUDY OF THE SOUND

4.1 Aim of the research

The aim of this research is to identify in the physics of sound the individual differences of the killer whales now living in Loro Parque. The achievement of this aim will allow the development of a software for the automatic sound classification, to be used in studying the link between animals' sound emissions and the corresponding behaviours. The collected data could be very useful for future applications both in controlled environment and in the wild. In the controlled environment it could be used as a valid instrument by trainers to get information about the animals' state and mood (situations of frustration or well-being). In the wild this instrument could be useful to carry out correct conservation plans and to study how killer whales' different dialects develop. My research is only the beginning of a wider and already planned project.

This study was carried out by analyzing the type and variety of the sounds emitted by the Loro Parque killer whales (Fig. 4.1) taking also into consideration the conditions of the animal at the time of the sound emission. This result was obtained thanks to the daily observation of the animals for several hours a day. In the study I matched each registered sound to the corresponding animal, taking also notes of the situation the animal was living at that specific moment (Chosen alone; Put alone; With other orcas) and by observing its behaviour (Annex 1).

Sound classification on the basis of the observed behaviour will be useful for the development of future researches.

Fig. 4.1 Orcas at Loro Parque

4.2 Sound production

For centuries people have heard the ocean inhabitants communication sounds and have started to investigate them. The first to be studied were those from the species that produced numerous vocalisations i.e. the southern right whales (Clark 1982) and the blue whales (Oleson et al. 2007).
Killer whales' sounds were first recorded in the early 1980s (Norris 2002).

For the study of the sound in the water, it is necessary to understand how the sound moves and behaves in this element: sound waves travel through water at a speed of about 1,5 Km/sec, that is four and a half times faster than sounds travelling through the air.

Killer whales probably rely on sound production and reception to navigate, communicate and hunt.
A killer whale makes sounds by moving the air between nasal sacs in the blowhole region. In contrast with humans, that make sounds forcing the air through the larynx, killer whale's larynx doesn't have vocal cords and consequently cannot produce sounds like we do. The first studies on sound production in the odontocetes were made on bottlenose dolphins (*Tursiops truncatus*). In one of this studies scientists have suggested that clicks are produced in the nasal region while whistles are produced in the larynx (Evans and Prescott 1962). After this studies scientists split into two groups:

- the American current, that says that the important parts of the auditory system in the odontocetes are: nasal system, melon and jaw (e.i Ridgway 1980)
- the European current, that supports the theory that all the sounds are produced in the larynx (e. g. Purves 1967; Purves and Pillari 1973).

In order to find out the truth about sound production in the Odontoceti some experiments were carried out. For example Diercks et al. (1971) used suction cup hydrophones for near-field sound recordings to test if there were one or two pairs of phonic lips active during sound production. By changing sound speeds and by studying refraction and reflective in the air sacs, they found out that the sound source in toothed

whales is localized in the forehead at a depth of 1.5-2 cm from the head surface, near the nasal caps.
Other studies (for example Dormer 1979) confirmed movements related to sound production in the nasal system, but couldn't demonstrate any movements in the larynx.

In the nasal region we can find a complex tissue called "dorsal bursa", that is the site of sound production (Fig. 4.1).

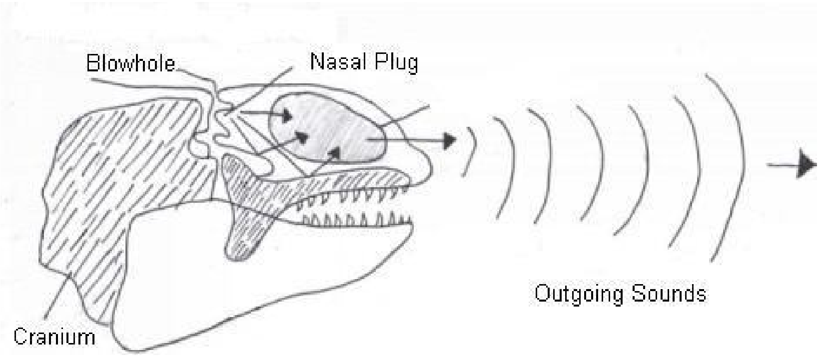


Fig. 4.1 Production sound system

This complex system includes the "phonic lips" and the melon. It seems that toothed whales produce some sounds by forcing the air through the nasal passage and past the phonic lips, making the surrounding tissue vibrate, so that sound is produced. The high-frequency sounds are generated in special structures in the nasal passages lying beneath the whale's blowhole. The sounds pass through the melon, the rounded region of a killer whale's forehead, which consists of lipids (fats). The melon acts as an acoustical lens focussing these sound waves into a beam, which is projected forward into water in front of the whale. Releasing air from the blowhole isn't required to produce sounds, but sometimes the two things are connected.

4.3 Type of sound

Today killer whales are known for producing three different types of sounds called: clicks, calls and whistles.

- Clicks are brief sound pulses, emitted in series, which are used for echolocation in order to prey or to get orientation; these have a frequency range between 20-108 kHz (Barret-Lennard et al. 1996; Au et al., 2004; Simon et al., 2007) (Fig. 4.2)

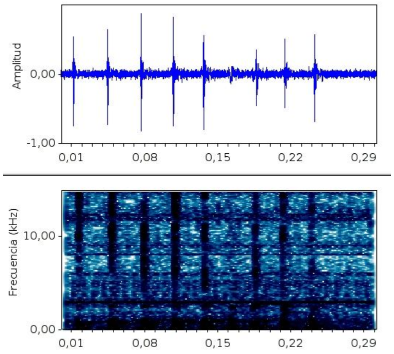


Fig. 4.2 Clicks

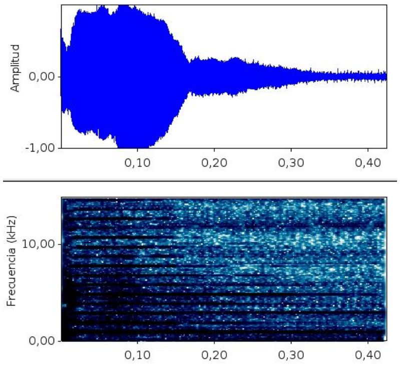


Fig. 4.3 Calls

- Calls are known in three forms: discrete calls, variable calls and aberrant calls. They are expected to be a contact signal during cooperative foraging (Hoelzel and Osborne 1986) (Fig. 4.3). The frequency range of calls is between 1-6 kHz (Ford 1989).

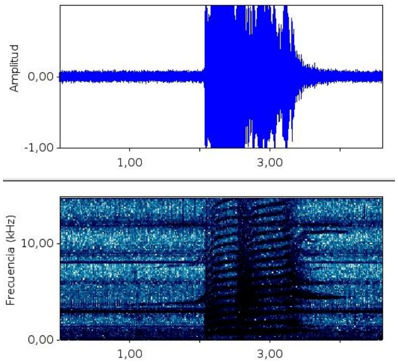


Fig. 4.4 Whistles

- Whistles are tonal sounds used in socializing (Fig. 4.4). They are also important for short-range communication (Deecke 2005). Their frequency range is between: 2-16.7 kHz (Thomsen et al. 2001).

Calls that sound the same time after time are called stereotyped calls. Whistles can be stereotyped as well. This characteristic is found in resident population, where it seems that different clans produce the same stereotyped whistles, showing that these whistles are used to communicate with other clans (Riesch et al. 2006). Studies on northern resident killer whales also showed that they produce more whistles when they are close to other individuals while only sporadically emit them when dispersed over large areas to hunt (http://www.seaworld.org/animal-info/info-books/killer-whale/communication.htm#header-echolocation). This is another reason to believe that whistles are used for communication between individuals.

The discrete calls are the dominant sounds used inside a killer whales' pod. This kind of sound has got many functions: promoting activities within the group or simply conveying messages between individuals. They are known to change over time. This is due to genetic differences, maturational changes (calves produce sound very different from the adult) and vocal learning. It is proved that some odontocetes have the ability of vocal learning (Deecke et al. 2000). The term “vocal learning” has been used to describe the influence of learning on different aspects of vocal communication (Janik and Slater 1997, 2000). Vocal learning is common among birds (Kroodsma and Miller 1996) but less studied and probably rare for non-human mammals (Filatova et al. 2007). Among mammals it was shown only for some bats (Esser and Schmidt 1989; Jones and Ransome 1993; Boughman 1998), phocidae (Ralls et al. 1985; Morrice et al. 1994) and cetaceans (Caldwell and Caldwell 1972; Richards et al. 1984; Payne and Payne 1985; Janik and Slater 1997; Rendell and Whitehead 2001). Typical for many terrestrial mammals are geographic variations in the acoustic repertoires. They usually result from geographic isolation and then genetically transmitted from generation to generation, rather than by vocal learning (Nikol’skii 1980; Conner 1982).

The specific vocal traditions of sympatric or neighbouring groups or sub-populations of mammals are called dialects (Conner 1982). For killer whales the individuals of any particular pod, share the same repertoire of calls. A study of Ford (1991) showed that the North-East Pacific killer whales have unique vocal repertoires of discrete call types and documented various levels of sharing of these among groups: certain groups shared a number of discrete call types and others had entirely different call repertoires. The existence of vocal dialects was also shown for North-East Atlantic killer whales (Moore 1988; Strager 1995). Even though analysis of call patterns demonstrated substantial differences among the dialects of different pods, when they are mutually associated may share certain calls. Killer whales that are separated by great geographical distances “speak” completely different dialects. An analysis on Icelandic and Norwegian killer whales' pods revealed that the Icelandic population produced 24 different calls while the Norwegian whales could emit 23 different calls, but the two populations did not share anyone between them. In fact, the vocal repertoire of each pod remains distinct enough so that scientists can identify pods by the sounds they let out.

Killer whales' dialects appear to be vocally learned because a calf is most likely to develop calls like those of its mother, so it shares only the repertoire of its mother’s pod, although most calves are fathered by non-pod males (Barrett-Lennard 2000). Vocal development studies at SeaWorld have determined that a calf learns its repertoire of calls selectively from its mother, even when other killer whales may be present and vocalize more frequently than the mother. They have also observed that a calf can vocalize within a few days from its birth, but sound production is shaped with age. Its first vocalizations are “screams” loud, high-pitched calls that bear no resemblance to adult-type calls. At about two months of age, they start to produce their first pulsed calls with similarities to adult-type calls.

Vocal behaviour does not appear to be genetically predetermined. Calves learn which calls to make and under what circumstances. From two to six months, a calf’s repertoire increases. They continue learning calls until puberty (http://www.seaworld.org/animal-info/info-books/killer-whale/communication.htm#header-echolocation).

In captivity, killer whales are known to be able to copy calls of conspecifics from other groups and populations (Bain 1986; Ford 1991).

Most studies about killer whales' acoustic behaviour have been made in the coastal waters of the North-East Pacific where the two main ecotypes of killer whales live: fish-eating resident and mammal-eating transient. These two ecotypes differ greatly in vocal activity (Ford et al. 1998; Baird and Whitehead 2000). Transient (mammal-eating) killer whales are less vocal than resident (Morton 1990; Deecke et al. 2005). Transient killer whales, which prey on marine mammals, probably rely more on passive listening than on echolocation to help them find prey. So they usually produce calls only after a marine mammal kill or during surface-active behaviour, while residents are much more vocal during most activity states (Deecke et al. 2005). Scientists theorize that these differences in sound production are related to the whales’ feeding habits. Transient killer whales, which prey mainly on marine mammals, keep quiet to avoid detection. The excellent hearing of a marine mammal might alert it to an echolocating or vocalizing killer whale, giving it the opportunity to flee.

It has been observed that fish-eating resident killer whales emit sonar clicks fairly frequently as they hunt for prey and may identify their favourite species in part on the unique acoustic characteristics of the fish’s swim bladder (Barrett-Lennard 1992).

This acoustic behaviour cannot be assumed to be the same in all the species. The new studies by Samarra (personal communication) on North Atlantic killer whales are showing that not all fish-eating killer whales use sound in the same way. There are also reports about the same pod using the sound in a different way when it's feeding on different resources, or even while preying on the same resource at different biological stages (spawning herring and mature herring).

4.4 Echolocation

The adaptation to an environment in which visibility is significantly reduced, at best only a few tens of meters, has led to the development of a sophisticated system which allows to "see" at a great distance: the echolocation.

The term echolocation refers to the ability of odontocetes (and some other marine mammals and most bats) to locate and discriminate objects by projecting high-frequency sound waves and listening for echoes. The sound waves produced by a killer whale bounce off objects in the water, and their echoes return to the killer whale (Fig. 4.5).

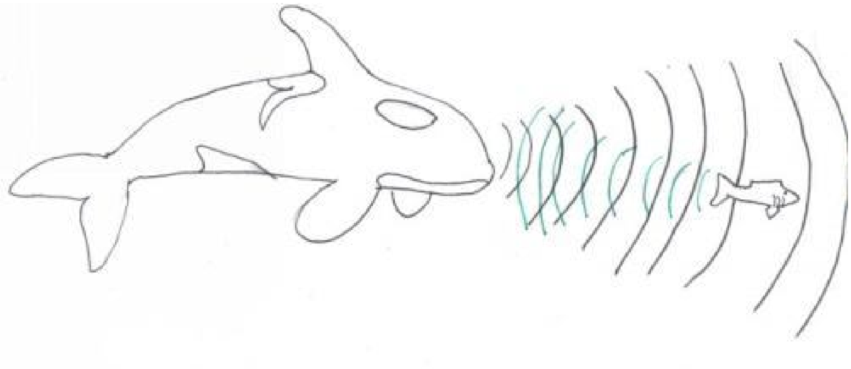


Fig. 4.5 Echolocation

A killer whale echolocates by producing clicks and by receiving and interpreting the resulting echo. When the sound beam hits an object, it is reflected back and channelled through the fluid, fat-filled lower jawbones to the sensory organs of the middle ear lying on either side of the skull (Knudtson 1996) (Fig. 4.6.).

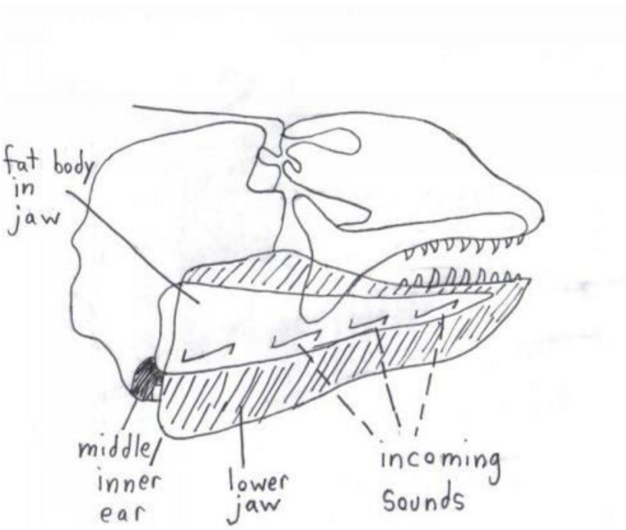


Fig. 4.6 Sound receiving system

In order to echolocalize, killer whales produce directional, broadband clicks in rapid succession, called a “train”. Each click lasts less than one millisecond. An echolocating killer whale can determine the size, shape, speed, distance, direction, and even some of the internal structure of objects in the water.

4.5 Categorization of sounds

Call type categorisation is critical to killer whale acoustic research. No one has yet provided a satisfactory definition of “call type” in killer whales. The most common description of the categorisation process refers to subjective approach, like “the distinctive audible characteristics of the calls” (Filatova et al. 2007).

The stereotyped discrete calls have a clear structure which makes it possible to categorize them (Ford 1989). The other calls can change in level and structure and consequently the category to which assign the sounds can change as well.

The problem of categorization arises in any classification system because classification should be discrete while the characteristics of most natural objects and aspects of nature are more or less gradual (Filatova et al. 2007). In the existing classification of killer whales’ discrete calls, only two levels have been defined: call type and call subtype (Ford 1984; Yurk et al. 2002).

4.6 Study on killer whales' sounds

Most studies on killer whales' vocalizations have taken place in the wild (e. g. Ford 1989; Ford 1991; Barrett-Lennard at al. 1996; Bigg et al. 1990). Most studies on killer whales and their vocalization in general, refer to the resident population of British Columbia, but we cannot expect that all the killer whales have the same acoustic behaviour as those mentioned. An example of a study carried out in captivity is from Szymanski et al. (1999) who measured the captive killer whales' audiograms.

Studies referring to individual vocalization are best attained under controlled circumstances and therefore an aquarium is the ideal location. This is due to the fact that in the wild it is very difficult to measure which animal produces the sound that is heard in the recording studies. For the environment in aquariums gives the opportunity to identify the individuals, separate them to obtain the individual sounds and determine the behaviour. The study of Dahlheim and Awbrey in 1982 was one of the first carried out with the aim of determining if individuals or groups of killer whales differ in their vocalization. The study was conducted on captive killer whales living in five oceanariums in the USA: Sea World in San Diego, with five animals; Marineland in Palos Verdes, with three animals; Marineworld in Redwood City, with two animals; Vancouver Public Aquarium, with two animals and Sealand in Victoria with one animal. They collected underwater recordings from these 13 killer whales and the identity of the animal making the sound was determined by noting no bubble emission from the blowhole or by the location of the animal relative to the hydrophone. The frequency of the recording system was from 40Hz to 19kHz, and seemed adequate, because previous recordings and a review from the literature showed peak energy in the signals of killer whales to be below 20kHz. The classification of the recordings was based on six acoustical variables for each sound:

1. minimum frequency (lowest frequency observed);
2. maximum frequency (highest frequency observed);
3. duration (time period of the signal);
4. starting frequency of the fundamental;
5. ending frequency of the fundamental;
6. frequency interval between harmonics.

For sounds with obvious harmonic structure, the beginning and ending frequency of the stressed harmonic was included. Alternatively, if a vocalization was more broadband, with less obvious harmonic structure, the beginning and ending frequency of the "stressed" area in the signal (stressed areas appear darker on the spectrogram display) was included.

At the end of this study greater acoustical differences were noted among the oceanarium and within the oceanarium. They have supposed that the different capture areas of the individuals could be reflected in dialectal differences in the calls maintained for over ten years. Sex could also be a discriminant data, as the analysis results showed that ten sound types significantly separated the seven males of the study from the six females. The whistle seemed not to present differences.

Dahlheim and Awbrey's study that determines the animal as sound source is not always adequate. In fact, looking at the position of the animals respect to the hydrophone is really important, but thinking of a connection between sound production and bubble absence is not defensible . Samarra, for example, (personal communication) said that a very interesting thing about killer whale Morgan is that she always emits sounds in relation with bubbles.

Bioacoustics studies can be an important means of tracking pod movements. If they provide a reliable index of genetic variability, they can also become a useful management tool. For example in the case of Morgan, genetics suggested Norwegian herring-feeding population. The study conducted by the University of St. Andrews in Scotland, on killer whales' sounds production in the North Atlantic waters (Iceland, Shetland and Norway’ waters) were used to discover which population Morgan was from. They found a pod with calls similar to those from Morgan's repertoire in a group of Norwegian killer whales (the P pod). But the recording of this pod's sounds cannot be linked to the photo identification of the pod because during the recording it was dark and weather conditions prevented from getting a good photo-identification of the pod. Besides, this “P” pod was only seen once in 2005. Therefore despite the finding of some dialect matchings, we can’t say that the “P” pod is Morgan’s familiar pod, but only that it is probably related.

