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Acoustic Repertoire of Sperm Whale (Physeter macrocephalus) Bachelor Groups in the Waters Surrounding Ischia, Italy (Tyrrhenian Sea)

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ACOUSTIC REPERTOIRE OF SPERM WHALE (*PHYSETER MACROCEPHALUS)* BACHELOR GROUPS IN THE WATERS SURROUNDING ISCHIA, ITALY (TYRRHENIAN SEA)

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ABSTRACT

The subpopulation of sperm whales (*Physeter macrocephalus*) in the Mediterranean Sea is presently list as "Endangered". This study is an attempt to provide detailed data on sperm whale Bachelor Groups surrounding Ischia, Italy in the Tyrrhenian Sea (Mediterranean Sea). 24 hours, 38 minutes, and 38 seconds of sperm whale Bachelor Group acoustic data was analyzed in order to describe acoustic repertoire, classify behavioral associations to acoustic types, and identify habitat-use. The data showed that the acoustic repertoire of sperm whale Bachelor Groups is dominated by Usual Clicks. Additionally, a click type that maintains an inter-click interval (ICI) in between Usual Clicks and Creaks was identified during acoustic analysis and named "Transition Clicks".

Acoustic events were categorized into Single Code and Combination Code events; representing situations where one acoustic code was heard versus situations where two or more different acoustic codes were heard simultaneously. Analysis revealed that Single Code events represented 71.25% of the sperm whale Bachelor Group acoustic repertoire. The Usual Click/ Transition Click combination represented 73.74% of Combination Code events. A significant difference was shown between time spent in Single Code versus time spent in Combination Code for Usual Clicks and for Squeals. Acoustic repertoire data revealed the possibility for a strong collaborative acoustic structure and a speculated strategy for evolutionary success among sperm whale Bachelor Groups in Ischia, Italy.

Additionally, the study showed that sperm whale Bachelor Groups spend 77.87% of the analyzed time engaged in orientation/searching/foraging behavior and 1.09% engaged in socializing behaviors. Event maps revealed a 'hotspot' of sperm whale Bachelor Group activity in the waters to the northwest of Ischia, Italy, within the submarine Canyon of Cuma, and outside of the boundaries for the Regno di Nettuno Marine Protected Area (MPA).

It is recommended that the results of this study be utilized in extending the Regno di Nettuno MPA to include the 'hotspot', and possible critical area, for sperm whale Bachelor Groups. The results of this study and published literature of the sperm whales in this area could be utilized to create population-specific management strategies for more effective measures in ending population decrease and preserving the species. Further research should be carried out to analyze in detail the role of Transition Clicks in sperm whale acoustics and the possibility of a collaborative acoustic structure that has yet to be displayed in any other sperm whale population worldwide.

Keywords: Sperm Whale, *Physeter macrocephalus*, Acoustic Repertoire, Bachelor Groups, Regno di Nettuno, Ischia, Italy

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1. INTRODUCTION AND PURPOSE

Conservation behavior, the application of animal behavior studies to wildlife conservation issues, is a valuable tool in the creation of management plans to conserve species biodiversity (Blumstein and Fernandez-Juricic, 2010; Cooke et al., 2014). Understanding a species' behavior and daily life is crucial to its conservation. This study analyzes sperm whale (*Physeter macrocephalus*) vocal and surface behavior and sets the results within the broader concept of conservation behavior for the preservation of species biodiversity.

Relatively little is known about sperm whales in the Mediterranean Sea. Studies have shown that there are genetic differences separating the subpopulation of sperm whales in the Mediterranean from those in the Gulf of Mexico, the North Sea, and the western North Atlantic Ocean (Engelhaupt et al., 2009; NOAA Northeast Fisheries Science Center, 2015). Analyses of behavior for the different subpopulations would be useful for a comparative study in order to better assess differences, reasons for those variances, and, ultimately, generate specific, population-tailored strategies to better conserve and protect the species. In order to effectively compare subpopulations, baseline studies of each should be performed.

The majority of sperm whale activity takes place in the deep ocean, making direct behavioral observations difficult. However, below the surface, acoustics function as an aid to help us gain insight to these activities. The combination of behavioral surface studies and acoustic recordings through hydrophones give us a better understanding of the daily lives of these animals (Whitehead, 2003). While the information attained through these two channels is far from a complete view of sperm whale behavior, it does allow us to compile baseline behavioral data as we work to reveal new approaches in the study of sperm whale behavior.

Ischia, Italy, is an island off the coast of Naples that offers a unique opportunity for the study of cetaceans. The area is well known for its high pelagic biodiversity and constant presence of seven different Mediterranean cetacean species, including sperm whales, fin whale (*Balaenoptera physalus*), striped dolphin (*Stenella coeruleoalba*), Risso's dolphin (*Grampus griseus*), short beaked common dolphin (*Delphinus delphis*), Bottlenose dolphin (*Tursiops truncatus*), and pilot whale (*Globicephala melas*) (Pace et al., 2012).

The oceanographic characteristics of the waters surrounding the island play a large role in the high levels of biodiversity. The submarine canyon of Cuma is a deep submarine system of canyons located north of the island and reaches maximum depths of approximately 800 m (Pace et al., 2012). The canyon acts as a sedimentary basin carrying materials and increasing upwelling speed. It also acts as a conveying duct to the waters of the deep basin (Pennetta et al., 1998), consequently attracting large, apex predators such as sperm whales in search of prey.

Since 1991, the Ischia Dolphin Project in Ischia, Italy has conducted long-term research on cetacean species in the waters surrounding the island, with much of the research effort focused on the area of the canyon of Cuma (Oceanomare Delphis Onlus, 2013). The ultimate goal of the project is conservation of whale and dolphin habitat. The study has produced a large amount of data, as well as contributed to the establishment of the Marine Protected Area "Regno di Nettuno" (Neptune's Kingdom). Behavioral sampling, acoustic recordings, and photo-identification have been utilized by the project to collect data. While sperm whale vocalizations have been recorded, there has yet to be a complete description of the acoustic repertoire of the sperm whales in the area. Having an acoustic repertoire of the sperm whale population in the area will provide a strong foundation for the comparison of the Ischia population to other populations in the Mediterranean Sea, as well as in the Atlantic Ocean and worldwide.

The purpose of this study was to describe the acoustic repertoire of sperm whale Bachelor Groups in the waters near Ischia, Italy, and correlate vocal patterns with behavioral states. Bachelor Groups are comprised of sexually mature males, typically 6-35 years of age (Best, 1979; Whitehead, 2003). Sperm whale Bachelor and Breeding Groups are commonly seen in Ischia waters (Pace et al., 2012; Pace et al., 2014). The study analyzed

Bachelor Group acoustics with the intention of relating results to a future study on Breeding Group acoustics.

The analysis will create a baseline for future studies of sperm whale behavior and provide data necessary for population-specific conservation and management strategies. The project will also assist in the protection of the Cuma canyon system and possible critical habitat for the sperm whale in Ischia waters, promoting the coordinated effort of Oceanomare Delphis Onlus with the Italian Ministry of Environment and the Marine Biology Society (Pace et al., 2012).

Future goals of this project include a comparative study between sperm whales of Ischia and elsewhere in the Mediterranean Sea to better understand sperm whale behavior. Although there is no information available regarding the relationship between Mediterranean and Atlantic sperm whale populations, previous observations suggest a high degree of isolation between the two (Notarbartolo di Sciara, 2002).

2. *PHYSETER MACROCEPHALUS*

For many, the sperm whale (*Physeter macrocephalus*) might be a familiar, albeit mythical, creature that was immortalized by Herman Melville's *Moby Dick*; however, the contribution and complexity of this species goes far beyond a fabled "beast".

Sperm whales belong to the order Cetacea, sub-order Odontoceti (Notarbartolo di Sciara, 2002). In addition to being the most phylogenetically distinct of all odontocetes, the sperm whale is also the largest of the toothed whales, second largest among all extant animals and possesses the largest brain on Earth (Whitehead, 2003). Mature females grow to approximately 11 meters and weigh about 13.6 metric tons, while mature males have been known to surpass the average of 15-18 meters and weigh about 40.8 metric tons (Rice, 1989; Whitehead, 2003).