Another important thing to say is that marine mammals don’t only use sounds to communicate (Fig. 4.7), but a variety of postures and gestures as well. Toothed whales may also communicate using some behaviors, such as head-butting and jaw-snapping, that are usually assumed to communicate aggression, but that in killer whales seem to be also linked to playtime. The purpose of other behaviors, including breaching and pec-slapping, is not clearly understood.

Fig. 4.7 Morgan is speaking and making bubbles

5. Materials and Methods

Marine mammals use a complex set of vocalizations which may serve to communicate and coordinate their movements in a group (Fig. 5.1).

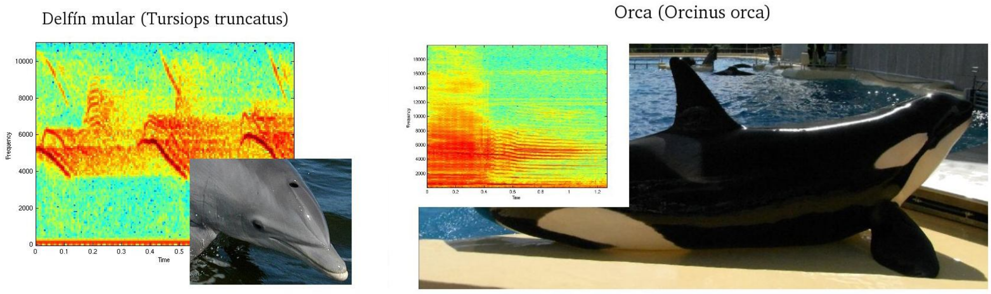


Fig. 5.1 Examples of cetaceans' vocalization

Bioacoustics is the discipline that deals with the study of sounds emitted by animals.

The analysis of bioacoustics signals requires:
Recording
Detection
Classification

As stated above, in killer whales vocalizations differ among population groups, and even within the same group there are differences that distinguish individuals.

This thesis is the pilot study of a wider project that is aimed at finding:

- which specific individual call types are produced by the six killer whales at Loro Parque, Tenerife.
- which types of behaviours can be connected to these individual call types produced by the six killer whales in Loro Parque, Tenerife.

In recent years several methods to detect marine mammal vocalizations have been developed and tested.

In Loro Parque the physicists from the La Laguna University have created a testing environment in the Orca ocean structure. There they are trying to develop devices for the recording, detection and classification of the sound.

The system consists in a layered structure. The first layer is aimed at acquisition, with the task of obtaining a continuous flow of data from the hydrophones. The next layer is for detection; it is responsible for selecting those parts of the continuous flow that contain events that could be interesting. The third layer is for classification aimed at determining what type of vocalization is contained in the event selected by the lower layer, in order to identify the individual who has produced it. Finally, there may be a fourth layer, the layer of temporary analysis, aimed at detecting temporal patterns between vocalizations. This is important for the localization of the acoustic source as well. The advantage of using a layered model to develop these devices is that it is possible to combine different techniques, thanks to the interfaces between layers (Lüke et al. 2009 http://www.bioacoustics.info/article/framework-develop-prototype-bioacoustic-devices-aid-open-sea-killer-whale-protection).

At the present moment not all the levels have been developed yet. Below the systems now operating will be shown; these are the ones used to collect the data for this thesis.

Hydrophones

The system consists of 12 built-in hydrophones distributed in three of the four pools of the structure (there are no hydrophones in the medical pool). Three of them are on the bottom of the main pool, all the others are in the walls of the pools (Fig. 5.2). They are connected to an acquisition card from United Electronics in a personal computer being able to simultaneously record eight channels at 200kHz sample frequency, that provides a maximum detectable frequency of 100kHz. This system also allows to generate a continuous recording of one channel and to playback it through a louder speaker, in order to hear in situ what is happening in the pools. Direct recording of the raw data stream to the disk has to be available for debugging purposes. The creation of a raw recording database is not feasible due to the big amount of generated data files which could not be saved for long time on the computer system. This forces to find strategies to reduce the data amount, recording only interesting parts at the detection layer (Lüke at al. 2008 unpublished data; Lüke at al. 2010).

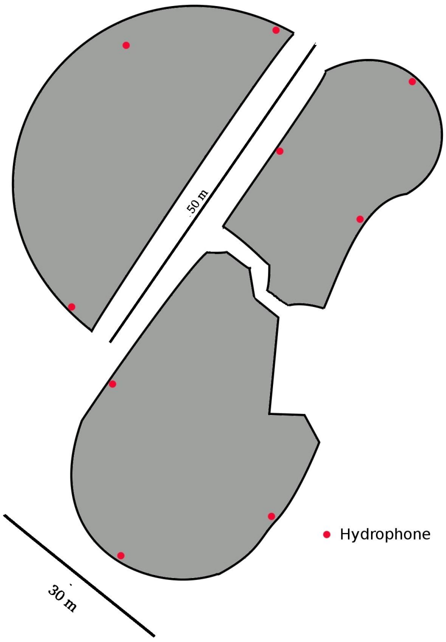


Fig. 5.2 Hydrophones’ position in Orca ocean

Detection

Signal detection consists in the discrimination between signals plus noise and background noise intervals.

In this case it was interesting for the physicists of the University to develop and test real-time capable methods. It has also to be clarified that event detection in this layer doesn’t mean to detect killer whales’ vocalizations only. Every signal that is not a background noise is detected. As detection algorithms provide a data reduction, an event database can be created and stored on the computer system. The database can be further used to perform statistical analysis, event classification, or to locate and track the sound sources in upper layers.

The detection problem can be formulated as a simple exclusive binary test between null hypothesis H0 (absence of signal) and alternative hypothesis H1 (presence of signal), shown in the equation below:

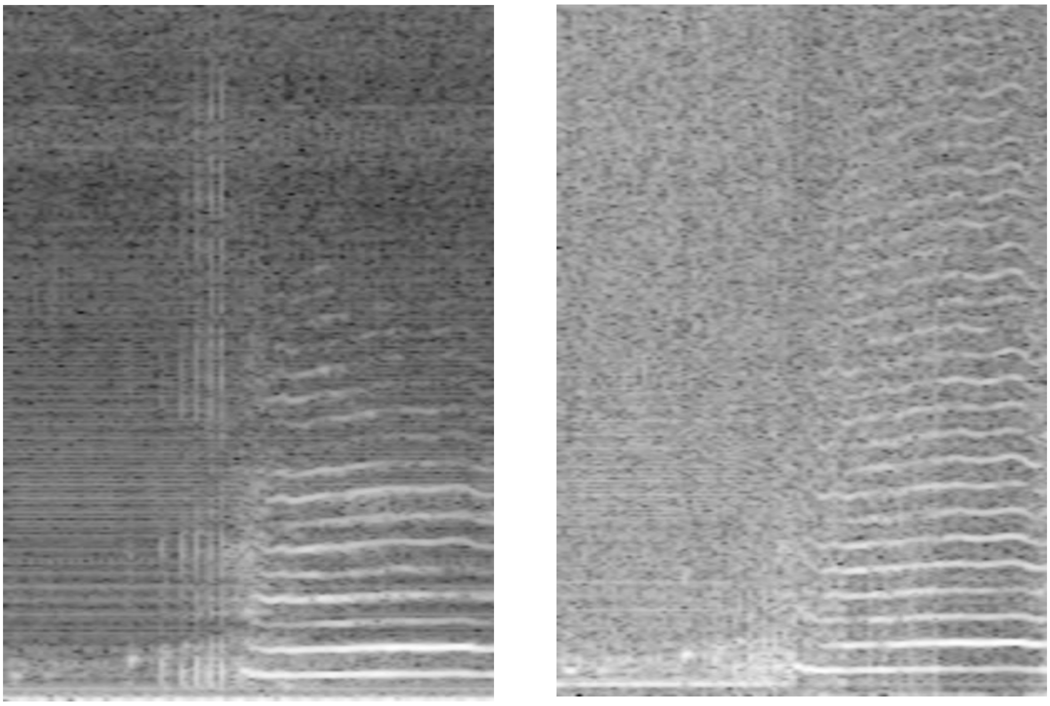
$$H0 : x(n) = noise(n)$$

$$H1 : x(n) = signal(n) + noise(n)$$

where x is the underwater recording, that can be composed of only ambient noise under hypothesis H0 or signal (killer whale’s vocalizations, antropogenic sounds, water splashes, etc. . .) under hypothesis H1.

The evidence variables are compared with a threshold to decide between the null and alternative hypothesis. This approach has an advantage: if a good discrimination function is found it becomes possible to detect sounds of other nature, not only *Orcinus orca*'s vocalizations. In open sea this allows to detect the presence of other cetacean species or anthopogenic noise (Lüke et al 2010).

At this point the goal for the scientists was to find the best way to create an event database from a continuous data stream. For this reason they experimented different detection algorithms (with low computational complexity) in four hypothetical situations (letting the algorithms create a synthetic signal). At the end of the experiment the "zero crossing" method was identified as it provided the best performance on the data (Fig. 5.3).

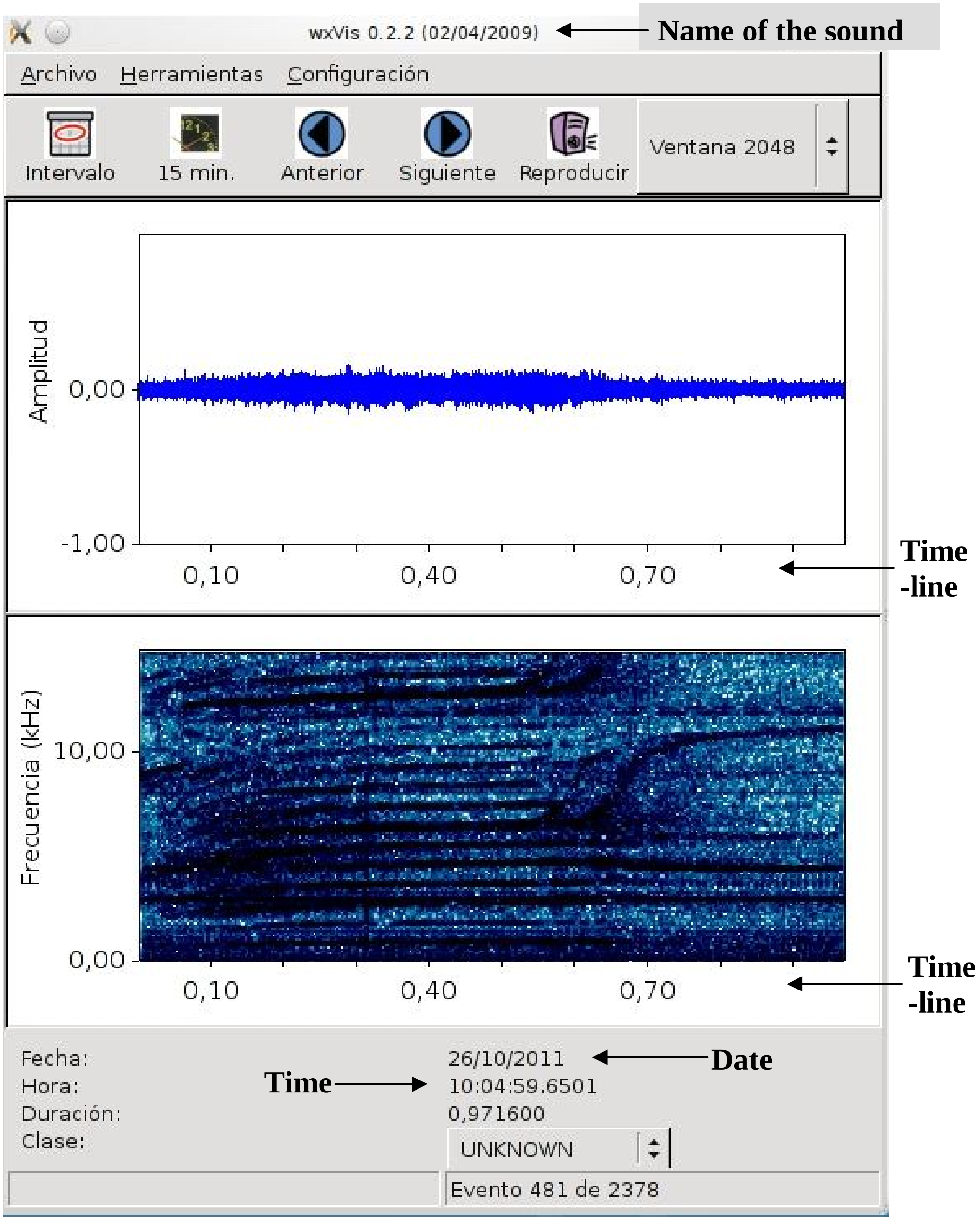


(a) Spectrogram of O. orca's vocalization

(b) Spectrogram of sign of the same signal filtering out low frequencies

Fig. 5.3 Spectrograms of an *Orcinus orca*'s vocalization

They integrated this algorithm into the recording system in order to automatically detect events and generate a database for a selected channel. The detection of events which runs 24 hours stores the detected events in a database. They also created a software to consult the data present in the event database. Through this software it is possible to consult the event data belonging to a chosen date and hour (Fig. 5.4).



Ventana 2048

Fecha: 26/10/2011
Hora: 10:04:59.6501
Duración: 0,971600
Clase: UNKNOWN

Evento 481 de 2378

Fig. 5.4 Software screenshot

By using this software we could consult all the event data starting from the beginning of September 2011 referred to the channel 0 (the hydrophone in the pool A Fig. 5.2). By looking at the software interface we could choose good quality sounds (Fig. 5.5) and checked on our register if the time of vocalization corresponded to an animal.

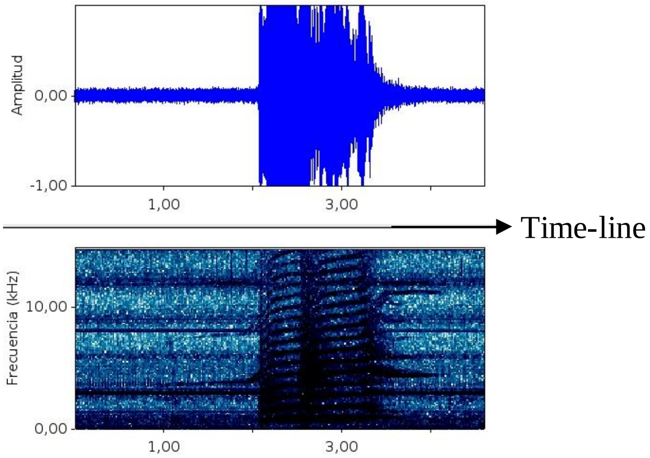


Fig. 5.5 Software screenshot (call with whistle)

Classification

Currently a software algorithm for event classification is under development. Most known methods are computationally inefficient and probably not suitable for real-time. So new real-time capable methods need to be designed and tested or existing methods improved (Lüke et al. 2008 unpublished data).

Our work

Our work was divided into 3 parts:

- Observation
- Choice of the sounds
- Classification

The first part consisted in the animal observation. We went to Orca ocean facilities 5 days a week (from Monday to Friday) and maintained a register with the observations. We usually carried out the observation for 2 hours and a half in the morning (from 9:00 to 11:30); and for 1 hour and a half during the afternoon (from 15:00 to 16:30). Time is one of the most important factors for this work. We had to take notes of hours, minutes and seconds. In order to do this we used our cell phone chronometer. Every Monday we asked our chief to look at the time of the program in order to synchronize our cell phone with it. After that, in order to be more sure about the time, we wrote down in the register additional information about the opening or closing time of one of the gates that separate the different pools. In the interface program (see above) it is possible to detect really well the sound of an opening gate banging against the pool wall, and this allows to look at the time of this event and to compare it with the time on our register. If the two times were the same, we could continue the study without problems; if the two times didn't match, we had to change all the times written in the register adding or subtracting the seconds of differences.

In the register we took note of the starting time and the distribution of the animals in the pools. Then if an animal was alone in the pool where we were recording, we only wrote down the time when the animal changed its behavior; if there were more animals in the pool where we were recording, we had to write down the time and the behavior only referring to the animal that was looking at the hydrophone: at the same time we took note of the other animals' position at that moment. We also wrote the times when we saw an animal making bubbles because it could be connected to a sound emission.

After the observation part, we had to fulfill the work with the "Interface software".

In the office we could enter onto the program (that is installed on the computer of the La Laguna University at our disposal for this research), the range of data of our interest (date, time and recording channel) then we could start to consult the event database. We didn't enter bad quality sounds (Fig. 5.6) or electronic noise (Fig. 5.7).

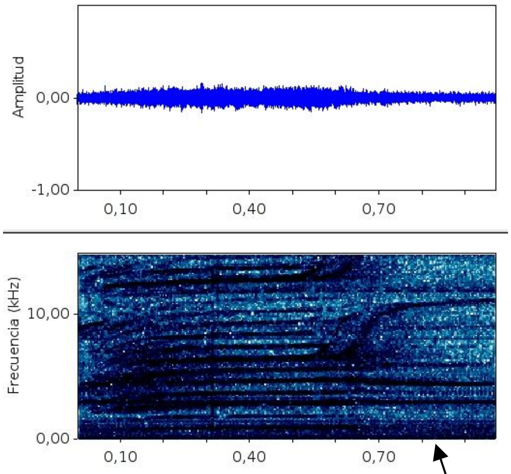


Fig 5.7 Interface software
Bad quality sound

Here we can see a sound

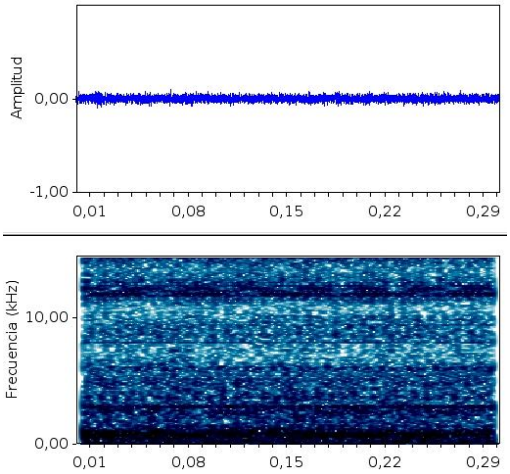


Fig 5.7 Interface software
Electronic noise

When we met a good quality sound (like the one in Fig 5.5) we controlled the register to see if at the same time an animal was alone in front of the hydrophone. If it was so, we could select the option “autosalvar” that allows to save a sound which bears the name of a killer whale in a folder of our choice. After setting the data for the auto-save function, we could enter the killer whale’s name in the space below the image (Fig 5.8).


Fecha: 26/10/2011
Hora: 10:03:40.2715
Duración: 0,713930
Clase: UNKNOWN
Evento 415 de 2378

Fig 5.8 lower part of the interface program

The work described so far allowed us to create a folder with a little database. After two months of work we had a database of about 300 sound events.

This was the basis for us to start with the third step: the classification.

In order to make classify sounds, we used the program called Audacity. We had to select the sound to enter and then we had to transform it for a good analysis result (Fig 5.9). After importing the sound, we had to transform it into a spectrogram (Fig 5.10).

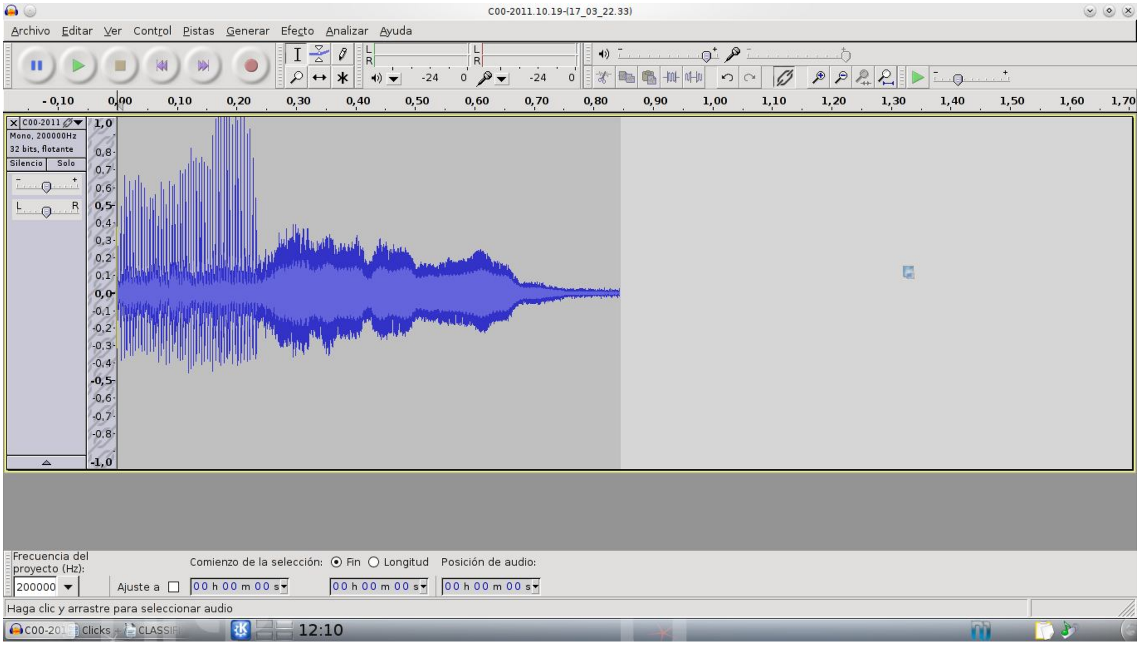
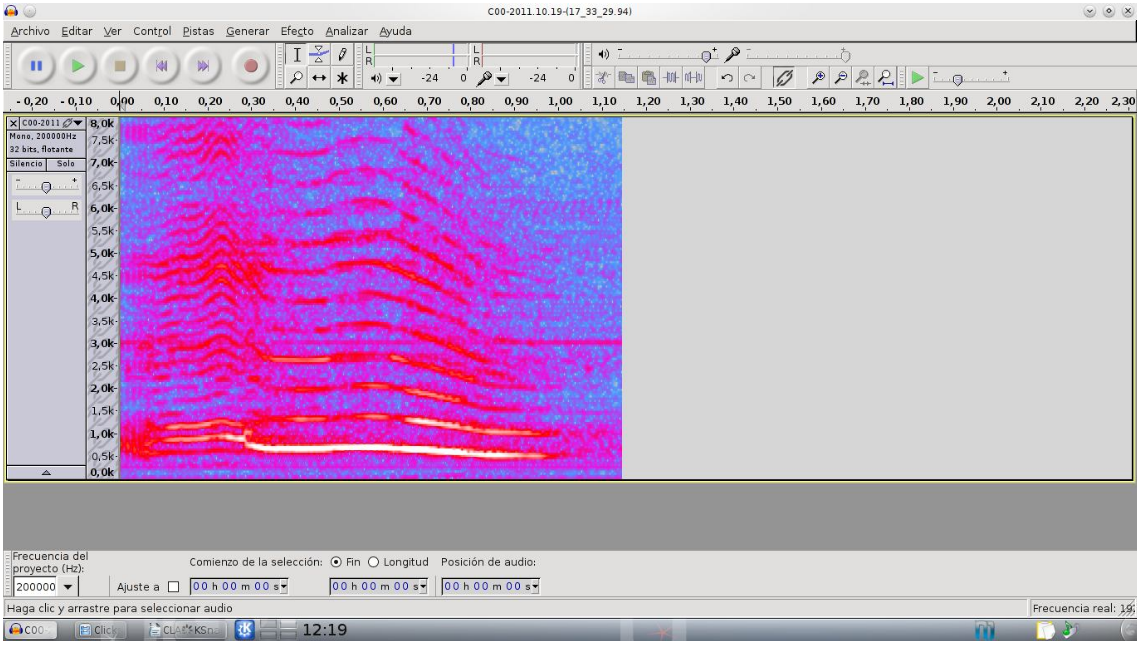

C00-2011.10.19-(17_03_22.33)
Mono, 200000Hz
32 bits, flotante
Frecuencia del proyecto (Hz): 200000
Ajuste a ☐
Comienzo de la selección: 00 h 00 m 00 s ● Fin ○ Longitud 00 h 00 m 00 s
Posición de audio: 00 h 00 m 00 s
Haga clic y arrastre para seleccionar audio

Fig. 5.9 Image from Audacity after importing the sound


C00-2011.10.19-(17_33_29.94)

C00-2011

Mono, 200000Hz

32 bits, flotante

Frecuencia del proyecto (Hz): 200000

Ajuste a ☐

Comienzo de la selección: ● Fin ○ Longitud

Posición de audio:

00 h 00 m 00 s

Haga clic y arrastre para seleccionar audio

Frecuencia real: 19

Fig. 5.10 Image in Audacity after the sound transformation into a spectrogram

For classification purposes we uses the spectrogram and the frequency contour, which are the frequency lines you can see in a spectrogram. This is because the sound is too much complex to be visually analyzed.

The program was set on the sample frequency of 200kHz (the frequency we were recording at), that allowed to look at a spectrogram in a range of 100kHz.

We chose to classify setting a frequency of 48kHz that allows to see the spectrogram in a range up to a maximum frequency of 24kHz (the half of 48kHz). These choise is linked to the final goal of this research that is about sound classification aimed to communicate in killer whales. The frequency of communication sounds isn’t higher than 24kHz. The sounds that have highest frequency are ultrasounds and these are not important in killer whales’ communication (personal communication).

Looking at the differences in the spectrograms and in the sounds (with Audacity, we could also hear the sound), we made our classification.

In order to continue this work the next step is to study the already identified vocalizations; to classify them for each animal; to identify the differences from the standpoint of the physics of sound. The researchers at the La Laguna University already started and right now they are doing this further work. This is very important, because it would allow the identification of the animal just relying on the sound produced, and it will allow to collect a lot of data even when more than one animal is in the recording pool.

When this point will be reached, it will be possible to continue with the study of the sounds produced in relation to the animal behavior. In my research I've already begun to match vocalizations to some simple behaviors but I could not collect data during the socialization of individuals (not being able to identify the animal that had emitted the sound).

6. Results

6.1 Classification

The classification of the sounds, was made by printing the sounds in a band from 0 to 24kHz in order to define the frequency contours, as this band is where the communication calls are usually classified. In the additional Hz there are ultrasounds, which are highly stereotyped and not useful for classification purposes. I often considered the spectrogram within a band from 0 to 8kHz in order to better identify the differences between sounds.

My classification:

CALLS:

Boat sound

consists in many horizontal lines one above the other. The time length of the sound is, normally, not more than 2 seconds (Fig. 6.1).

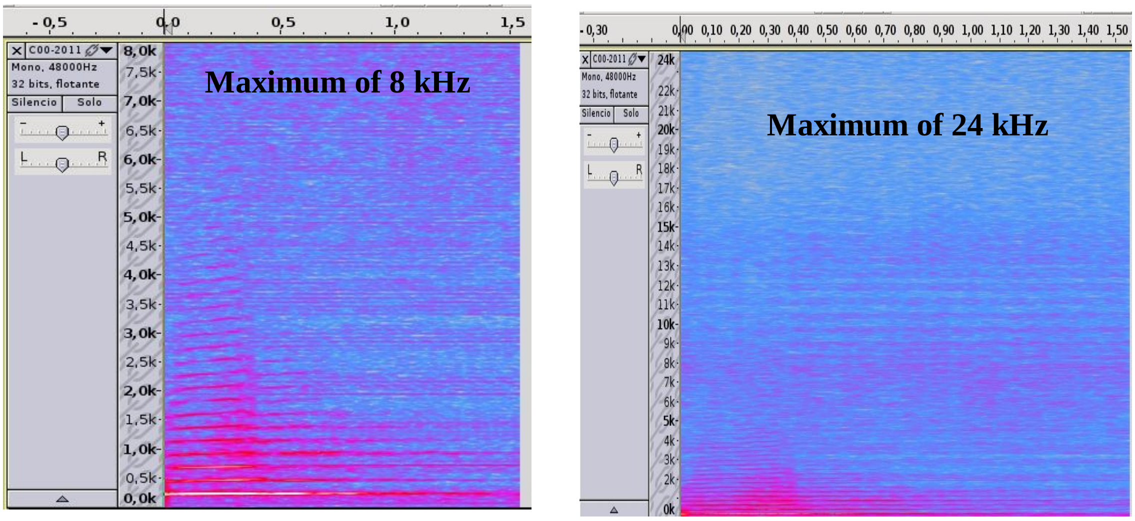


Fig. 6.1 Spectrograms of Boat sound
(x axis=time in seconds; y axis=frequency in kHz)

Boat sound 1

a pulsed sound is visible before the Boat sound (Fig. 6.2). A whistle could also be present.

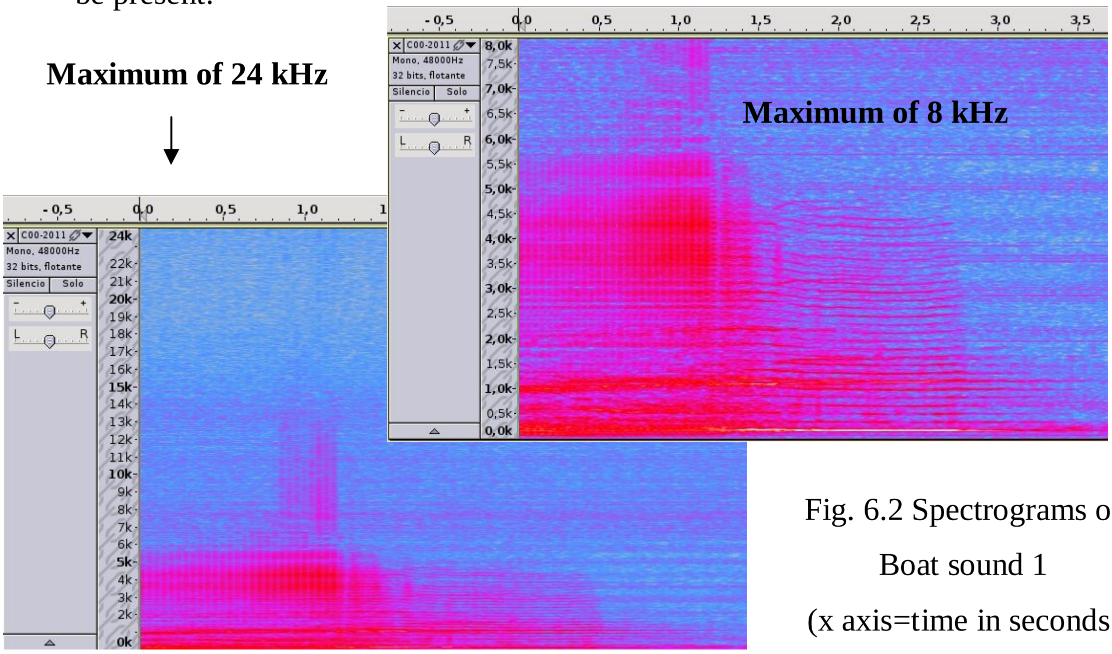


Fig. 6.2 Spectrograms of Boat sound 1 (x axis=time in seconds; y axis=frequency in kHz)

Long (waka waka)

a vertical line is visible at the beginning, from this point several horizontal lines spread one on the top of the other. The sound has a length between 5 and 8 seconds (Fig. 6.3).

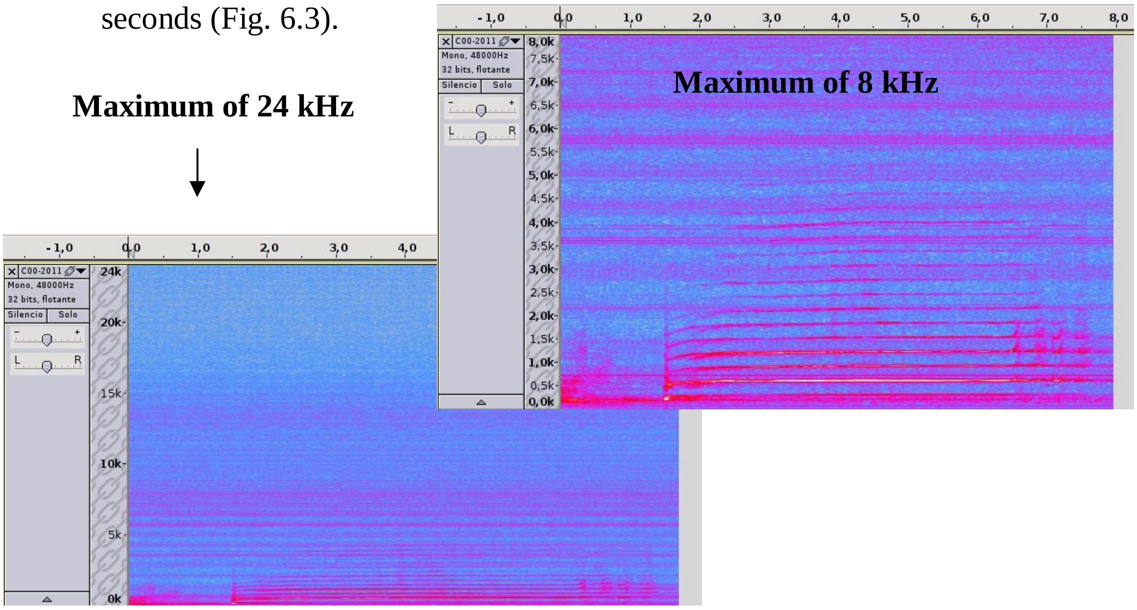


Fig. 6.3 Spectrograms of Long sound (x axis=time in seconds; y axis=frequency in kHz)

Elephant sound

starts with horizontal lines one above the other (very short in time), but afterwards it rises up with horizontal lines at 1.5kHz and goes on every 1kHz (one on the top of the other) (Fig. 6.4).

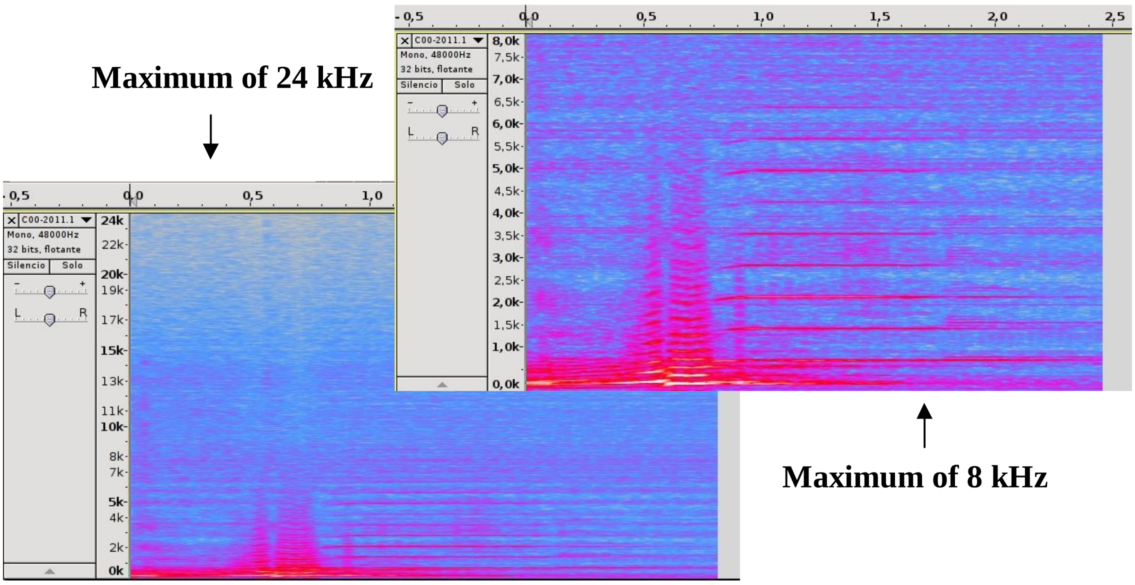


Fig. 6.4 Spectrograms of Elephant sound (x axis=time in seconds; y axis=frequency in kHz)

Elephant sound 1

a pulsed sound is visible before the elephant sound (Fig. 6.5). A whistle could also be present.