2.1 Abundance and Distribution

At present, estimates for the worldwide population of sperm whales is fragmented and incomplete. The most accepted global population estimate of 300,000 – 450,000 whales is proposed by Whitehead (2002) and considered to be imprecise (NOAA Northeast Fisheries Science Center, 2015). Inaccurate and underreported modern catch data, the wide-ranging distribution of the whales, and minimal time spent at the surface complicates efforts to attain accurate global abundance numbers (NOAA Northeast Fisheries Science Center, 2015).

Sperm whales are one of the most widely distributed mammals on Earth, second only to killer whales (*Orcinus orca*) and humans (Whitehead, 2003). The species inhabits all oceans and most semi-enclosed seas (Notarbartolo di Sciara, 2002; Whitehead, 2003). Sperm whale distribution typically includes higher latitudes during the spring and summer months and temperate and tropical latitudes during the autumn months (Notarbartolo di Sciara, 2002). While sperm whales have a wide range, their distribution is not uniform and whalers were the first to recognize areas of sperm whale concentrations, or "grounds" (Townsend, 1935; Antunes, 2009). Several factors have been suggested to influence sperm whale distribution, including marine productivity, prey availability, continental shelf breaks, cyclonic eddies, oceanic fronts, warm core rings, submarine canyons, and other oceanographic features (Jaquet and Whitehead, 1996; Waring et al., 1993; André, 1997; Griffin, 1999; Biggs et al., 2000; Gregr and Trites, 2001; Waring et al., 2001; Whitehead, 2003; Watwood et al., 2006; Pace et al., 2012).

A striking difference exists between female/young adults and adult male sperm whale distribution (Whitehead, 2003). Adult male sperm whales are regularly found in higher latitudes near the poles, while females and young males inhabit a much smaller range corresponding to warmer sea surface temperatures.

2.2 Life History and Social Structure

The social structure of sperm whales is generally described in three groups: Breeding Groups or Social Units, Bachelor Groups, and adult males (Whitehead, 2003; Drouot et al., 2004a). Breeding Groups, also known as Social Units, are composed of sexually mature females and offspring of both sexes (Whitehead, 2003). It is possible for Breeding Groups to unite into much larger "clans" (Whitehead et al., 2012). Bachelor Groups are loose aggregations of similar-sized males that have left their mother's social units, which occurs between ages 3-15 (Best, 1979; Whitehead, 2003). As males age, the cohesion among Bachelor Groups decline and many adult males become solitary around age 40 and older. Adult males will typically lead a solitary life near the polar latitudes, making variable migrations between higher latitude feeding grounds and lower latitudes for breeding. Females and immature males do not seem to make seasonal migrations but rather their movements appear to correspond with shifts in food availability (Whitehead, 2003). Additionally, females and immature males seem to remain within the boundaries of tropical and temperate waters (Ivashin, 1981; Gannier et al., 2002; Whitehead, 2003; Drouot et al., 2004a).

2.3 Reproduction and Breeding

Adult male sperm whales will travel from the polar cold-water feeding grounds to breed with females residing in warmer waters among Breeding Groups. Peak breeding season occurs from March through June in the northern hemisphere and from October through December in the southern hemisphere, although mating activity is possible throughout the year (Best et al., 1984; NOAA Northeast Fisheries Science Center, 2015).

Females will typically conceive one calf every 4-6 years until about the age of 40, when pregnancy rates decrease drastically (Best et al., 1984; Whitehead, 2003). Gestation periods average 15 months and newborn sperm whales measure approximately 4m in length and weigh roughly 1 metric ton (Best et al., 1984). Nursing of young will lasts until about 2 years of age, although there have been cases of sperm whales with milk in their stomachs at up to 13 years of age (Best et al., 1984). Nursing females have been reported to separate from their Breeding Groups while caring for their offspring (Gero et al., 2014). However, it has also been well-documented that sperm whales participate in alloparental care and allonursing, with females from the entire clan being involved in the care, and even nursing, of offspring (Gero et al., 2009). Young sperm whales will begin to wean and ingest solid foods at about 1 year of age. Sexual maturation in female sperm whales will typically occur between 7-13 years of age, while males do not reach full sexual maturation until about 20 years of age and older (Clarke et al., 2011).

2.4 Natural Mortality and Threats

With low reproductive rates and long life spans averaging 60- 80 years, sperm whales are considered a 'K-selected' species and populations are controlled strongly by member competition for resources (Whitehead, 2003). Natural mortality in sperm whales also includes disease and predation (Rice, 1989).

While the sperm whale may be a top predator, it is not at the top of the marine food chain. The killer whale (*Orcinus orca*) is a natural enemy of the sperm whale and has a number of documented attacks on the species, particularly on Breeding Groups comprised of females and immature whales (Best et al., 1984; Jefferson et al., 1991; Brennan and Rodriguez, 1994; Visser, 1999; Pitman et al., 2001; Whitehead, 2003). It should be noted, however, that killer whale attacks on sperm whales are rare and far less numerous than observations of the two species in non-predatory interactions (Jefferson et al., 1991; Whitehead, 2003).

It has been an established belief that adult sperm whales are practically free from the threat of natural predators (Rice, 1989; Dufault and Whitehead, 1995; NOAA Northeast Fisheries Science Center, 2015). Unfortunately, the most significant threat to sperm whales are humans. Although the direct harvest of sperm whales has been banned since the IWC Whaling moratorium of 1986, the effects from years of heavy, targeted whaling may continue to have disproportionately negative effects on a population that has been slow to recover (Best et al., 1984; Whitehead et al. 1997; Mizroch and Rice, 2013; Ivashchenko et al. 2014; NOAA Northeast Fisheries Science Center, 2015). Furthermore, vessel strikes, interaction with fisheries, anthropogenic noise, oils spills and contaminants and climate change are all current potential threats whose degree of negative impact on the recovery of populations remains uncertain (NOAA Northeast Fisheries Science Center, 2015).

2.5 Foraging and Main Prey

Typically, sperm whales inhabit offshore waters and continental slopes which tend to correspond with areas of high primary production and consistent prey source (Rice, 1989; Jacquet and Whitehead, 1996). These extremely large predators make a rather large and significant impact on deep ocean food webs and nutrient cycling in the ocean. It is estimated that the world sperm whale population consumes about 100 Mt/yr (Clarke, 1976; Kanwisher and Ridgeway, 1983; Whitehead, 2003; Watwood et al., 2006).

The primary prey of sperm whale in most areas of the world seems to be mesopelagic and bathypelagic cephalopods (Clarke, 1962; Clarke, 1980; Rice, 1989; Whitehead, 2003; Gannier and Praca, 2006); however, in some areas, fishes comprise a substantial part of sperm whale diets (Kawakami, 1980; Whitehead, 2003). In addition to differences in diet based on area of the world, sperm whale foraging can differ based on sex (Whitehead, 2003). In general, male sperm whales are found in the higher latitudes and closer to shore, thus in shallower waters; female sperm whales are rarely found in shallow waters above continental shelves (Caldwell et al., 1966; Best, 1999; Gregr et al., 2000; Whitehead, 2003). This variation in distribution also affects the whales' method of hunting. Due to their presence in shallower waters, male sperm whales are more likely to dive to the bottom, their diet consists of more bottom-dwelling animals and a larger amount of cephalopods. In contrast, fish make up a significant part of the female sperm whale diet along with cephalopods (Whitehead, 2003).

Cephalopod behavior has also been suspected to influence sperm whale distribution by aggregating pods to certain areas (Jaquet and Whitehead, 1996; Connor, 2000; Whitehead, 2003). During spawning, cephalopods tend to aggregate in groups which could yield relatively easier prey sources for sperm whales (Clarke, 1980). Different species of cephalopod exhibit different spawning times and modes which could be a contributing factor to the sperm whale wide dietary range (Whitehead, 2003).