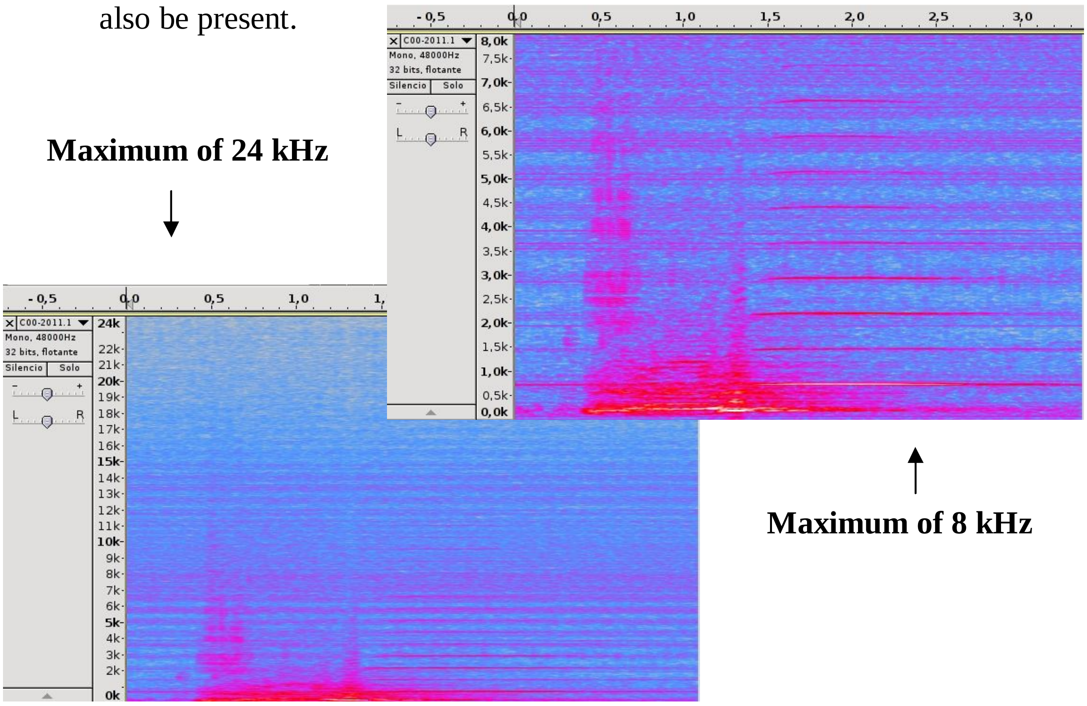


Fig. 6.5 Spectrograms of Elephant sound 1 (x axis=time in seconds; y axis=frequency in kHz)

Two part

consists in 2 short calls; between them there is a silence time where, anyway, a whistle could be present (Fig. 6.6 and Fig. 6.7)

Fig. 6.6 How Audacity program presents the two-part sound
(x axis=time in seconds; y axis=frequency in kHz)

Maximum of 8 kHz →

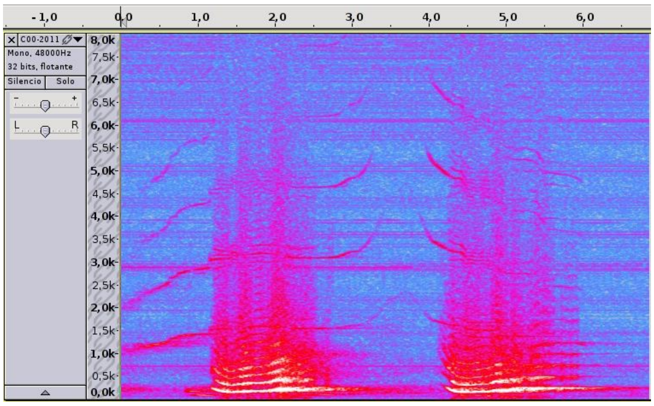


Fig. 6.7 Spectrogram of

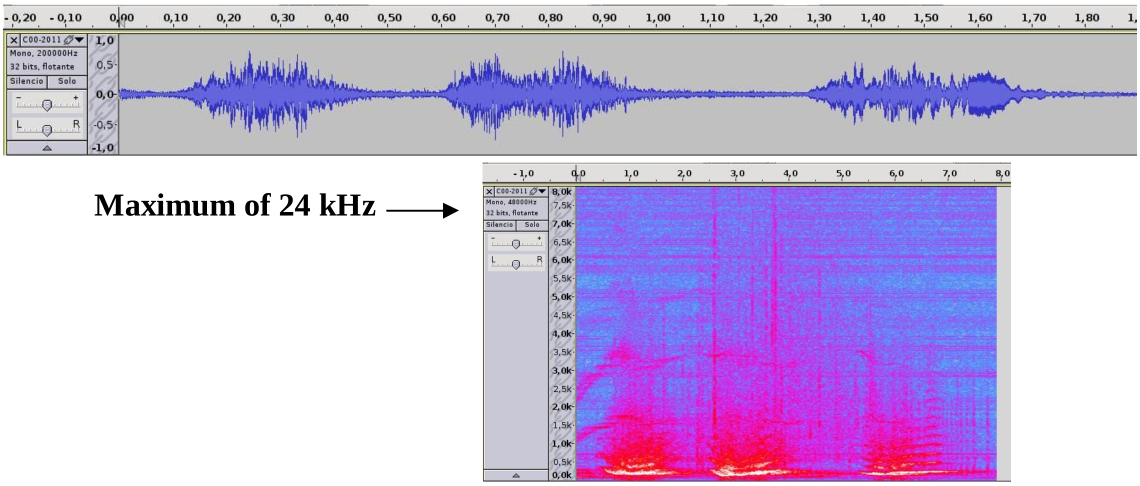
Two part sound

(x axis=time in seconds;

y axis=frequency in kHz)

Three part

consists in 3 short calls; among them there is a silence time where, anyway, a whistle could be present (Fig. 6.8).



Maximum of 24 kHz →

Fig. 6.8 How Audacity program presents the three-part sound; and its spectrogram
(x axis=time in seconds; y axis=frequency in kHz)

WHISTLE:

The classification of this class was made primarily basing on temporal data. To better identify the differences in the time length of the whistle respect to the call, in the spectrogram analysis it was very useful to put the upper limit to 8 kHz.

Type 0 (not before)

starts with a call of about 2 seconds and a whistle in the end. The whistle starts in the call, but finishes about 1 second later (Fig. 6.9).

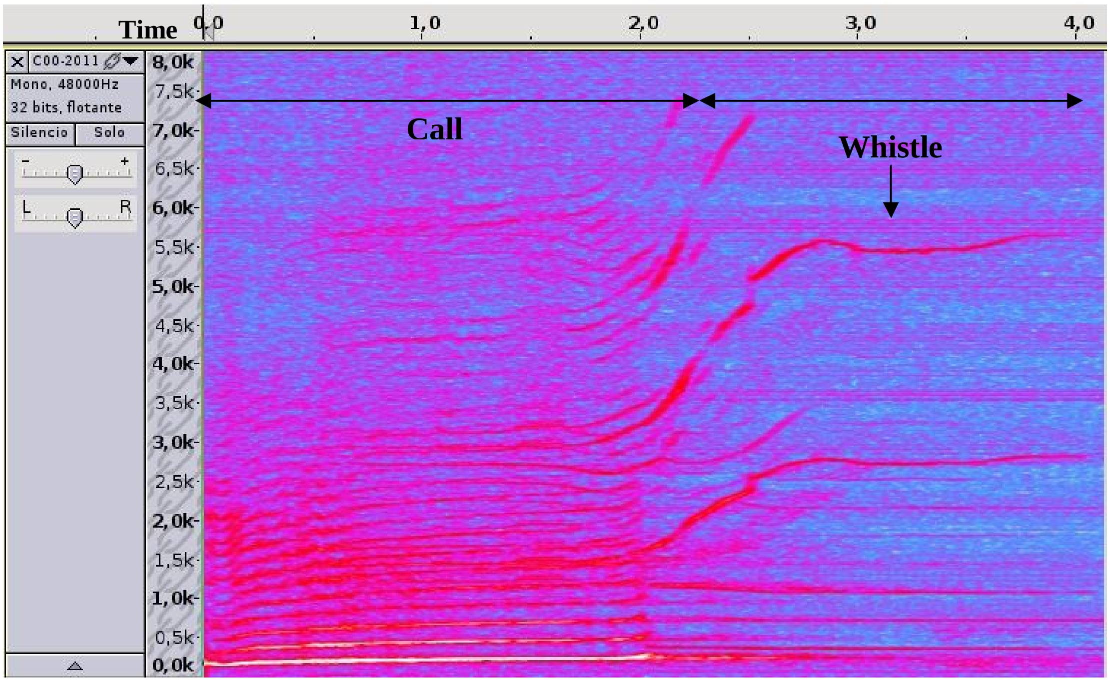


Fig. 6.9 Spectrogram of Whistle type 0

Type 1

consists in a call and a whistle. The whistle starts a little before the call (not more than 1 second) and finishes a little after it (not more than 2 seconds) (Fig. 6.10).

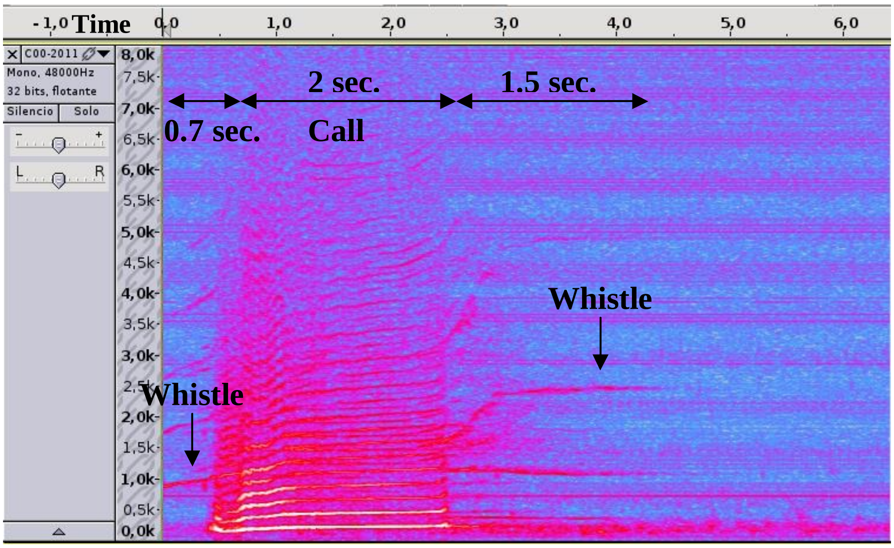


Fig. 6.10 Spectrogram of Whistle Type 1

Type 2

the whistle starts about 2 seconds (1,5 seconds) before the call and in the end doesn’t reach 2 seconds (Fig. 6.11).

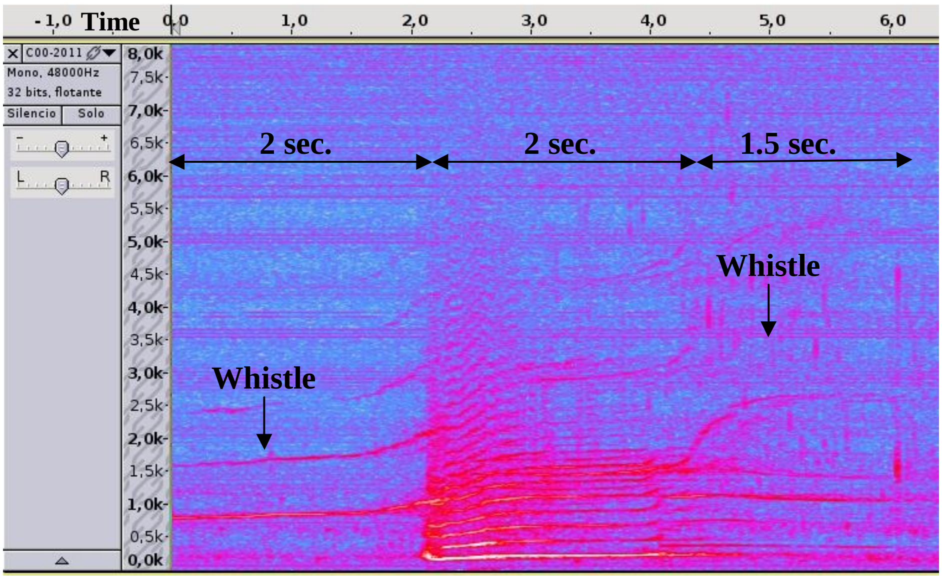


Fig. 6.11 Spectogram of Whistle type 2

Type 3 (long end)

the whistle starts a little before the call (about 1 second) and in the end is long not less than 2 seconds (Fig. 6.12).

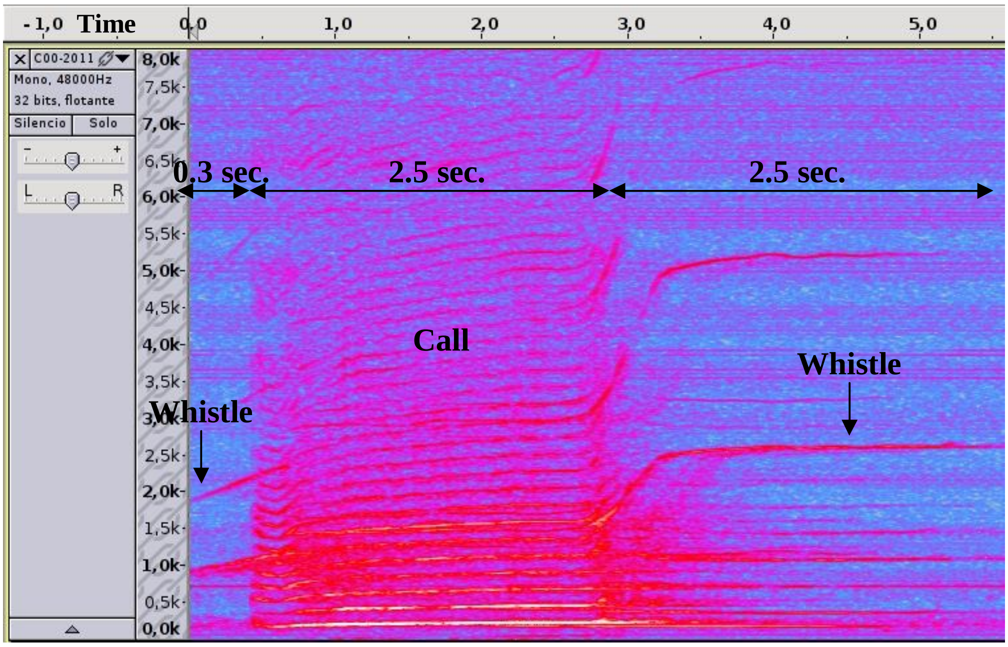


Fig. 6.12 Spectrogram Whistle type 3

Type 4 (hard end)

a whistle starts before the call and finishes inside it (Fig. 6.13).

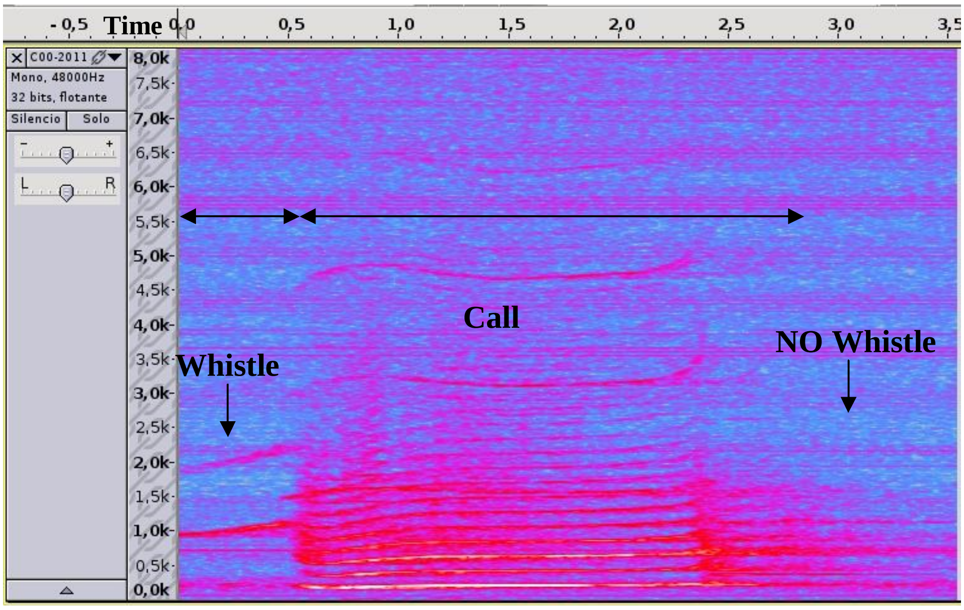
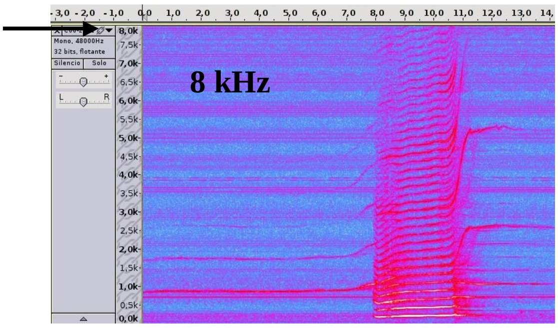
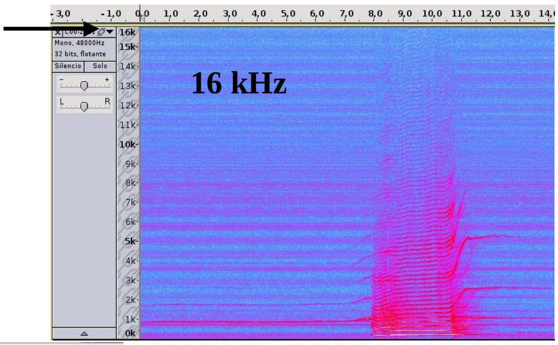


Fig. 6.13 Spectrogram Whistle 4

Type 5 (long start)

a long whistle starts more than 2 seconds before the call, it often reaches 4 seconds before the call. If it starts “only” 2 seconds before the call it is short after the end of the call. If it starts 4 seconds before the call it could continues for 1,5 or 2 seconds after the end of the call (Fig. 6.14).





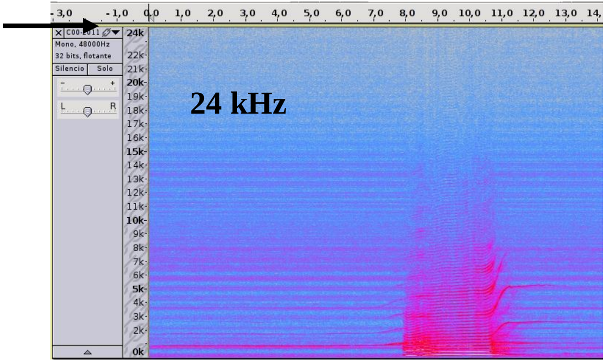


Fig. 6.14
Spectrograms of
Whistle type 5

CLICKS:

Solo clicks

they can reach loud frequency, so we can use the spectrogram with a maximum range of 100khz, that is our maximum resolution (Fig. 6.15; Fig. 6.16).

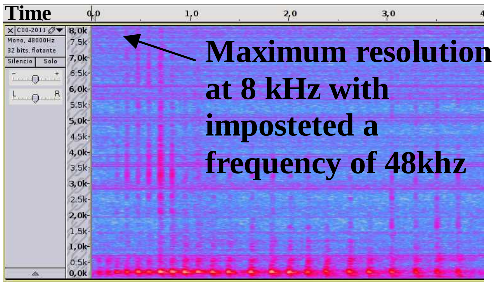


Fig. 6.15 Spectrograms of Clicks

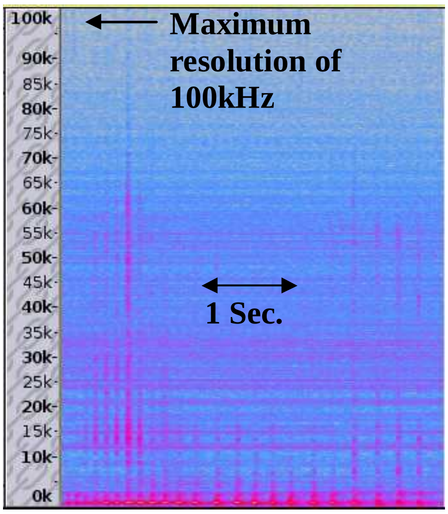


Fig. 6.16 Spectrograms of Clicks

6.2 Summary tables

The data used in these tables were collected from the beginning of October 2011 to the end of November 2011 (29 November: Morgan's arrival).

In the following two tables (Table 6.1 and Table 6.2) it is possible to see all the analyzed sounds, including the ones that were collected in the first days of October. These first data weren't divided per situation (Chosen alone, Put alone or With other orcas) and per behaviour (Annex 1), but only per animal.

Table 6.1 Type of calls related to animals

	CALL	WHISTLE	Solo CLICKS	tot
SKYLA	35	35	2	72
TEKOA	56	75	2	133
KETO	11	26	0	37
KOHANA	10	21	2	33
ADÁN	25	9	6	40
Tot:	137	166	12	315

Table 6.2 Situation in which the animal is, related to the animal

	CHOSEN ALONE	PUT ALONE	WITH OTHER ORCAS	BEFORE CLASIFICATION
SKYLA	6	38	28	0
TEKOA	55	50	9	19
KETO	2	24	9	2
KOHANA	0	0	31	2
ADÁN	2	9	6	23
Tot:	65	121	83	46

Total amount of sounds: 315

From now onwards all the tables show the data resulting from the sounds that we have completely classified i.e. a total amount of 270 sounds (Table 6.3)

Table 6.3 Distribution of collected sound in behaviour category for each animal

	MOVEMENT	TRAINING	CONTACT WITH TRAINERS	AERIAL SCAN	SPYHOP	Tot:
SKYLA	52	6	12	2	0	72
TEKOA	107	6	1	1	0	115
KETO	28	4	3	0	0	35
KOHANA	21	0	9	0	1	31
ADÁN	12	5	0	0	0	17
Tot:	220	21	25	3	1	270

In general we have more data collected while the animals were making the movement behaviour, in comparison with other behaviours (Fig. 6.17).

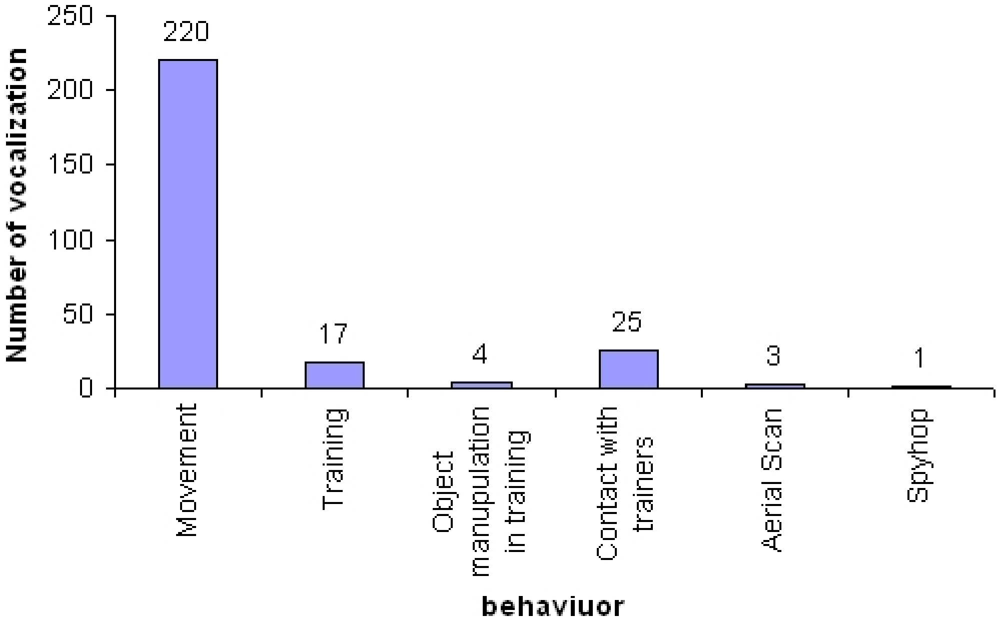


Fig. 6.17 Distribution of collected sound in behaviour category

6.3 Graphics

In the histogram (Fig. 6.18) it is possible to see the total amount of the sounds for each group of my classification. I have only considered the sounds classified in the same way by me and Renée (so I eliminated 14 sounds).

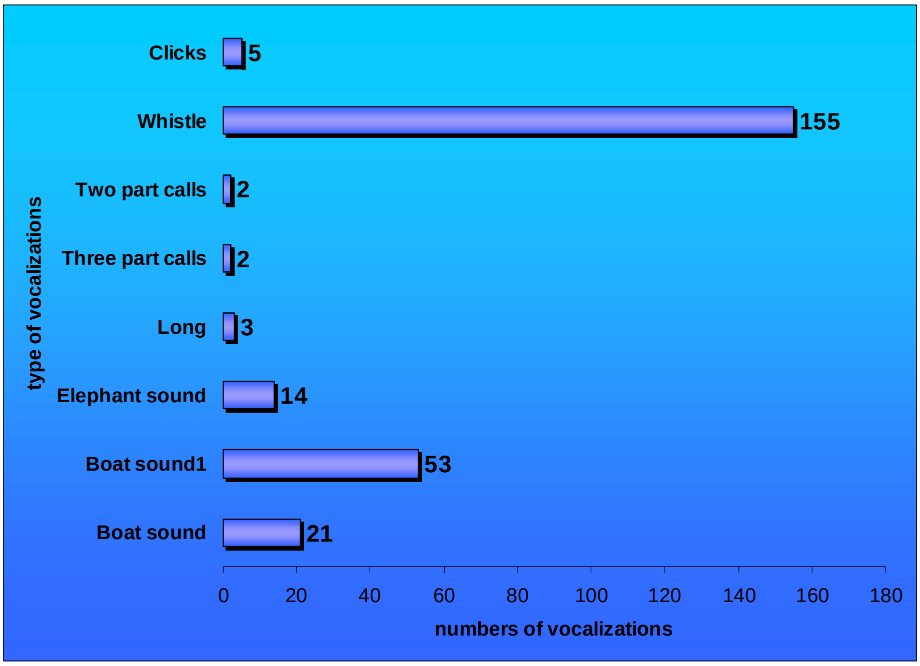


Fig. 6.18 Total amount of different types of sounds

In my classification at 48kHz I have six whistle subclasses. We can see the distribution of the total amount of the sounds collected for each subclass in the histogram (Fig. 6.19).

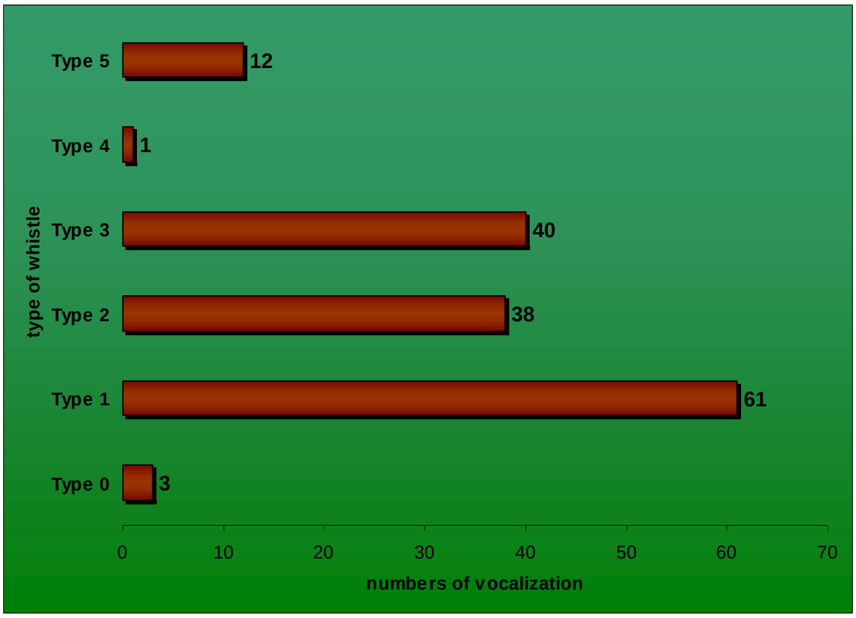


Fig. 6.19 Total amount of different whistle

The sounds were classified also looking at the animals' behaviour. The histogram below illustrates the three behaviours for which we found more sounds. It is possible to observe the different frequency of the classified categories for the three behaviours (Fig. 6.20; Fig. 6.21; Fig. 6.22).

In order to calculate the frequency I added the total number of the events present in the situation movement, then I divided the number of sounds of each class for the total number.

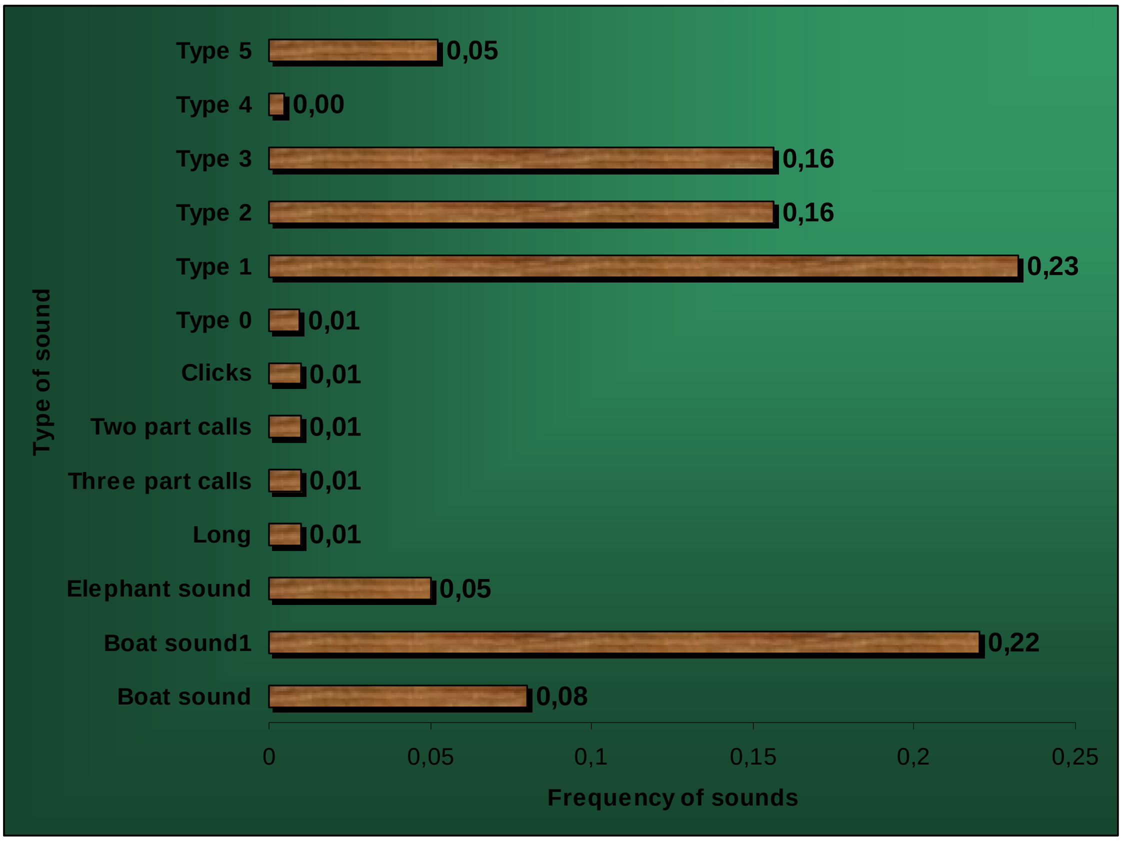


Fig. 6.20 The different types of sound in movement

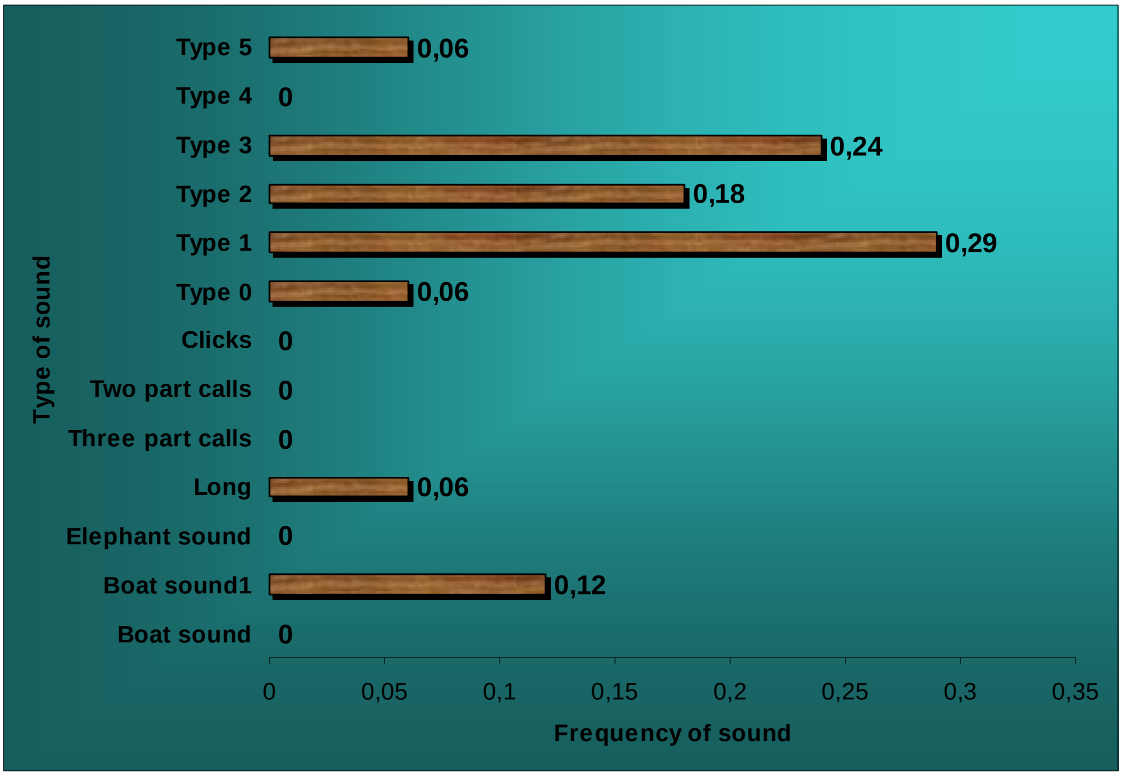


Fig. 6.21 The different types of sound in training

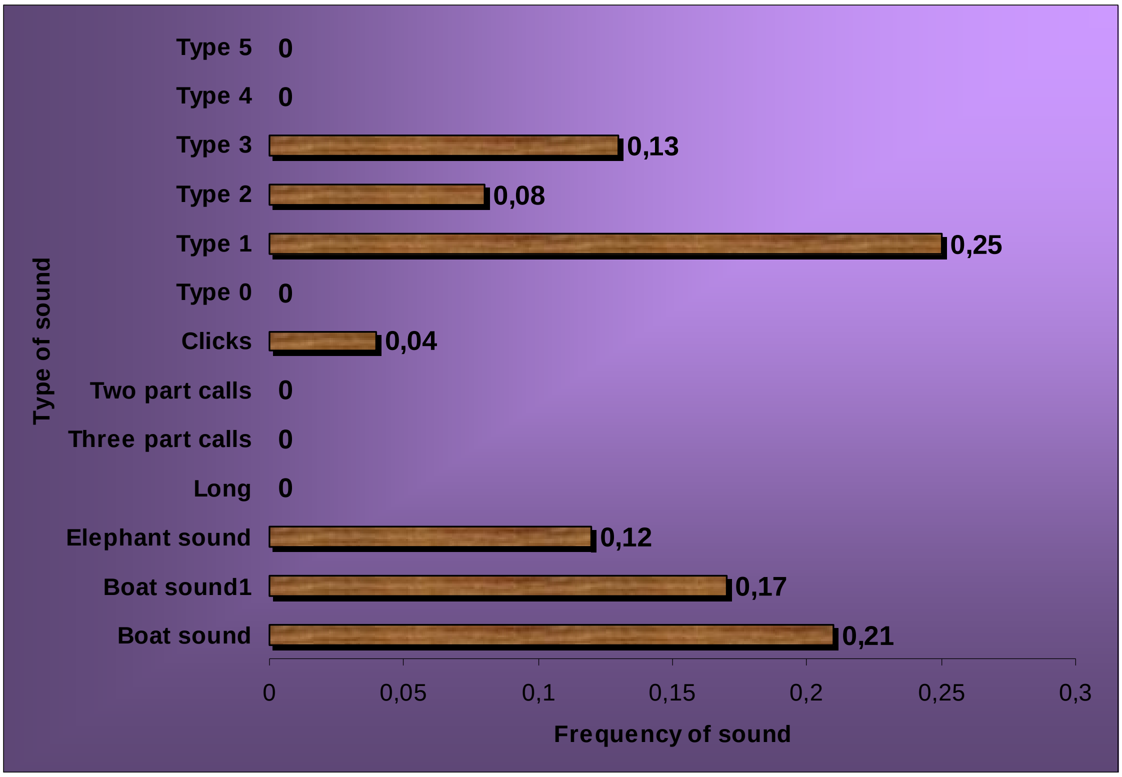


Fig. 6.22 The different types of sound in contact with trainers

Another interesting thing could be look at the different frequency of sounds relationated to the animals.

In total we collected 16 vocalizations by Adán. They don't represent all the types of sound present in my classification (Fig. 6.23).

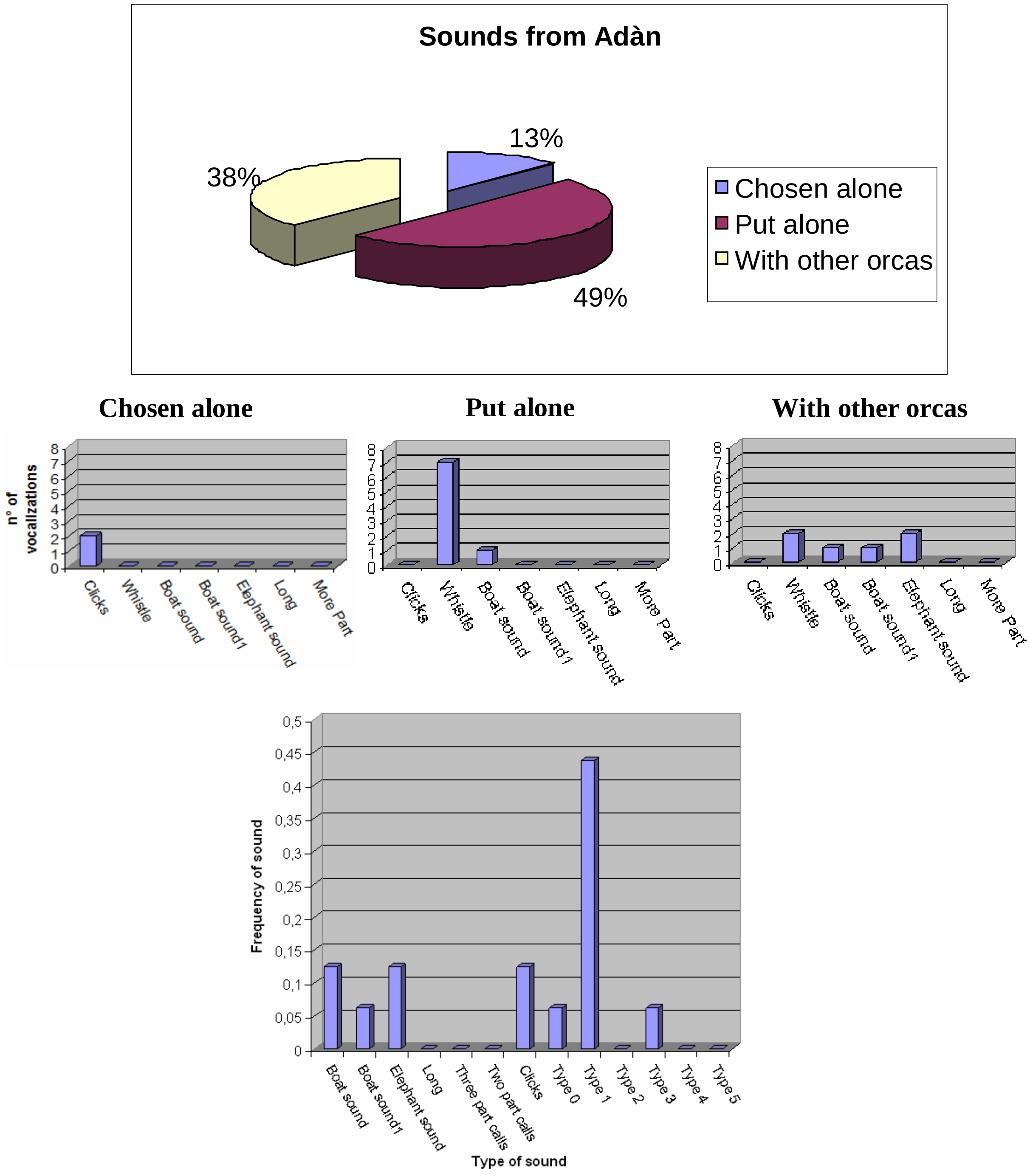
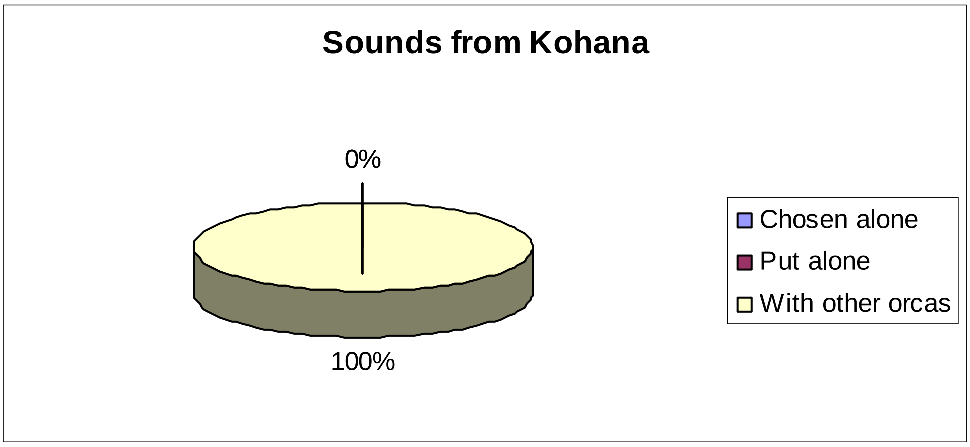


Fig. 6.23 Distribution of Adàn's sounds in the different categories

From Kohana we collected a total of 30 sounds, all issued in the situation “With other orcas”. When she was Chosen or Put alone, we have never found sounds with a good quality (Fig. 6.24).