A number of studies have tried to distinguish any type of diurnal variation in sperm whale foraging; however, most have failed to find any diurnal pattern in feeding success and have found clear evidence that sperm whales forage at all times of day (Okutani and Nemoto, 1964; Clarke, 1980; Whitehead, 1996; Best, 1999; Whitehead, 2003). There also seems to be no evidence of patterns in sperm whale foraging related to lunar cycles or seasonal variations (Clarke, 1956; Clarke et al., 1988; Clarke, 1980; Whitehead, 1996; Best, 1999; Whitehead, 2003).

2.6 Deep Divers

Sperm whales are distinguished by their deep foraging dives, which usually last between 30-45 minutes and are 300-800 m in depth; however, sperm whales can often stay underwater for over an hour and dives of 1-2 km have been frequently recorded (Watkins, 1980; Papastavrou et al., 1989; Watkins et al., 1993; Whitehead, 2003; Watwood et al., 2006). The dives are normally separated by periods of rest at the surface which can last between 7-10 minutes. These deep foraging dives make up a significant part of sperm whale behavior, comprising approximately 62-72% of the whale's life (Whitehead, 2003; Watwood et al., 2006).

While sperm whales perform short dives, typically only to move away from a disturbance at the surface, most of their dives are deep, preceded by a 'fluke up' and commonly associated with foraging (Whitehead, 2003). The composition of a sperm whale foraging dive can be broken up into three stages: descent, foraging at depth, and ascent. Spending approximately 15 minutes descending, 15-30 minutes foraging, and 15 minutes ascending; the sperm whale dive profile often, but not always, has a U-shaped profile (Gordon, 1987; Whitehead, 2003).

Perhaps one of the most important features of a sperm whale foraging dive is the use of 'clicks' as sonar. The sperm whale vocal output varies throughout the dive and seemingly corresponds to different purposes for foraging (Whitehead, 2003). These clicks may not only be an indispensable tool for sperm whales during foraging but are also a critical component for scientists to better understand the behavior of sperm whales below the surface.

3. SPERM WHALE ACOUSTICS

3.1 The Spermaceti Organ and the Production of Sound

One of the unique features of the sperm whale is the spermaceti organ. This organ takes up approximately 25-33% of the animal's body, dominating the head area (Whitehead, 2003). The spermaceti is an oil-filled structure with a variety of different theories regarding its function; however, the most widely accepted theory is that the spermaceti is a sound producing organ (Clarke, 1970; Norris and Harvey, 1972; Clarke, 1978; Carrier et al., 2002; Whitehead, 2003).

According to most recognized theories, sperm whales produce sound by forcing air through a lip-like structure, called the 'museau du singe' (Mo), at the anterior end of the spermaceti (see Figure 1); this creates a sound pulse (Cranford, 1999; Madsen, 2003; Møhl et al., 2003; Whitehead, 2003). The sound pulse propagates inside of the spermaceti organ being reflected from the air sac at the posterior end of the spermaceti (Fr). The pulse is then partially reflected through the junk (Ju), which is a large mass of tissue saturated with oil beneath the spermaceti organ and thought to function as an acoustic lens, then finally broadcast into the ocean (Whitehead, 2003). A part of the pulse passes back and forth along the spermaceti organ again and is released into the ocean shortly after the original pulse. These sound pulses created by sperm whales are known as "clicks" (Whitehead, 2003).

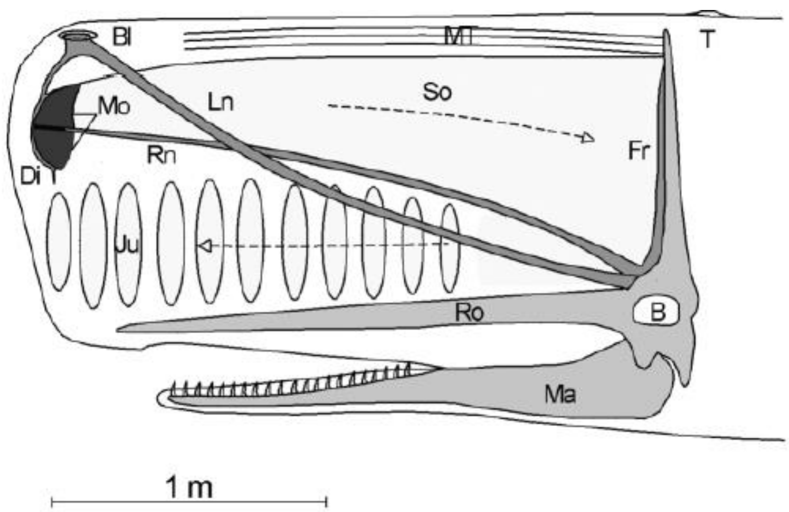

Figure 1. Sperm Whale Spermaceti Organ and Sound Production. Diagram of the head of a 10 m long sperm with a tag. B, brain; Bl, blow hole; Di, distal air sac; Fr, frontal air sac; Ju, junk; Ln, left naris; Ma, mandible; Mo, monkey lips/museau de singe; MT, muscle/tendon layer; Ro, rostrum; Rn, right naris; So, spermaceti organ; T, tag. (Madsen et al., 2002; Whitehead, 2003).

3.2 Sperm Whale Clicks: What are they?

A sperm whale click is made up of regularly spaced sound pulses, with the inter-pulse interval (IPI) being the time it takes for one pulse to travel twice along the spermaceti organ; the pulses are reflected from the air sacs at the frontal and distal ends of the spermaceti (Whitehead, 2003; Mussi et al., 2005). Sperm whale clicks are extremely powerful and are the highest biologically produced source levels ever recorded, up to 223 dB re 1 µ Pa @ 1m and energy between 5 and 25 kHz (Møhl et al., 2000; Whitehead, 2003).

3.3 Click Types and Tonal Sounds

Sperm whale clicks have been categorized into several types; however, the principal types of sperm whale clicks include Usual Click, Creak, Coda, and Slow Clicks. These four principal types of clicks can be separated by a number of characteristics including their inferred primary functions (Figure 2) (Whitehead, 2003). Usual Clicks are associated with searching echolocation, Creaks are associated with homing echolocation, Codas are thought to function in social communication, and Slow Clicks are believed to be a type of communication by males (Madsen, 2002; Whitehead, 2003).

3.3.1 Click Type: Usual Clicks

Usual Clicks are long trains of regularly spaced clicks, typically lasting for several minutes and usually made during deep dives (Whitehead, 2003). Inter-click interval (ICI) of a click is the amount of time between consecutive clicks; this is a good measurement tool for the distinction of click types (Whitehead, 2003). Usual Click ICI's range between 0.5- 1.0 seconds (Figure 2) and they can be heard at ranges of up to 16km. The most supported theory by sperm whale scientists is that Usual Clicks are used as a form of searching echolocation/ sonar to scan for potential prey (Backus and Schevill, 1966; Norris and Harvey, 1972; Gordon, 1987; Weilgart, 1990; Goold and Jones 1995; Møhl et al., 2000; Jacquet et al., 2001; Madsen et al., 2002; Whitehead, 2003). Usual Clicks are short in duration, highly directional, have a low repetition rate and a frequency content that is well-suited for long-range echolocation (Madsen et al., 2002).

Click Type	Apparent Source Level (dB re 1μPa [Rms])	Directionality	Centroid Frequency (kHz)	Inter-click Interval (s)	Duration of Click (ms)	Duration of Pulse (ms)	Range Audible to Sperm Whale (km)	Inferred Primary Function
Usual	230	High	15	0.5–1.0	15–30	0.1	16	Searching echolocation
Creak	205	High	15	0.005–0.1	0.1–5	0.1	6	Homing echolocation
Coda	180	Low	5	0.1–0.5	35	0.5	~2[a]	Social communication
Slow	190	Low	0.5	5–8	30	5	60	Communication by males

[a]This value is inferred from values for other click types and subjective relative audibility of click types at sea.