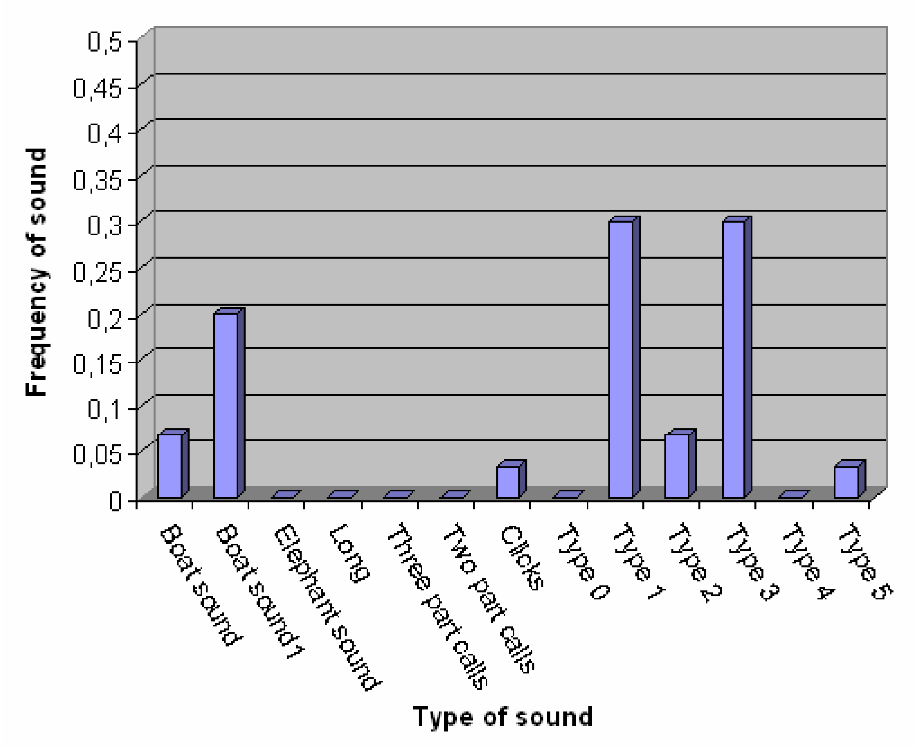


Fig. 6.24 Distribution of Kohana’s sounds in the different categories

From Keto we collected a total of 31 sounds (Fig. 6.25)

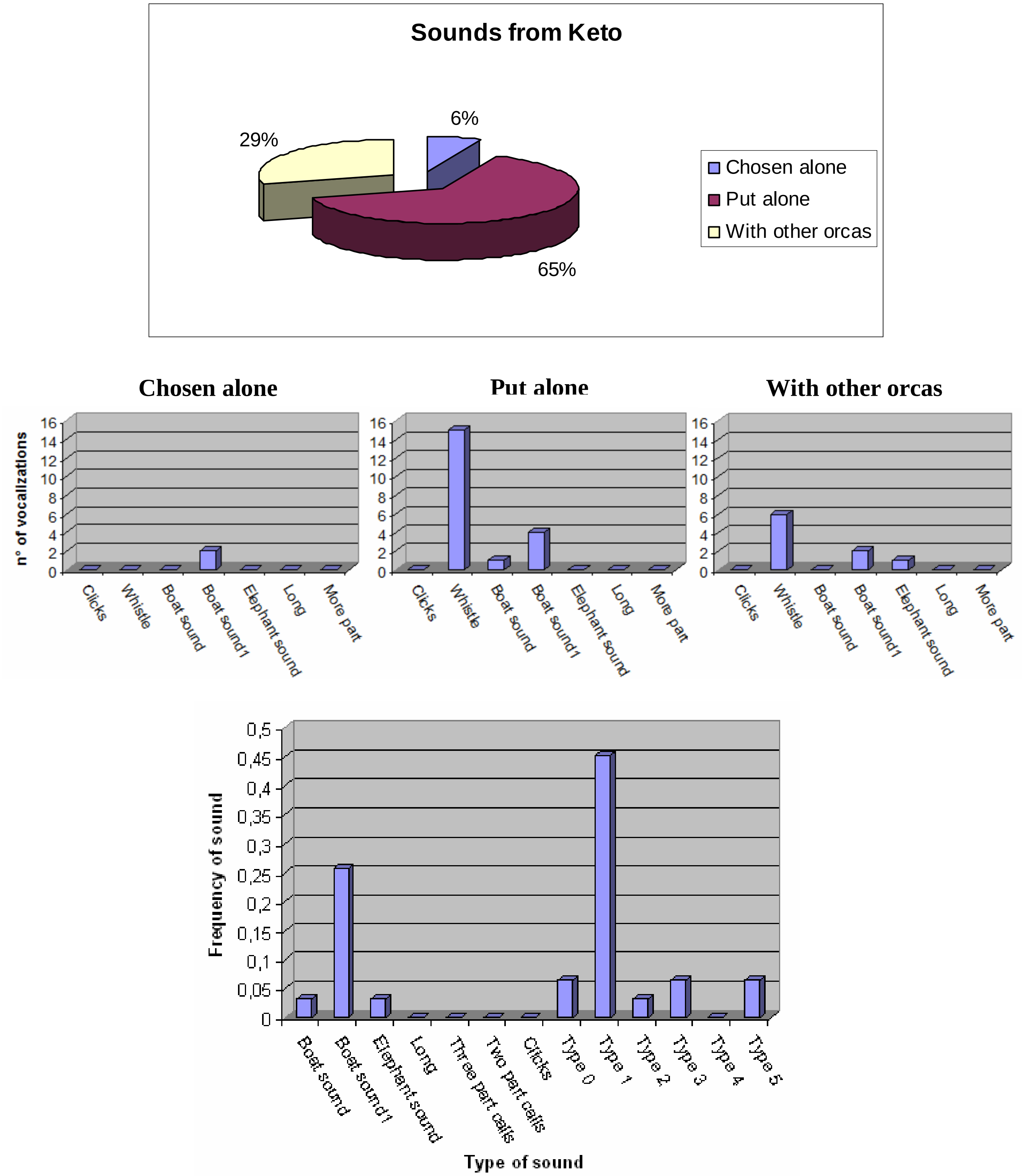


Fig. 6.25 Distribution of Keto's sounds in the different categories

From Skyla we collected a total of 70 sounds (Fig. 6.26)

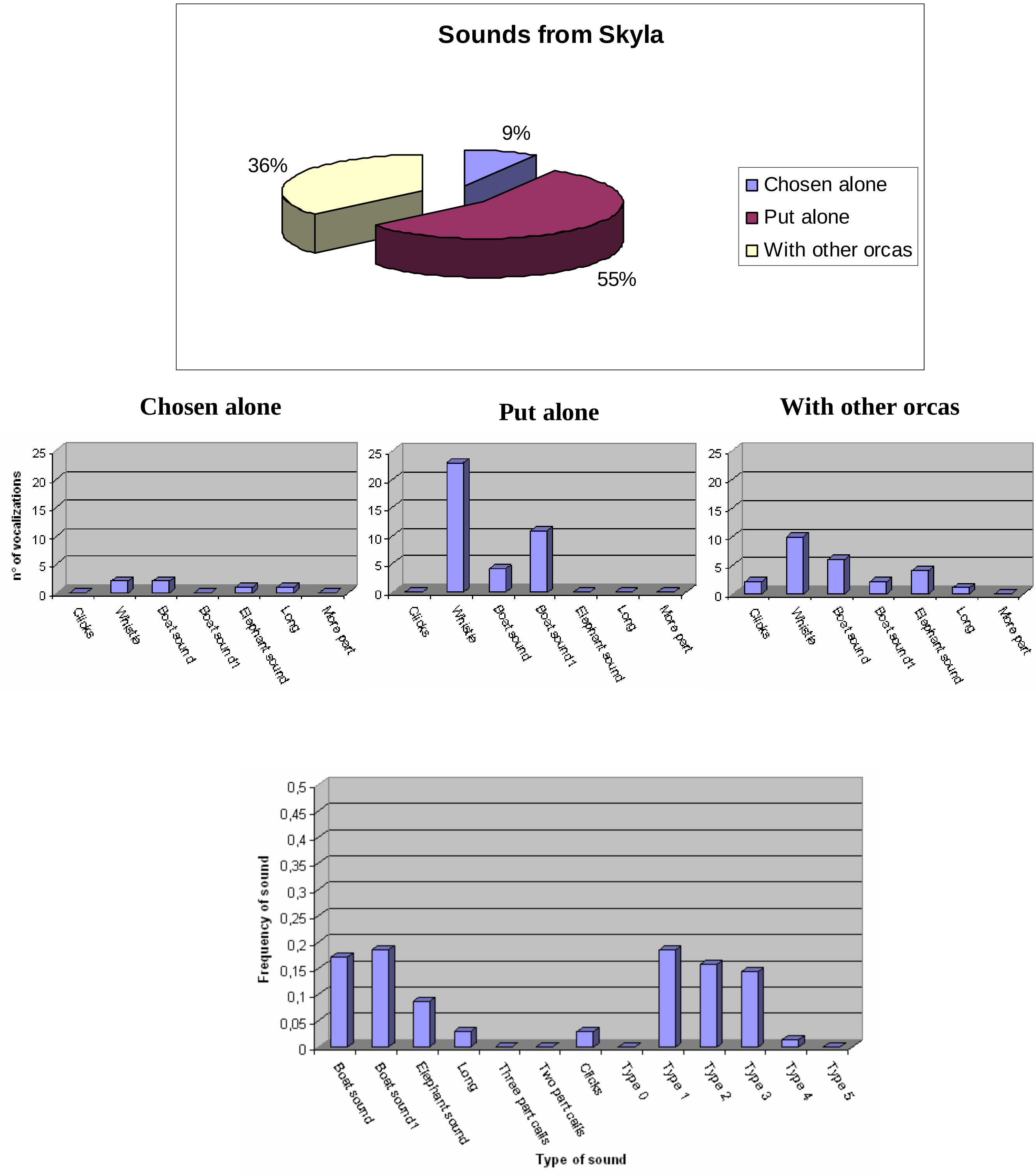
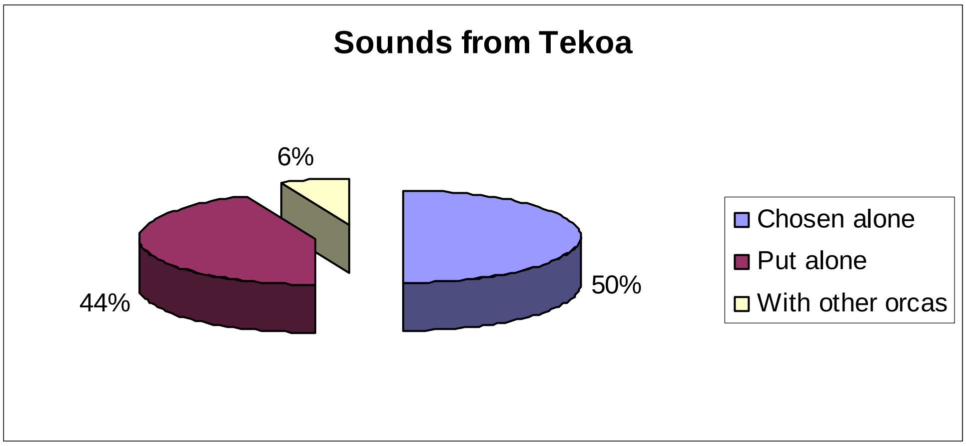
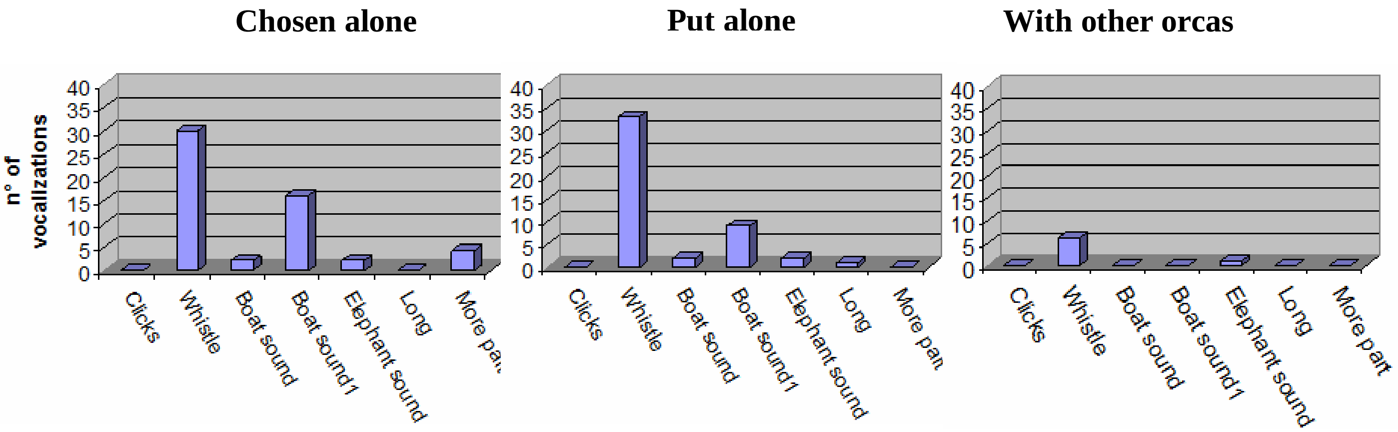


Fig. 6.26 Distribution of Skyla's sounds in the different categories

From Tekoa we collected a total of 108 sounds (Fig. 6.27).





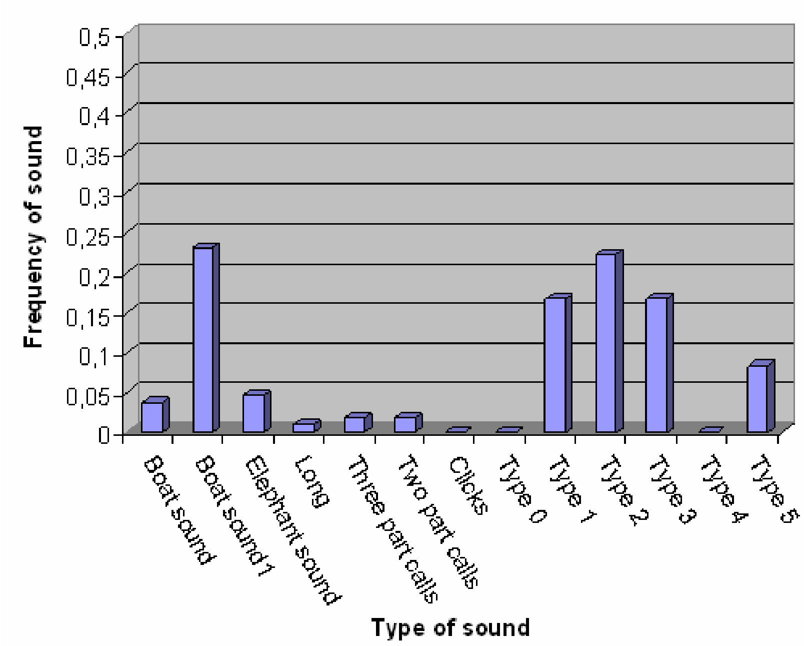


Fig. 6.27 Distribution of Tekoa's sounds in the different categories

6.4 Statistical Analysis

I calculated the frequency of vocalizations per minute in different situations and it was created an excel spreadsheet. The situations are: Chosen alone; Put alone and With other orcas. The frequencies of vocalization per minute were calculated by dividing the number of good quality vocalizations found at a certain time for the same time. In the event with more than one killer whales, the result obtained was divided by the number of killer whales present during the sound recording in the pool. The frequencies thus obtained were grouped into different groups in order to create different summary statistic tables (Tables 6.4; 6.5 and 6.6). From these data we also obtained three summary histograms, one for each situation (Fig. 6.28; 6.29; 6.30).

Table 6.4 With other orcas:

Counting	152
Mean	0.316645
Standard deviation	0.515768
Coefficient of variation	162.886%
Minimum	0
Maximum	3.33
Range	3.33
Standardized asymmetry	15.2422
Standarized kurtosis	30.0983

The standarized asymmetry and standarized kurtosis can be used to determine if the sample comes from a normal distribution. The range of this statistic outside is from -2 to +2 and out of this range it indicates a significant deviation from normality (Gaussian distribution of data) that might tend to invalidate any statistical test that covers the standard deviations.