Figure 2. Click Type and Description (Madsen, 2002; Madsen et al., 2002; Whitehead, 2003)

3.3.2 Click Type: Creaks

Creaks are much faster click trains with an ICI of 0.005- 0.1 seconds (Figure 2). They are also highly directional but less powerful and much shorter than Usual Clicks; they can be heard at ranges of up to 6km (Whitehead, 2003). On average, a Creak will last between 0.1- 45 seconds (Madsen et al., 2002). Creaks have properties that make them more suited for short-range echolocation. They are emitted by sperm whales during dives and at depth; the click rate typically accelerates over the course of the Creak and can be interpreted as the sperm whale homing in on prey (Whitehead, 2003). Creaks at depth have been associated with foraging and rapid maneuvers and are believed to function as a short-range echolocation signal adapted for prey capture (Jacquet et al., 2001; Whitehead, 2003; Miller et al., 2004; Oliveira et al., 2013; NOAA Northeast Fisheries Science Center, 2015) Studies have shown that in certain areas, creak rates during various times of the day could be related to prey availability (Gannier et al., 2012).

Clicks within this same ICI range can also be emitted at the surface; these clicks are referred to as “Rapid Clicks” or “Chirrups”. Rapid Clicks tend to be shorter in length than Creaks emitted at during dives and carry a more constant ICI (Whitehead, 2003). It is thought that this could be beneficial when scanning social partners or other objects at the surface (Whitehead, 2003).

3.3.3 Click Type: Codas

Codas are described as the most unusual click type and are typically a pattern of three to about twenty clicks. These clicks seem to have a different structural make-up than any other type of click; they display less directionality, longer click duration, more pronounced secondary clicks, and reduced power (Madsen et al., 2002). Coda click ICI is between 0.1- 0.5 seconds (Figure 2). It is proposed that Codas are more suited for communication than for echolocation (Madsen et al., 2002; Whitehead, 2003). Coda sequences can vary in their click-pause patterns and in the circumstances during which they are emitted. They can sometimes be heard at the end of a Usual Click train but, most frequently, are heard in exchanges with other whales (Watkins and Schevill, 1977; Whitehead, 2003). Codas can be heard by themselves or during complicated and overlapping sequences in which animals seem to be responding vocally to each Coda sequence (Weilgart, 1990; Whitehead, 2003). Additionally, sequences have been heard where a Coda begins or ends with a Creak, these instances are referred to as “Coda-creaks”. It has been noted that there are acoustic differences in Coda types among populations of sperm whales, and it has been suggested that Coda types may have distinct functions (Antunes et al., 2011; Ferguson, 2013; Amano, 2014). It has also been proposed that Coda types could be genetically inherited based on mitochondrial Deoxyribonucleic acid (DNA) similarities in whales with similar Coda repertoires (Whitehead, 1998; Antunes, 2009).

3.3.4 Click Type: Slow Clicks

Slow Clicks (sometimes called "clangs") are loud, ringing clicks that are repeated every 5-8 seconds (Gordon, 1987; Whitehead, 2003). These clicks can be distinguished from other click types, not only by their structural make-up, which includes much lower repetition rates, longer duration, and very low frequency and directionality, but also by their general sound. Slow Clicks include emphasized "ringing" frequencies and seem much louder than any other type of click, these clicks can be heard by counter-specifics at ranges of up to 60km (Gordon, 1987; Weilgart and Whitehead, 1988; Goold, 1999; Whitehead, 2003). The ICI of a Slow Click is generally between 5-8 seconds (Figure 2).

Slow Clicks have only been heard in the presence of mature or maturing males; however, it is possible that females emit Slow Clicks on rare occasions (Weilgart and Whitehead, 1988; Whitehead, 2003). Whitehead (1993) states that males emit Slow Clicks much more frequently while on breeding grounds in lower latitudes than while on feeding grounds in higher latitudes. The function of these clicks remains a mystery to scientists and the lack of concrete evidence allows for a number of possibilities to be considered. Slow Clicks have been attributed to both echolocation (Gordon, 1987; Mullins et al., 1988; Goold, 1999; Tyack and Clark, 2000; Jaquet et al., 2001; Oliveira et al., 2013) and communication (Gordon, 1987; Weilgart and Whitehead, 1988; Mullins et al., 1988; Whitehead, 1993; Tyack and Clark, 2000; Madsen et al., 2002; Barlow and Taylor, 2005; Oliveira et al., 2013). One proposed theory ties Slow Clicks with a function in the mating system, attracting females and/or repelling males, and as a courtship display (Mullins et al., 1988; Whitehead, 2003). It is thought that, from the recent collection of diving and acoustic data, it is more likely that Slow Clicks are related to long-range acoustic communication more so than for foraging and orientation (Oliveira et al., 2013).

3.3.5 Other Click Types and Tonal Sounds

Other forms of clicks include "gunshots". These are extremely rare, loud and impulsive sounds with long duration (Whitehead, 2003). They have been reported in two separate instances, off Sri Lanka (Gordon, 1987) and in Scapa Flow from a pod of entrapped males (Goold, 1999). There is similarity in structure to Slow Clicks and it has been discussed that gunshots might be a variation of Slow Clicks (Goold, 1999). Another proposed function of gunshots is for the debilitation or stunning of prey through intense low frequency (Norris and Møhl, 1983; Gordon, 1987; Cranford, 1999; Whitehead, 2003; Oliveira et al., 2013). An exact function for gunshots is still unresolved.

Clicks comprise the overwhelming majority of sperm whales sounds but sperm whales also emit tonal sounds, or non-click vocalizations, including "Squeals" and "Trumpets" (Goold, 1999; Whitehead, 2003; Teloni, 2005; Oliveira et al., 2013). Squeals have been described as narrowband sounds with a frequency-modulated structure perceived as tonal to the human ear (Goold, 1999; Druout, 2003). Trumpet sounds are narrowband vocalizations with harmonics. They are said to sound like the "muffled trumpeting call of an elephant" (Gordon, 1987; Whitehead, 2003). The true functions of tonal sounds remain largely unknown. Some of the literature has attributed these sounds to socialization while others have considered it to be a form of "clearing the throat" or readying the vocal apparatus for use (Gordon, 1987; Whitehead, 2003; Teloni et al., 2005).

3.4 The Acoustic Study of Sperm Whale Clicks

The study of sperm whale clicks has evolved to include a number of different methods and tools including new tagging techniques, depth-meters, hydrophones, accelerometers and magnetometers (Johnson and Tyack, 2003; Zimmer et al., 2003; Miller et al., 2004; Zimmer et al., 2005; Laplanche et al., 2005). Some forms of acoustic data collection run the risk of disrupting or altering the natural behavior of the animals, such as tagging. The use of hydrophones and passive acoustics have proven to be efficient techniques that allow scientists to attain results similar to tagging while maintaining much higher levels of discreetness and allowing for more natural behavior from the whales (Leaper et al., 1992; Gillespie, 1997; Gannier et al., 2002; Madsen et al., 2002; Laplanche et al., 2005) Once click data is collected, acoustic analysis is typically performed using oscillograms, which looks at the pressure versus time of sperm whale clicks, or spectrograms, which looks at the frequency versus time of sperm whale clicks (Figure 3) (Whitehead, 2003). Frequency (f) can be defined as the rate of oscillation, or vibration, measured in cycles/seconds, or hertz (Hz) (Richardson et al., 1995). ICI, along with rhythmic pattern, can be combined in the use of oscillogram and spectrogram analysis to enable scientists to measure and categorize clicks into the various click types. Figure 3 (Whitehead, 2003) shows an example of the four principal click types displayed in oscillogram and spectrogram analysis.