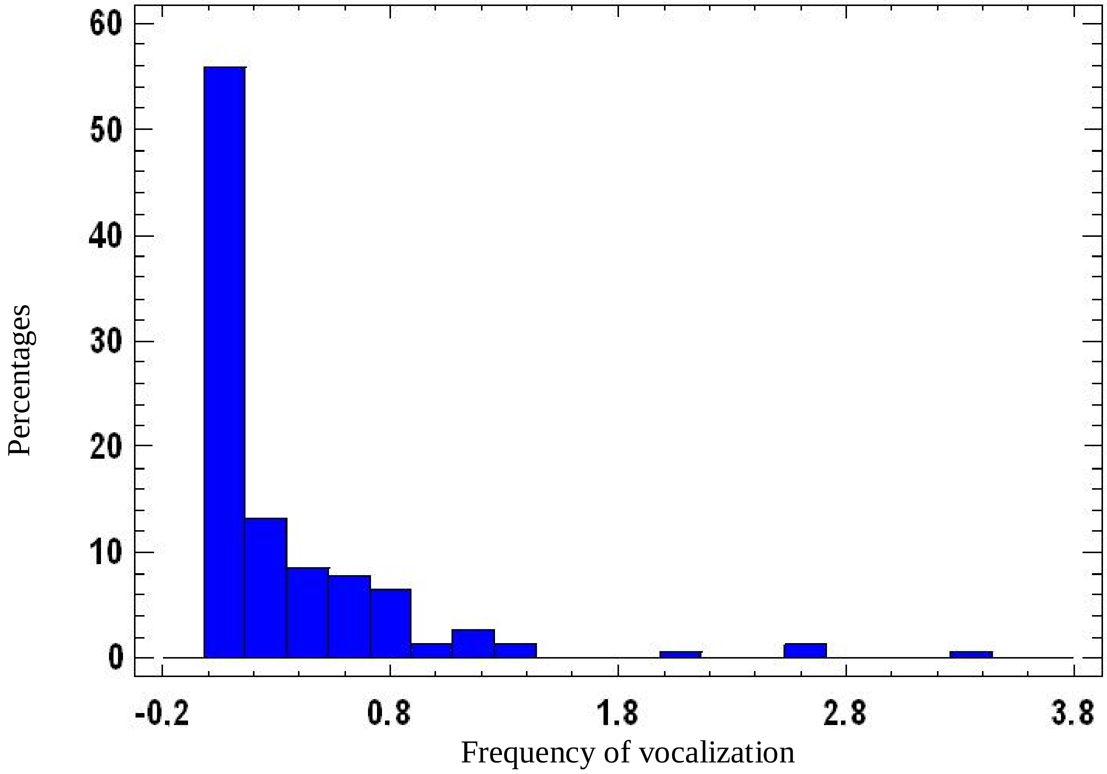


Fig 6.28 Histogram of frequency for “With other orcas”

Table 6.5 Chosen alone:

Counting	69
Mean	0.563333
Standard deviation	1.31434
Coefficient of variation	233.314%
Minimum	0
Maximum	6.32
Range	6.32
Standardized asymmetry	9.25606
Standarized kurtosis	12.6627

As in the previuos case the standardized asymmetry and standaryzed kurtosis appear to be out of range. So we can say that also in this case the sample is not from a normal distribution.

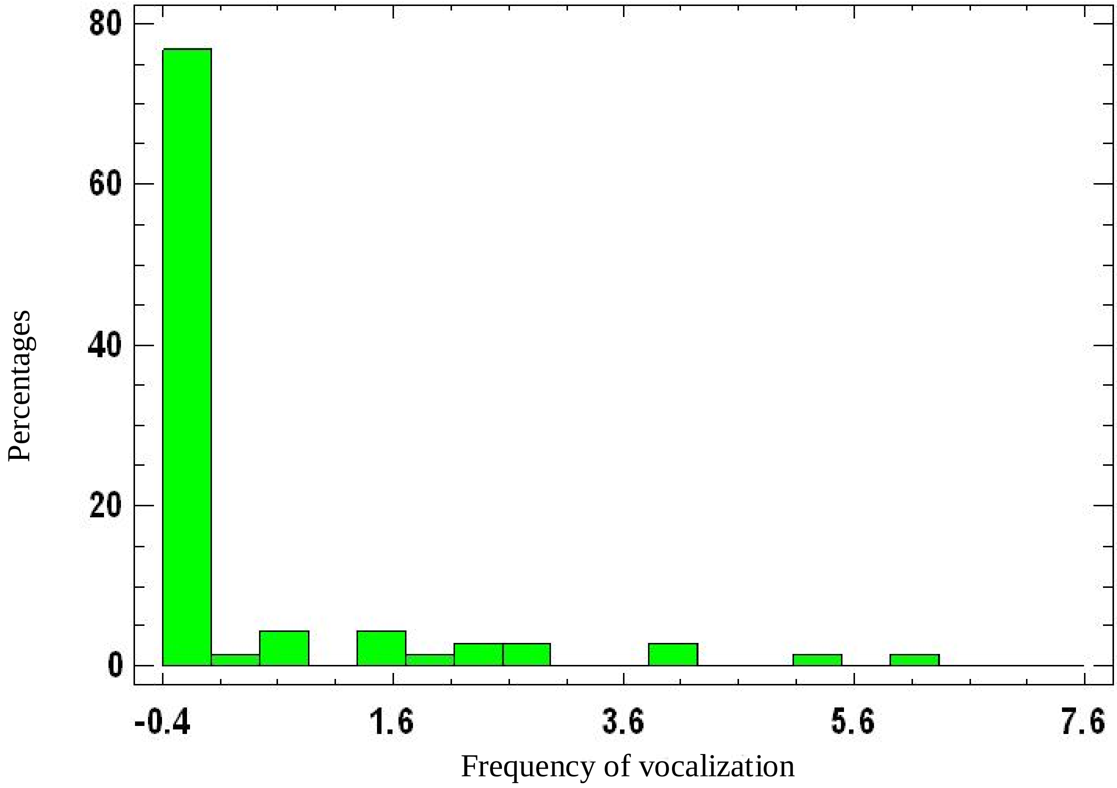


Fig 6.29 Histogram of frequency for “Chosen alone”

Table 6.6 Put alone:

Counting	77
Mean	0.0707792
Standard deviation	0.199425
Coefficient of variation	281.757%
Minimum	0
Maximum	1.12
Range	1.12
Standardized asymmetry	13.1242
Standarized kurtosis	25.1116

As in the previous two cases the standardized asymmetry and standaryzed kurtosis appear to be out of range. So we can say that also in this case the sample is not from a normal distribution.

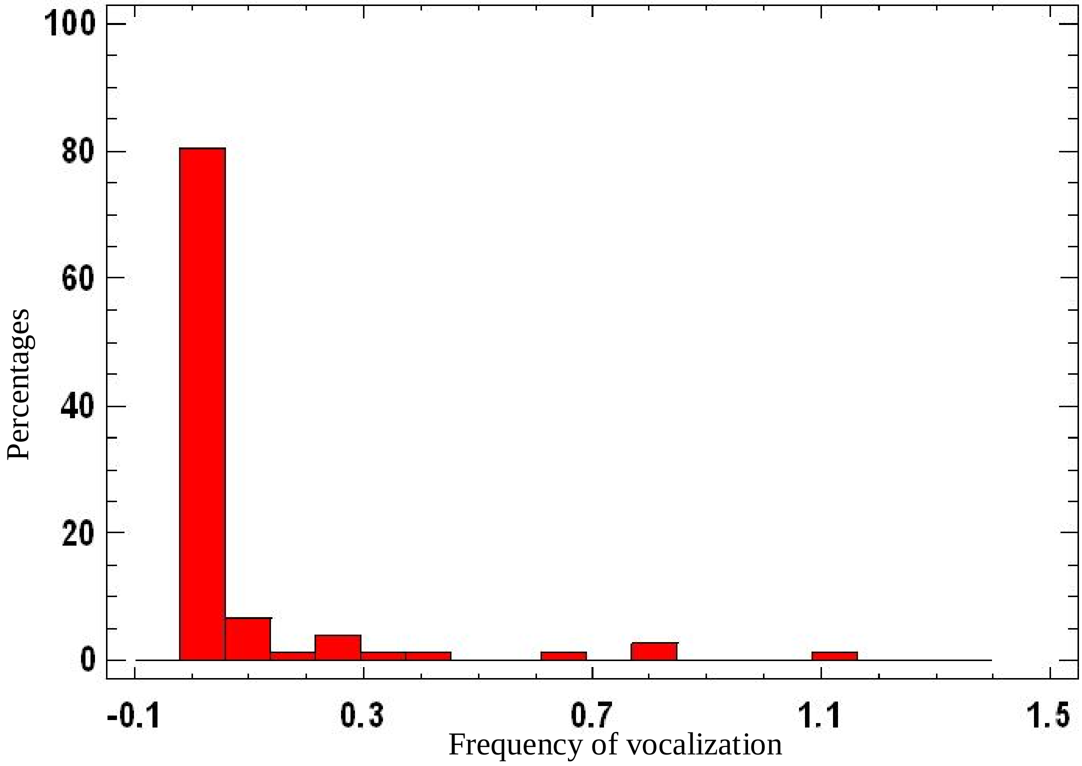


Fig 6.30 Histogram of frequency for Put alone

We made several comparisons:

1 Without human/ With human

In this analysis the frequencies of vocalizations emitted in the presence or absence of human beings are compared (Table 6.7)

Table 6.7 Summary statistics

	Without human	With human
Counting	217	116
Mean	0.421928	0.0644828
Standard deviation	0.0868411	0.187544
Coefficient of variation	205.82%	290.844%
Minimum	0	0
Maximum	6.32	0.92
Ramge	6.32	0.92
Standardized asymmetry	22.0038	14.4441
Standarized kurtosis	50.0127	22.6023

Thanks to the summary table, we see that standardized asymmetry and standardized kurtosis are outside the normal range (the normal range is from -2 to +2). This might tend to invalidate the tests that compare the standard deviations. It is therefore safer to use tests that compare the medians of the two samples.

Median of the sample 1	0.05
Median of the sample2	0

Test W by Mann-Whitney (Wilcoxon):

Null hypothesis: median 1 = median2

Alternative hypothesis: median 1 ≠ median 2

Mean ranke of the sample 1 = 188.823

Mean ranke of the sample 2 = 126.177

W = 7850.5   P-value = 1.65019E-10

Reject the null hypothesis for alpha = 0.05.

This test is constructed by combining the two samples, sorting the data from the smallest to the largest, and comparing the average ranks of two samples in the combined data. Since the P-value is less than 0.05 there is a significant difference between the medians with a confidence level of 95.0%.

Test by Kolmogorov-Smirnov

Estimated DN statistical	0.836207
Bilateral K-S statistic for large samples	7.27027
P-value approximated	0

This test compares the distributions of the two samples. It is performed by calculating the maximum distance between the cumulative distributions of the two samples. In this case, the maximum distance is 0.836207, which can be represented graphically (Fig. 6.31). Of particular interest is the approximated P-value that being lower than 0.05 tells us that there is a statistically significant difference between the two distributions with a confidence level of 95.0%

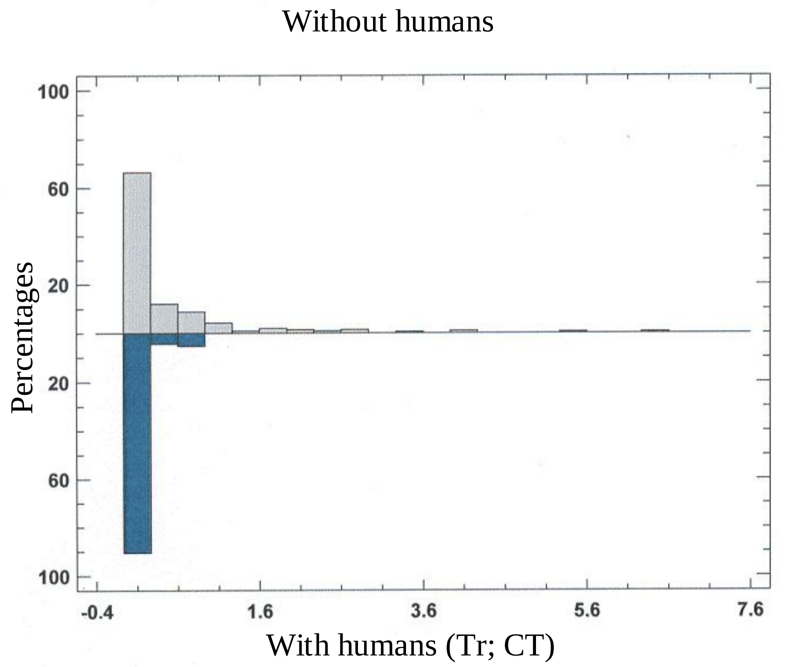


Fig 6.31 Distribution of frequencies of vocalization in the two situation

2 With other orcas / Alone

In this analysis vocalization frequencies/minute are compared, by comparing moments when killer whales stay together with moments when they are alone in the sound recording pool (Table 6.8).

Table 6.8 Summary statistic

	With other orcas	Alone
Counting	152	146
Mean	0.316645	0.303562
Standard deviation	0.515768	0.944384
Coefficient of variation	162.886%	311.101%
Minimum	0	0
Maximum	3.33	6.32
Range	3.33	6.32
Standardized asymmetry	15.2422	20.5179
Standarized kurtosis	30.0983	46.9276

Thanks to the summary table, we see that also in this analysis the standardized asymmetry and standardized kurtosis are outside the normal range (the normal range is from -2 to +2). As stated above this could invalidate the tests that compare the standard deviations. It is therefore safer to use, also here, tests that compare the medians of the two samples.

Median of the sample 1	0.1
Median of the sample2	0

Test W by Mann-Whitney (Wilcoxon):

Null hypothesis: median 1 = median2

Alternative hypothesis: median 1 ≠ median 2

Mean ranke of the sample 1 = 173.651

Mean ranke of the sample 2 = 124.356

W = 7425.0 P-value = 3.48573E-8

Reject the null hypothesis for alpha = 0.05.

This test is constructed by combining the two samples, sorting the data from the smallest to the largest, and comparing the average ranks of two samples in the combined data. Since the P-value is less than 0.05 there is a significant difference between the medians with a confidence level of 95.0%.

Test by Kolmogorov-Smirnov

Estimated DN statistical	0.767123
Bilateral K-S statistic for large samples	6.61996
P-value approximated	0

This test compares the distributions of the two samples. It is performed by calculating the maximum distance between the cumulative distributions of the two samples. In this case, the maximum distance is 0.767123, which can be represented graphically (Fig. 6.32). Of particular interest is the approximated P-value that being lower than 0.05 tells us that there is a statistically significant difference between the two distributions with a confidence level of 95.0%

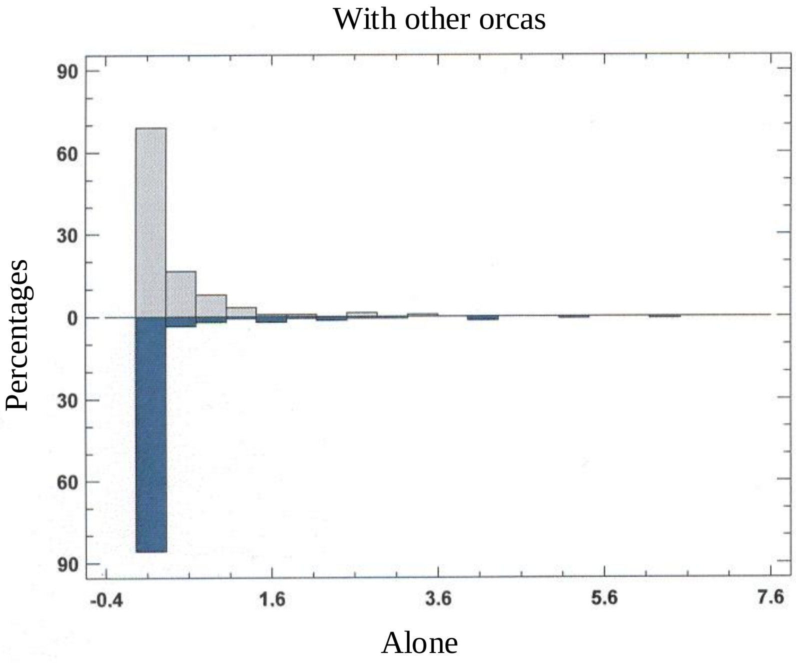


Fig 6.32 Distribution of frequencies of vocalization in the two situation

3 With other orcas/ Chosen alone/ Put alone

In this analysis we compared vocalization frequencies/minute in three different situation: when killer whales stay together; when they are chosen alone and when they are put alone in the sound recording pool (Table 6.9).

Table 6.9 Summary statistic

	Counting	Mean	Standard deviation	Coefficient of variation
With other orcas	152	0.316645	0.515768	162.886%
Chosen alone	69	0.563333	1.31434	233.314%
Put alone	77	0.0707792	0.199425	281.757%
Total	298	0.310235	0.755454	243.51%

	Minimum	Maximum	Range	Standardized asymmetry	Standarized kurtosis
With other orcas	0	3.33	3.33	15.2422	30.0983
Chosen alone	0	6.32	6.32	9.25606	12.6627
Put alone	0	1.12	1.12	13.1242	25.1116
Total	0	6.32	6.32	31.0906	85.4762

Table of means with ranges LSD to 95%

	Counting	Mean	Standard error (s aggregate)	Lower limit	Upper limit
With other orcas	152	0.316645	0.0598578	0.233346	0.399944
Chosen alone	69	0.563333	0.0888419	0.4397	0.686967
Put alone	77	0.0707792	0.0841002	-0.046256	0.187814
Total	298	0.310235			

Here we find the mean and standard error for each data column. The standard error is a measure of variability of sampling. It is formed by dividing the pooled standard deviation by the square root of the number of observations in each interval. The intervals around each mean are based on the procedure of LSD (Least Significant Difference) by Fisher (Fig. 6.33).

In the chart below, you can see the range of means and test multiple ranges, these ranges are used to determine which means are significantly different from the others.

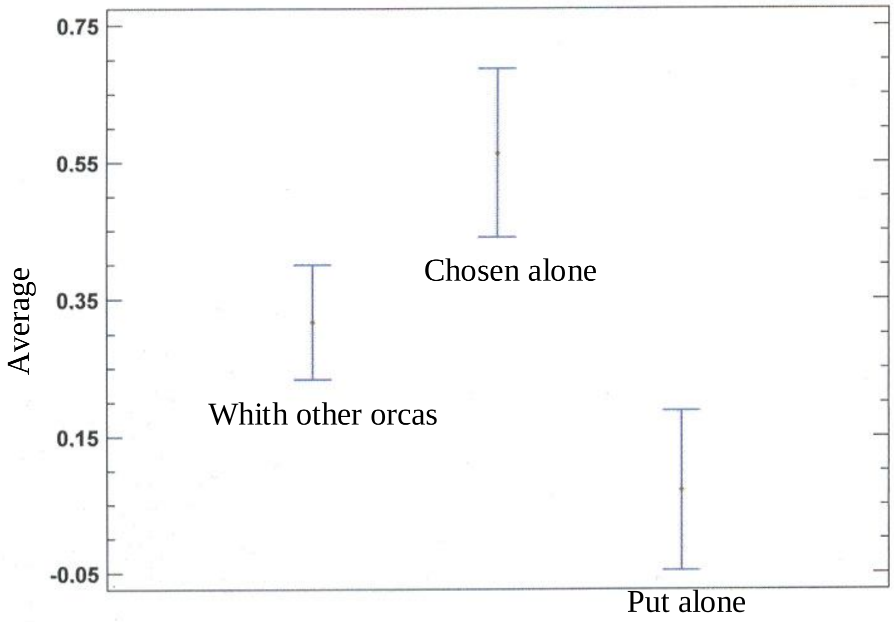


Fig 6.33 Averages and ranges LSD 95.0%

Test of multiple ranges (LSD al 95,0%):

	Counting	Mean	Homogeneous groups
Put alone	77	0.0707792	X
With other orcas	152	0.316645	X
Chosen alone	69	0.563333	X

	Significant	Difference	+/- limits
With other orcas- Chosen alone	*	-0.246689	0.210827
With other orcas- Put alone	*	0.245866	0.203155
Chosen alone- Put alone	*	0.492554	0.240759

* indicates a difference statistically significant

These two tables apply a procedure for multiple comparisons to determine which means are significantly different from the others. The second table shows the estimated difference between each copy medium. An asterisk has been placed next to the three copies to indicate that these show statistically significant differences with a confidence level of 95.0%. The first table identifies three homogeneous groups using the column of X. Within each column the levels containing Xs form a group of means within which there are no statistically significant differences. The method successfully used to discriminate the means is the procedure of LSD (Least Significant Difference) by Fisher. With this method there is a 5% risk of declaring that each pair of means are significantly different when the real difference is 0.