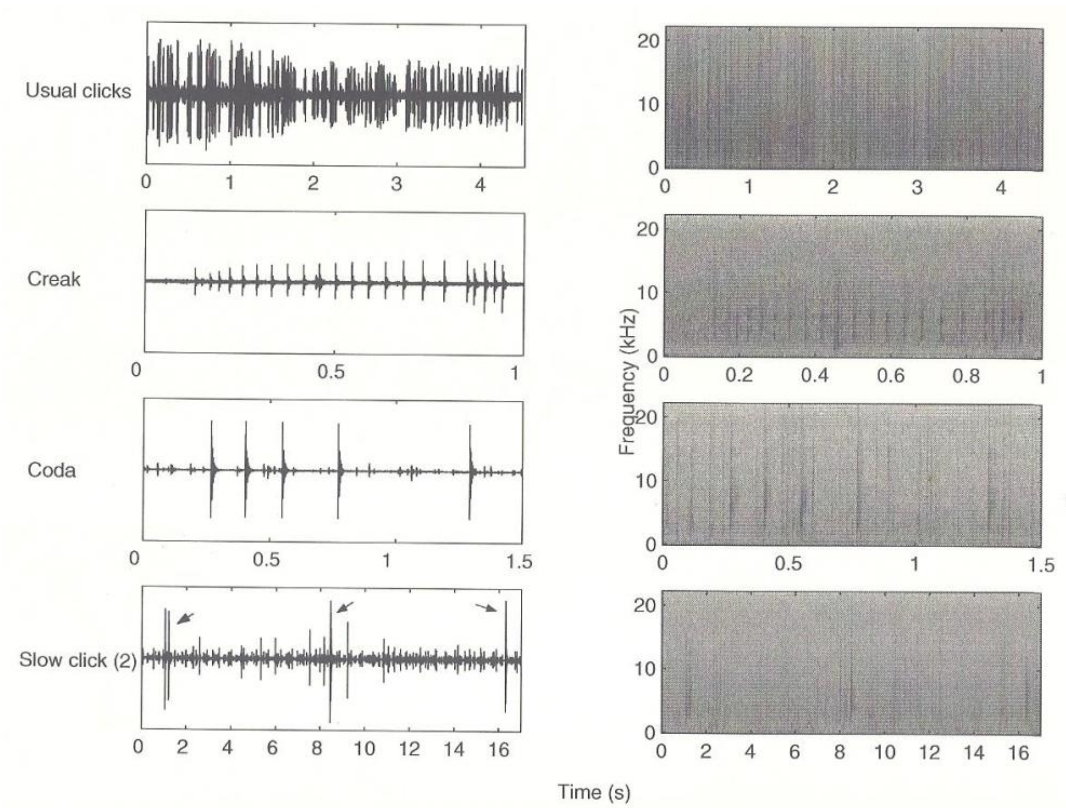

Figure 3. Oscillograms (pressure vs. time; left) and spectrograms (frequency vs. time; right) of sperm whale clicks (Whitehead, 2003).

3.5 Why Study Clicks?

Sperm whales spend a large part of their lives below the surface, at depths that make scientific observation extremely difficult. Through the use of new technologies and acoustic study tools, the field of sperm whale research has grown significantly and allowed for further understanding of their behavior below the surface. Perhaps one of the most effective tools in this understanding is the study of sperm whale clicks. Sperm whale vocalizations are the key to begin to understand their behavior below the surface (Whitehead, 2003). Sperm whale and other odontocete vocalizations have revealed associations between the types of sound produced and behavioral activities (Clark, 1982; Whitehead, 2003).

During deep foraging dives, sperm whales emit a series of clicks which have been linked to echolocation (Norris and Harvey, 1972; Goold and Jones, 1995; Drouot et al., 2004a). Usual Clicks and Creaks have been attributed to long and short range echolocation by nearly all sperm whale scientists while, on the contrary, a few believe that the clicks are contact calls for communication (Backus and Schevill, 1966; Norris and Harvey, 1972; Watkins, 1980; Watkins et al., 1985; Gordon, 1987, Goold and Jones, 1995; Møhl et al., 2000; Jacquet et al., 2001; Madsen et al., 2002; Whitehead, 2003). Most sperm whale scientists also agree that Codas and Slow Clicks are utilized for communication (Madsen et al., 2002; Whitehead, 2003; Impetuoso et al., 2004; Mathias et al., 2012).

By relating certain sperm whale vocalizations to behavioral states, we can begin to piece together their activity below the surface and understand how they utilize the habitats. At the very least, getting an idea of how certain areas are used by the animals allows us to better protect the areas and, in turn, protect a species.

4. SPERM WHALES IN THE MEDITERRANEAN SEA

4.1 Distribution in the Mediterranean Sea

Sperm whales are widely distributed in the Mediterranean Sea, concentrating in deep offshore waters, areas of sea mounts and submarine canyons, and steep slopes, specifically continental slopes, where their main prey, mesopelagic squid, appears to concentrate (Notarbartolo di Sciara, 2002; Druout et al., 2004; Azzellino et al., 2008; Praca and Gannier, 2008; Praca et al., 2009; Mussi et al., 2014). They have been seen in almost all areas of the Mediterranean Sea, with the exception of the Black Sea, and are present year round (Frantzis et al., 2014; NOAA Northeast Fisheries Science Center, 2015). However, the Mediterranean distribution of marine species is not evenly distributed (Pace et al., 2015). Due to a variety of geomorphologic structures, such as submarine canyons, seamounts, deep trenches, etc., marine species aggregate in certain areas that provide unique feeding grounds or nurseries, making these areas of critical importance for species conservation (Cañadas et al., 2002; Gannier et al., 2002; Drouot, 2003; Drouot et al., 2004a; Gannier and Praca, 2006; Pace et al., 2015). From genetic studies and comparison of photographic identification catalogues, it appears that the sperm whales of the Mediterranean are a semi-isolated subpopulation that do not typically cross into the Atlantic Ocean (Drouot et al., 2004b; Engelhaupt et al., 2009; Carpinelli et al., 2014).

Surveys have demonstrated that, similar to sperm whales in other areas, during summer months the Mediterranean subpopulation displays a distinct segregation of mature male sperm whales in the northern Mediterranean Sea from females, calves, and immature males in the southern region. It appears that mature males travel between feeding and breeding grounds while females, calves, and immature males display a more sedentary lifestyle (Drouot et al., 2004a; Frantzis et al., 2011; Carpinelli et al., 2014; Mussi et al., 2014).

Although there is currently no overall abundance estimate for the Mediterranean sub-population, records from various research groups in different areas of the Mediterranean indicate that the sperm whale subpopulation has declined over the past 20 years (Canadas et al., 2005; Aguilar and Barroell, 2007; Lewis et al., 2007; Pirotta et al., 2011; Carpinelli et al., 2014). The Mediterranean sperm whale subpopulation is currently listed as 'Endangered' under the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) and the International Union for Conservation of Nature (IUCN) Redlist (Notarbartolo et al., 2012).
The Mediterranean is an area of high interaction between ecological and human influence, posing large potential impacts to marine biodiversity. The research of species inhabiting this area is necessary and critical for the establishment of effective management strategies.

4.2 Ischia, Italy

The volcanic island of Ischia, Italy is located at 40° 44'N, 13° 55'E and lies in the southern Tyrrhenian Sea which is part of the Mediterranean Sea. The Tyrrhenian Sea is unique from other areas of the Mediterranean in that it is one of the few places where Breeding Groups, immature, and mature sperm whales can be observed (Drouot et al., 2004a; Mussi et al., 2014). Just off the coast of the island is the submarine canyon system of Cuma, a large, deep submarine valley that reaches a maximum depth of 800 m (Pace et al., 2012). The system as a whole has been categorized into different canyons; Cuma, and Punta Cornacchia, and erosional channels; Forio and Punta Imperatore (Figure 4) (Pace et al., 2012).

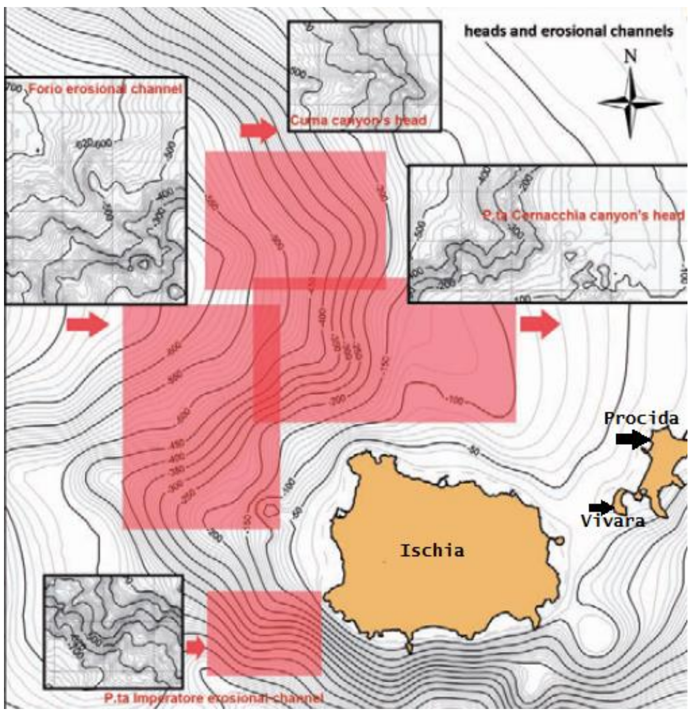

Figure 4. Bathymetric map of Ischia and surrounding waters, including the canyon system of Cuma. Also displayed on the map are neighboring islands, Vivara and Procida (Pace et al. 2012).

The presence of the canyon system creates upwelling and results in high primary productivity, attracting larger predators to the area. Seven different Mediterranean cetacean species have been recorded near the island since 1991 (Pace et al., 2012). Sperm whales are most frequently seen in waters northwest of Ischia, which is the region corresponding to the deepest parts of the submarine canyon system (500-800 m) (Pace et al., 2012). Sperm whales are also sighted along the western side of the island and in the deep, large valley between Ischia and nearby island, Ventotene. It is believed that the bathymetric features play an important role in the distribution of sperm whales and other cetacean species within the area (Pace et al., 2012).

The area is well known for high pelagic biodiversity and has been described as a feeding and/or breeding ground for a number of cetacean species, as well as a designated critical habitat by the International Union for Conservation of Nature (IUCN) Cetacean Action Plan for the endangered short beaked common dolphin (*Delphinus delphis*). The area also provides an important and thriving economic and recreational resource, supporting a large amount of commercial and leisure activities. In 2007, a Marine Protected Area (MPA) known as “Regno di Nettuno” (Neptune’s Kingdom), was established around the island of Ischia and neighboring islands, Procida and Vivara (Figure 5) (Mussi et al., 2004).

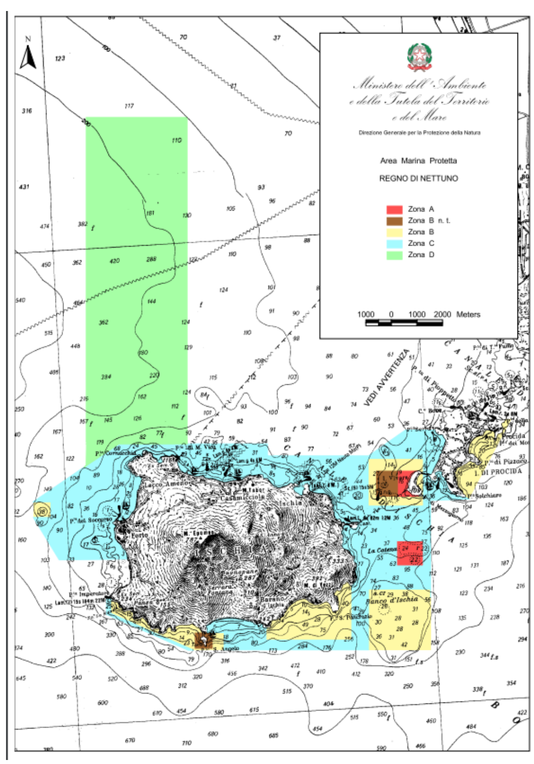

Figure 5. Map of Regno di Nettuno MPA. Zones A-D fall under the protection of the MPA with varying levels of restrictions.

The MPA was meant to mitigate some of the effects that the large amount of human activity could have on marine species. The more pelagic area of the MPA was modeled specifically after the area identified as a critical habitat for the endangered short-beaked common dolphin (Reeves et al., 2003; Pace et al., 2012; Mussi et al., 2014). However, comparison of short-beaked common dolphin habitat to sperm whale habitat in the waters surrounding Ischia (Pace et al., 2012) shows a vast, unprotected stretch of water that could be a critical area for the currently endangered sperm whale subpopulation.

5. OBJECTIVES, HYPOTHESES, AND APPLICATIONS

5.1 Objectives of the Project

1- Quantitative analysis of the acoustic repertoire of sperm whale Bachelor Groups in the coastal waters off Ischia, Italy.
2- Classify associations between vocalizations and behaviors
3- Identify sperm whale Bachelor Group habitat usage

5.2 Hypotheses

Ho1: Ischia sperm whale Bachelor Group vocalizations are not dominated by Usual Clicks

Ha1: Ischia sperm whale Bachelor Group vocalizations are dominated by Usual Clicks

Ho2: Sperm whale Bachelor Groups do not display foraging behaviors in the waters surrounding Ischia, Italy

Ha2: Sperm whale Bachelor Groups display foraging behaviors in the waters surrounding Ischia, Italy

My hypothesis is that Ischia sperm whale Bachelor Group acoustic repertoire is dominated by Usual Clicks. Usual Clicks are defined as a long train of regularly spaced clicks, often lasting for several minutes. The general click types of sperm whales include Usual Clicks, Creaks, Codas, and Slow Clicks. The general click types can be broken down further into detailed acoustic types by ICI, location of the whale when click is performed, and rhythmic pattern. Sperm whale vocalizations also include non-click type acoustics which are considered tonal sounds. The majority of these acoustic types can then be inferred to behavioral states (Whitehead 2003).

If the Ischia sperm whale Bachelor Group acoustic repertoire is dominated by a specific acoustic type, then a behavioral state can be assigned to an equivalent portion of sperm whale activity below the surface. If Ischia sperm whale Bachelor Group vocalizations are dominated by Usual Clicks, then it can be inferred that Bachelor Group sperm whales spend much of their time utilizing echolocation (Backus and Schevill, 1966; Norris and Harvey, 1972; Watkins, 1980; Watkins et al., 1985; Gordon, 1987; Goold and Jones, 1995; Møhl et al., 2000; Jacquet et al., 2001; Madsen et al., 2002, Whitehead, 2003). It is also hypothesized that sperm whales display foraging behaviors in the waters surrounding Ischia Italy. The use of echolocation in sperm whales, through Usual Clicks and Creaks, has been attributed to foraging (Whitehead, 2003). If sperm whale acoustic analysis displays Usual Click and Creak click types, then it can be inferred that sperm whales are foraging in the waters surrounding Ischia, Italy.

5.3 Applications

By gaining a better understanding of sperm whale activity below the surface in Ischia, behavior-specific management plans can be created in order to better conserve the endangered subpopulation of sperm whales in the Mediterranean, as well as the sperm whale population worldwide. Locally, the results of this study will assist in the conservation of sperm whales in Ischia waters and the protection of the submarine canyon of Cuma by allowing officials to create population-specific management plans. The contribution of this study ranges far beyond Ischia waters, as the results and baseline data can be extrapolated and/or compared to sperm whale populations worldwide. The results of the study can be applied globally in the creation of more effective management strategies and protection of the species while conserving biodiversity.

6. MATERIALS AND METHODS

6.1 Study Site

The study area included the waters off the coast of Ischia, Italy, located at 40° 44'N, 13° 55'E, in the southern Tyrrhenian Sea (Pace et al., 2012). Surveys were focused over the submarine canyon system of Cuma which lies off the coast of Ischia, Italy and reaches up to 800m in depth. Parts of the region fall within the "Regno di Nettuno" (Neptune's Kingdom) Marine Protected Area.