Test of Variances:

	Test	P-value
Levene’s Test	8.47417	0.000263969

Confront	Sigma1	Sigma2	F-ratio	P-value
With other orcas/ Chosen alone	0.515768	1.31434	0.153992	0.0000
With other orcas/ Put alone	0.515768	0.199425	6.68882	0.0000
Chosen alone/ Put alone	1.31434	0.199425	43.4362	0.0000

The statistics displayed in this table, checks the null hypothesis that standard deviations within each of the three columns are the same. Of particular interest is the P-value. Since the P-value is less than 0.05 there is a statistically significant difference between the standard deviation with a confidence value of 95.0%. This violates one of the major assumptions underlying the analysis of variance and invalidates most of the standard statistical tests. The table also shows a comparison of the standard deviations for each pair of samples.

Test of Kruskal-Wallis

	Sample size	Mean rank
With other orcas	152	173.651
Chosen alone	69	132.232
Put alone	77	117.299

Statistical test=31.7941 P-value=1.24739E-7

The Test of Kruskal-Wallis tests the null hypothesis that the medians within each of the three columns are equal. The data of all the columns are first combined and distributed in rows from the smallest to the largest. The average rank is then calculated for each data column. Since the P-value is less than 0.05 there is a statistically significant difference among the medians with a confidence level of 95.0%. To determine which medians are significantly different from the others look at the chart “box and whiskers”.

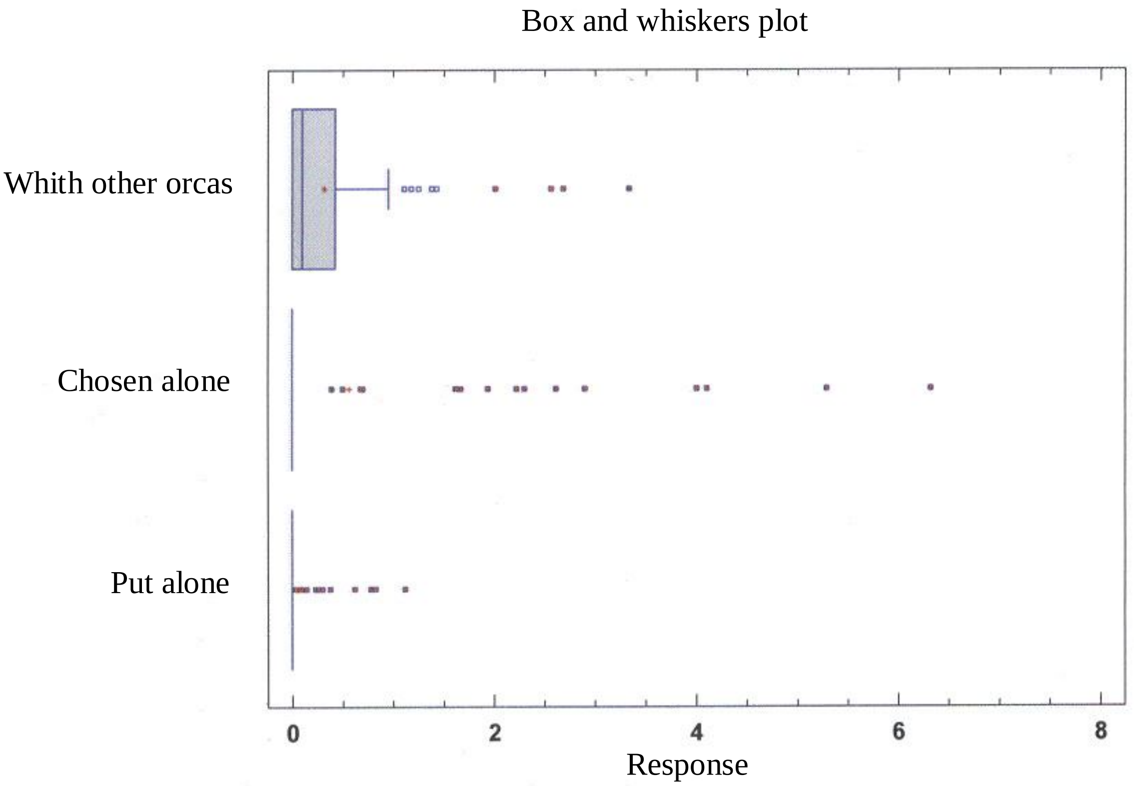


Fig 6.27

Mood median test:

Total n=298

Median total=0

Sample	Sample size	n< =	n> =	Median
With other orcas	152	62	90	0,1
Chosen alone	69	53	16	0
Put alone	77	59	18	0

Sample	LC less than 95.0%	LC higher than 95.0%
With other orcas	0.023811	0.2
Chosen alone	0	0
Put alone	0	0

Statistical of test=39.5539 P-value=2.5762E-9

The Mood median test, tests the hypothesis that the medians of all three samples are identical. This is done by counting the number of observations in each sample in each side of the median total, which is equal to 0.0. Since the P-value for the chi-square is less than 0.05, the medians of the samples are significantly different at the 95.0% confidence level. Confidence intervals for each median are included (if available) even at 95.0% based on order statistics of each sample.

6.5 More Comments

The various observations made in Orca Ocean, revealed some interesting behaviors, but not supported by sufficient data to be statistically analyzed. These observations may be useful in order to investigate a topic of research on the behavior of these fascinating animals.

The first observed behavior was shown by Keto (the largest male) vs Tekoa (the other sexually mature male). The behavior consists in Keto keeping his penis out approaching Tekoa. By speaking with trainers it results that the same behavior was also observed vs

Adán shown both by Keto and by Tekoa. The hypothesis that was formulated is that this is a behavior directed at affirming the hierarchical dominance of larger individuals over smaller ones.

Another behavior that has been linked to the social hierarchy is that of biting. We have observed "attacks" by Kohana or Keto against Tekoa (the animal at the lowest level in the hierarchy of the group). We have often seen animals biting each other, especially after the arrival of Morgan. This behavior was also noted among the females as if it were a game. Probably not all behaviors can be generalized.The same behavior (such as biting the companions) in certain circumstances could be an expression of dominance over another animal and in other circumstances could be an expression of playing. It might be interesting the study the sounds emitted in these circumstances. It is likely to be different depending on the purpose of the behavior. If we prove that, this could confirm the theory just advanced.

The social hierarchy within the group is still not clear, because only recently Kohana has become sexually mature, and therefore might become the leader of the group, or is about to. A very interesting observation could support the hypothesis that Kohana has already become the leader of the group. In pool A (the main pool) there were 3 killer whales: Kohana, Skyla and Keto. The trainer threw a fish each, close to their head, and these were immediately eaten. Three other fishes were thrown towards the centre of the pool. Kohana at that time was near an entrance gate and far away from the centre of the main pool; the other two killer whales were closer to the centre (and to the three fishes). Skyla and Keto ate two of the three fishes leaving the third one for Kohana which arrived later on. After watching this episode we advanced two theories: the first claimed that Skyla and Keto didn't want to annoy Kohana because she was the leader, the second idea claimed that killer whales are so well trained that they only eat what is given to each of them.

For the study of vocalizations it is interesting what occurred to Tekoa. On two occasions we recorded one sound different from the usual. It was presumably produced by Tekoa. The first time was during an "attack" by the other killer whales (and on this occasion it isn't sure that the sound was produced by Tekoa). The second occasion was during a training of a new behavior. After making three times the behavior without achieving what the trainer was asking him, we met in the database this "different" vocalization.

Our hypothesis is that this vocalization could be related to a moment of stress or frustration of the animal, but more information should be collected in this regard.

Finally I would like to illustrate some of behaviors observed in Morgan.

Just arrived she remained one day in the medical pool and then was gradually introduced to the other killer whales. All of us observed that, for at least the first four times she was placed in a pool with a "new" individual, at the beginning she swam very fast followed by the others. This may be due to excitation of the young animal, wishing to find companions to play with.

The other observation about Morgan seems to be linked to an attitude of fear. In the Netherlands she lived in a very little pool (slightly larger than the medical pool of Orca ocean), and when she was moved to Loro Parque the size of the pools was probably big for her (at the beginning). Trainers have repeatedly tried to convince her to get into the main pool, but without success. They also attempted to get her to the main pool by training her together with Koana and Skyla offering fish to the three killer whales from the big pool. The two "old" females entered the large pool while she remained in the smaller one. In the following weeks Morgan entered the big pool several times following the other two females, but she swam back at high speed after a few moments. Only at the end of December (a month after her arrival) she was able to stay calmly in the main pool.

7. Discussion

Through this study it appears that killer whales in Loro Parque “Orca ocean” use a complete vocalization system including clicks, whistles and calls, but, for what concerns sound classification, as in Filatova’s article (2007), a universal classification system still doesn’t exist.

My colleague Renée van Reeuwijk and I carried out classification independently. We compared our work on some occasions in order to understand e.g. whether a whistle appeared in a call (because sometimes this didn’t clearly appear in the spectrogram). At the same time both of us had read Dorothee Kremers’s thesis (2009) about sound categorization of the Loro Parque killer whales, but unlike Kremer's study, we found a lot of whistles in comparison with other vocalizations. Our observations, combined to the fact that most vocalizations have been recorded without the human presence, as we can see in the statistical analysis, are in line with Thomsen’s studies (1999), who found that 42 % of vocalizations during social interactions are whistles. As a matter of fact we can suppose that vocalizations emitted in the absence of human presence are aimed to communicate among individuals.

It’s interesting the fact that by comparing my classification with the one carried out by my colleague Renée it comes out that only 14 sounds differ out of the totality of 270. One of these 14 sounds is emitted by Adán, who is about 1 year old and, for this reason, still uses some vocalizations attributable to his young age. This makes more difficult to insert it in a specific sound category. This accords with the “vocal learning” theory supporting that calves learn vocalizations from their mother (Barrett-Lennard 2000). Also the study carried out at the Sea world shows that the vocalizations of *O. orcas* in their first year of age are “screams” loud, high-pitched calls that bear no resemblance to adult-type calls. Even though this last study supports that calves start to emit sounds similar to the mother's just after two months from their birth, this doesn't mean that some abnormal vocalizations can't be maintained longer.

Comparing vocalizations classified in this thesis with Ford's one (1987), referring to calls produced by whales in British Columbia, it is possible to find a pair of calls similar to ours, as for example Ford's CallN7i, similar to our Elephant sound, or N1v or N1ii, similar to our Long. In the Kremers's study we can see that she has found more calls resembling to those of Ford's classification (about seven). This confirms the fact that a lot of different kind of vocalizations do exist, but some could be in common among different pods. These last vocalizations might have been passed through by individuals captured in an area and learnt from animals originally belonging to other pods, but for a period living in the same oceanarium with them.

Studies on killer whales' vocalizations carried out in a controlled environment are still rare if compared to those in field: most of them in the North-eastern Pacific Ocean (e.g. Ford and Ellis 1999; Ford et al. 2000; Zerbini et al. 2007; etc…) and, recently, in the North Atlantic Ocean as well (Samarra et al.2010). From these studies it clearly appears that these animals can speak different dialects depending on the original group. Samarra specifies that no match should be fetched between registered sounds and those already classified in British Columbia. As a matter of fact numerous sounds registered in the North Atlantic waters studied by her result to be different (personal communication).

Ford mentions in one of his studies (1991) that several pods in the North-Eastern Pacific shared a number of discrete calls forming a clan.

It results from former scientific works the big difficulty to carry out in field studies based on unique vocalizations attribution to a specific individual. In controlled environment the same study seems to be less difficult even though sound attribution still remains a problem as mentioned in Dahlheim and Awbrey 's article (1982). In fact we cannot see many data in the summary tables. We could only use 270 data matching different situations and behaviors out of the 315 collected in the tables (Tables 6.1 and 6.2). Moreover we are not sure that these vocalizations reflect the complete whales' repertoire because they have not been collected in all possible behavioral situations. As noted by Samarra (personal communication), she studied the populations of the North Atlantic, only a few months a year because of adverse weather conditions for most of the year in the Nordic Seas. From these observations she could collect various information about diet and vocalizations; but she cannot be sure that during the rest of the year killer whales' diet and vocalizations do not vary.

Therefore we cannot say that the data collected in a few months a year from Samarra represent the entire repertoire of the North-Atlantic *O. orca*. Similarly, the data we collected can only represent a small part of the possible vocalizations for two reasons: the limited collection time and the inability to carry out a correct identification of the animal which is emitting the vocalization during socializing behavior (playtime, sexual behavior or simply swimming in group). The data collected when the animals were in group (like in field's experiments) allowed us to study the group dialect, but constrained our ability in describing the killer whales' individual dialect. So this kind of information is only useful for the group description.

On 29th November Morgan arrived in Loro Parque and we had to focus our observations on the new-arrived killer whale. We had to check her integration into the Orca ocean group. Therefore it became more difficult to record individual sounds because killer whales were often kept together in the same pool. These recorded data weren't used for the statistical analysis because the arrival of Morgan who used some different vocalizations could have modified the other killer whales' vocalizations. For the statistic analysis I only used the data collected from the beginning of October to the end of November.

Moreover vocalizations emitted during some behaviors were not collected e.g. "spontaneous jumps" or "rest". In this cases when the animal vocalizes out of the water if it is not very close to the position of the hydrophone the sound will not be recorded. In order to make a comprehensive study aimed to see if there are indeed differences in vocalizations related to a different behavior, we must devise a method of recording sound out of the water. This will be important not only for sounds emitted during the behavior "jump", but also for behaviors such as "Aerial scan", "Spyhop", "Contact with trainers" and "rest" that are often carried out with the head out of the water.

What concerns our work, where most vocalizations are concentrated in the behavior "movement" (Fig. 6.17), the study may begin with the identification of sounds associated with those behaviors performed underwater. Only if an animal was alone in the pool where we were recording, we could be sure that all the vocalizations of good quality came from that animal. Every time we were recording in a pool where there were two or more animals, we only kept the good quality vocalizations, which corresponded to an animal listed on the register, but anyway the probability of error was higher. Therefore during the research we were forced not to make a classification of many sounds because of dubious provenience.

Statistical analysis

It is possible to notice an interesting element from the histograms representing the summary statistics for the three different situations in which the animals were studied (With other orcas; Chosen alone; Put alone): any of the data distributions fits a Gauss curve (that is a normal data distribution). The histograms are however all similar one to the other and similar to a curve y=1/x so it is possible to compare them.

From the statistical analysis it results that, comparing all the vocalization frequencies per minute, it seems that animals “talk” more when they are on their own, rather than when they are interacting with the trainers. This makes arise two hypothesis:

1. vocalizations are used for communication among animals, so these are not necessary when they are in connection with human beings
2. in the trainers' presence, animals have to "pay attention" about what is required from them

At this regard we observed that vocalizations increase after training if killer whales are in the same pool and this supports both the above stated hypothesis. This would be better statistically analyzed by studying the vocalization in the situation of "Training". The study should compare the frequency of vocalizations before, during and after the episode "training". It could eventually be considered how many and which animals are involved as well.

In the situation "without human" there are statistically more vocalizations and these are distributed differently: in the situation "with human" vocalizations are all concentrated in a very low frequency (which even reaches 1.6 vocalizations per minute); while in the sistuation "without human "the vocalization frequency can exceed 6 vocalizations per minute (Fig. 6.31).

A very interesting result, that seems to correspond to the “Signature whistle hypothesis” for the bottlenose dolphins (*Tursiops truncatus*) (Figueiredo and Simão 2002) is given by statistical analysis that compare the vocalization frequencies of the two situations: "with other orcas" and "alone". This analysis shows that the killer whales produce more vocalizations when alone if compared to when they are in groups. This seems to be against the just discussed results, that reveal that vocalizations were mainly intended to communicate among individuals.

Going further into this matter another analysis was carried out by dividing the situation "alone" in its two components "Chosen alone" and "Put alone." At this point, the result is interesting: the *O. orca* emits more soundswhen alone in a pool for selection. This can create the hypothesis that vocalizations are used to call friends or tell them about the situation in another tank. Whatever the motivation is, this behavior becomes evident from the LSD graph (Fig. 6.33) where we can see the comparison among the three situations: the three confidence intervals are very different from each other and do not have overlapping areas. The graph also shows that the situation in which more vocalizations are emitted is "Chosen alone" followed by the situation "With other orcas" and finally "Put alone." This unfortunately limits the analysis because it tells us that it is counterproductive to ask the trainers to put an animal alone in a pool in order to get undubitable calls to develop its individual repertoire (just because we could collect only a few data from this animal). This is what happened with Kohana when we asked the trainers to put her alone. The abnormally low rate of Kohana's vocalizations could be related with her hierarchical position, as the social structure in the group is evolving from the dominance of the oldest animal (Keto) to the dominance of the oldest female (Kohana) as she gets mature. When the individual repertoire of killer whales will be determinated, a future research will be able to show wether the hierarchical structure in a group determines the vocalization rate and its classification.

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Annex 1

In the table below it is possible to compare a particular behaviour with its explanation. These are the ones identified in the period of the research.

Behaviour	Explanation
Rest	Hanging still on the water surface, with no moving of tail or fins. Occurs mostly in the middle of the pool or in the corners.
Movement (swimming)	Moving of the tail and fins to make the body move in any direction through the water. Different speeds are possible. Is combined with breathing.
Physical contact	One part of the body of an orca touches an other orca. Also expression of sexual behaviour.
Object manipulation	The orca touches a part or the whole object, pushes it under water and tosses it around.
Training	Orca is working with a trainer, performing certain types of behaviour on command.
Social behaviour	The orca performs behaviour in group swimming with another orca without touching it. Example working/swimming with more individuals
Contact with trainer	The orca lies still in the water and observes trainers. The body is turned a little bit to the left or right and the eyes are fixed on trainers. It also contains short interactions outside the trainings, like talking to an orca or petting.
Jump	When the orca is completely out of the water or has only some contact with the water with its tail.
Aerial scan	The orca raises its head from the horizontal lying position, out the water.
Spyhop	The orca raises its head vertically from the water, sometimes also the pectoral fins leave the water.