6.2 Research Design

Each survey trip covered approximately 60x74 km of area, limited by the distances that could be covered by the research vessel within a single day. Surveys were performed from a 1930 oceanic oak cutter (R/V *Jean Gab*), a sailing vessel that is 17.70 m in length with a 4.45 m beam, 2.50 m draft, and a 145 hp diesel engine (Pace et al., 2012). Survey trips were taken daily when conditions were at a sea state of 0 to 4 on the Beaufort scale, during good light conditions, and at a steady speed of 2-4 knots. A GPS receiver automatically recorded the position and coordinates of the research vessel every 3 minutes and a detailed trip log of the routes covered was recorded. The data being analyzed were from survey efforts June through October spanning three years from 2010-2012. The survey months were chosen to increase the possibility of successful survey trips. Surveys were not taken during months of inclement weather conditions that prevented proper data collection.

Only encounters with sperm whale Bachelor Groups were used for data in this study. Identification of sperm whale Bachelor Groups was done through the use of photo identification techniques and the Oceanomare Delphis Onlus sperm whale photo identification database. Approximately 29 hours of sperm whale Bachelor Group acoustic recordings were collected in 55 acoustic files.

Survey routes were chosen to optimize encounters with the sperm whales and were determined on a daily basis through the analysis of previous sightings, reports of sightings during the present day, bottom topography and depth, and weather and sea state (Impetuoso et al., 2004). Data recorded included start and end time of the survey trips, weather and sea state, location, species, start and end times of each observation, best estimate of group size and composition, behavioral categories, and acoustics.

6.3 Field Observations and Recordings

Visual surface observations were recorded using photo identification methods and surface behavior logs. Data were collected by one or two field officers, one field researcher, one captain, and one to four volunteers. Photos were taken with a Canon EOS 10D SLR digital camera and image stabilizer, telephoto zoom lens (100-400 mm, F4.5-5.6). Images were stored in JPEG format (12 bit, 2.4 MB, 3072x2048 pixels) and added to the Ischia Dolphin Project database. Binoculars used for field observations range between 7x50 and 8x50 power. Behavioral sampling included the recording of different variables such as group size and composition, surface behaviors, social interaction, time at surface, and dive time.

6.4 Acoustic Recordings

Acoustic recordings were collected utilizing a towed stereo hydrophone array incorporating two hydrophones with pre-amps (100Hz – 22 kHz bandwidth, ENEA UT-APRAD Radiation Sources Laboratory) spaced 3 meters apart and towed on a 100 m cable. Software programs used for recording and collection included Rainbow Click and Logger 2010. Rainbow Click is a program designed to detect and analyze sperm whale and other odontocete acoustics (Marine Conservation Research, 2010). Rainbow Click was used in order to determine the bearings of the whales by analyzing the differences in time of arrival of whale clicks between the two hydrophones. Logger 2010 is a field data logging program which automatically collected and stored data from the ship GPS. Logger 2010 kept a log of the route that the vessel covered and automatically recorded GPS coordinates every 3 minutes.

Rainbow Click and Logger 2010 were both designed by the International Fund for Animal Welfare (IFAW) in order to promote benign and non-invasive research. The software is free of charge to download and use for research; however, support is no longer available for either program.

6.5 Acoustic Coding

In order to describe the acoustic repertoire of sperm whale Bachelor Groups off the coast of Ischia, Italy, acoustic recordings, taken over a period of three years, were analyzed to identify acoustic types. Much of the literature categorizes sperm whale clicks into four basic click types- Usual Clicks, Creaks, Codas, and Slow Clicks (Gordon, 1987; Whitehead and Weilgart, 1991; Weilgart and Whitehead, 1997; Madsen et al., 2002; Whitehead, 2003; Zimmer et al., 2005). For analysis purposes in this project, the basic click types, along with other acoustic categories, were broken down further into ten acoustic types in order to describe the acoustics in more detail and with greater accuracy. Seven categories of clicks were identified along with two categories of tonal sounds and one category for Silence (Table 1).

Usual Clicks (UC) hold an ICI of greater than 0.5 seconds, are emitted during a dive, and are considered to be used as a form of orientation/searching echolocation; they have been attributed to orientation/searching/foraging behaviors.

An uncategorized click sequence with an ICI between 0.2- 0.5 seconds, generally emitted during dives or, on some occasions, near the surface, and seemingly utilized as an orientation/searching form of echolocation was identified during analysis and named a "Transition Click" (TC). Transition Clicks maintain an ICI in between the slower Usual Click (ICI greater than 0.5 seconds) and the much faster Creak (ICI less than 0.2 seconds) and may be similar to Usual Clicks in their basic function. Usual and Transition Click sequences are included in the larger, basic category of "Usual Clicks".

Creaks (CR) have an ICI of less than 0.2 seconds, are emitted during dives, thought to function as a homing type of echolocation and are considered to be specific to foraging behavior. However, click sequences with an ICI of less than 0.2 seconds may also be emitted at the surface, where they are referred to as Rapid Clicks or Chirrups (RC). Rapid

Clicks/Chirrups are thought to be related to socialization behavior. Creaks and Rapid Clicks comprise the larger, basic category of "Creaks".

Codas (CO), which are generally emitted at the surface but can also be detected during a diver, have an ICI between 0.1-0.5 seconds and are association with socialization. Coda-creaks (CC), which are a rapid click sequence combined with a Coda at the end, are also recognized as a socialization type of acoustic. Codas and Coda-creaks are assembled in the basic category of "Codas". Slow Clicks (SC) have an ICI between 3-8 seconds, are emitted during dives or at the surface and are considered to be used for socialization among males. Slow Clicks comprise their own basic category of clicks.

Trumpets (TP) and Squeals (SQ) can both be emitted at the surface or during dives and their true functions are generally unknown. Trumpets and Squeals comprise the larger, basic category of "Tonal Sounds"; although, it is currently unclear whether Squeals are truly a non-click tonal sound or a burst-pulse sound comprised of clicks at very high repetition rates (Weir et al., 2007). Finally, Silence (SL), lasting 3 or more seconds, comprises its own basic category.

Table 1. Click arrangements, classification, and functions. Including the ten acoustic types utilized in this study.

Basic Click Types	Acoustic Type	Code	ICI	Location	Behavior
USUAL CLICK	Usual Click	UC	>0.5 sec	Dive	Orientation/Search/Forage
	Transition Click	TR	0.2-0.5 sec	Dive/Surface	Orientation/Search/Forage
CREAK	Creak	CR	<0.2 sec	Dive	Homing/Forage
	Rapid Click (Chirrup)	RC	<0.2 sec	Surface	Socializing
CODA	Coda	CO	0.1-0.5 sec	Dive/Surface	Socializing
	Coda-creak	CC	0.1-0.5 sec	Surface	Socializing
SLOW CLICK	Slow Click (Clang)	SC	3-8 sec	Dive/Surface	Socializing among males
TONAL	Trumpet	TP	N/A	Dive/Surface	Unknown
	Squeal	SQ	N/A	Dive/Surface	Unknown
SILENCE	Silence	SL	N/A	N/A	N/A

Acoustic codes were assigned to events according to the guidelines listed in Table 1 and descriptions of acoustic types/click arrangements from the body of literature (Gordon, 1987; Whitehead and Weilgart, 1991; Weilgart and Whitehead, 1997; Madsen, 2002; Madsen et al., 2002; Whitehead, 2003; Zimmer et al., 2005). The ICIs of clicks were measured using Audacity, Version 2.1.0, in order to assign acoustic types. For Usual Click (UC), Transition Click (TR), and Slow Click (SC) types, code was assigned after the occurrence of 3 or more consecutive clicks. For Creaks (CR), Rapid Clicks (RC), Codas (CO), Coda-creaks (CC), Trumpets (TP), and Squeals (SQ), code was assigned at first occurrence. This was justified in that these acoustic type events are short in duration and can be identified on first occurrence. For Silence (SL), code was assigned after 3 or more seconds of silence.

6.6 Acoustic Data Analysis

Acoustic recordings were individually observed and analyzed using Audacity, Version 2.1.0, hosted by Google Code and SourceForge. A spectrogram was produced of each acoustic recording, comparing frequency (f) vs. time (t). Each individual acoustic event within the file was documented in an Excel sheet which also included date, real time, GPS coordinates, whale group size, whale identity through photo-identification (if possible), file name, total recording time, run number, file recording time for event, acoustic code, time spent, Coda details, whale position in water column (if available), observed behavior, and comments. Acoustic codes included UC (Usual Click), TR (Transition Click), CR (Creak), RC (Rapid Click), CO (Coda), CC (Coda-creak), SC (Slow Click), TP (Trumpet), SQ (Squeal), RV (Research Vessel) and SL (Silence). A combination of the codes was recorded as one acoustic event during times when a.) There were multiple whales emitting sounds and b.) The whales were emitting more than one acoustic type simultaneously.

For analysis purposes in this thesis, the code RV (Research Vessel), was removed from the data analysis since it marked moments during the acoustic files that clicks could not be properly identified due to the engine noise from the research vessel. The GPS coordinates were attained through readings taken by Logger 2010 program on the ship.

The position and coordinates of the research vessel were recorded approximately every 3 minutes while underway. Due to the fact that it was typical for more than one acoustic event to occur within 3 minutes, the GPS coordinates were extrapolated to include all events beginning from and going through the 3 minute window. This was justified by the fact that the ship was traveling between 2-4 knots while collecting data and the GPS coordinates from one 3 minute window to the next did not display a large difference. Overall, 24 hours 38 minutes and 38 seconds of sperm whale Bachelor Group acoustic recordings were utilized in this study, leading to the documentation and analysis of 4,316 separate acoustic events.

6.7 Statistical Analysis

The data collected was used to generate tables and graphs representing the time spent per acoustic code in Single Code events and Combination Events. For Single Code events, the acoustic code was the only code heard from one or multiple whales. For Combination Code events, the acoustic code was heard simultaneously with one or two other acoustic codes.

Due to the parameters of the data and the extreme dominance of the Usual Click type in the results, further statistical testing was not required in order to represent the overall acoustic repertoire and identify sperm whale Bachelor Group behavior and habitat usage. A true representation of the allotted time spent per acoustic code allowed for an accurate understanding of the acoustic repertoire. Bar graphs were chosen to represent the data distribution for the ten acoustic codes. Bar graph parameters included acoustic codes or behavioral associations, time spent, and percentages. Overall, the acoustic repertoire showed the relative frequency of acoustic events among Ischia sperm whale Bachelor Groups.

Sumo Logic, a real-time log analytic program, was used to generate location maps of acoustic code events. GPS coordinates and acoustic codes were used, as well as, behavioral states associated with acoustic codes. A Pearson's Chi-Square statistical test with boot-strapped standard errors was used in order to determine significant differences between Single Code and Combination Code time spent per acoustic code. The test was run at the 99% significance level utilizing the follow equation: c2(9, N = 90) = 3525, P <0.001.

7. RESULTS

7.1 Ischia Sperm Whale Bachelor Group Acoustic Repertoire

Data to describe the acoustic repertoire of Ischia sperm whale Bachelor Groups was categorized into two groups; either the acoustic code was represented alone, being performed by a single or multiple whales (Single Code) or where the acoustic code was represented in combination with one or two other acoustic codes (Combination Code). The Ischia sperm whale Bachelor Group acoustic repertoire showed an uneven distribution across the ten acoustic codes. Data showed that the acoustic repertoire is dominated by Usual Clicks with 15 hours, 46 minutes and 28 seconds of Usual Clicks in Single Code and 1 hour, 33 minutes and 12 seconds of Usual Clicks in Combination Code (Table 2).

Table 2. Ten Acoustic Codes with Time Spent in Single Code and Combination Code (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence and H= Hour, Min= Minute, Sec= Second).

Code	Time Spent-Single Code (h/min/sec)	Time Spent-Combination Code (h/min/sec)
UC	15:46:28	1:33:12
TR	1:33:33	1:10:10
CR	0:04:47	0:16:38
RC	0:00:18	0:01:14
CO	0:03:12	0:01:41
CC	0:00:02	0:00:03
SC	0:05:05	0:05:35
TP	0:00:00	0:00:00
SQ	0:00:06	0:00:02
SL	5:30:52	N/A

Usual Clicks represented 66.10% of the analyzed time for sperm whale Bachelor Group acoustics, followed by 21.03% of the time represented by Silence, and 10.41% of the time represented by Transition Clicks (Figure 6).

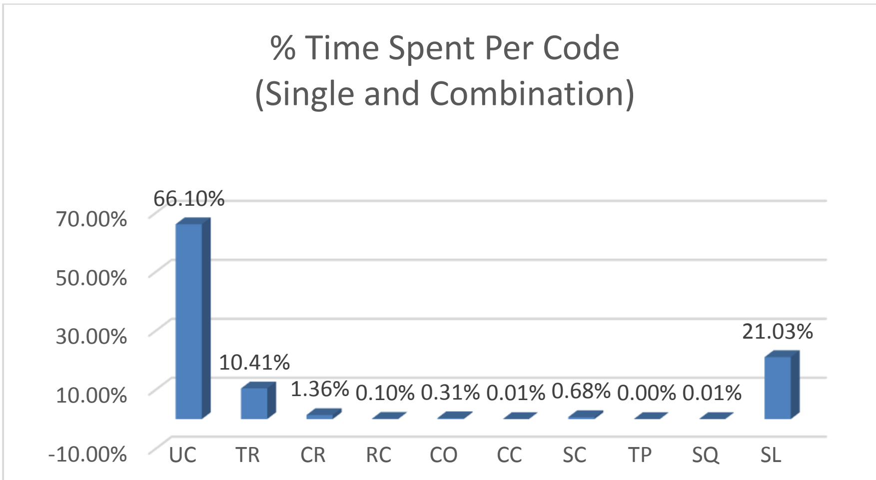

Figure 6. Percentage of time spent per code; showing single and combination events combined (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence).

The locations of acoustic code events were plotted and displayed an overall trend of increased activity for sperm whale Bachelor Group acoustics in the waters to the northwest of Ischia, Italy. Isolated events were also seen occurring directly to the west of the island and in the waters southwest of the island. No events were recorded in the waters east, northeast, or southeast of Ischia.

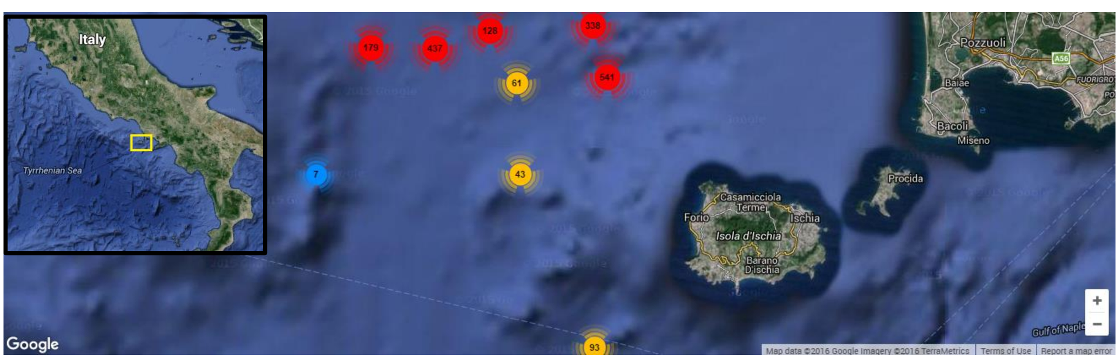

Figure 7. Locations of Usual Click Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

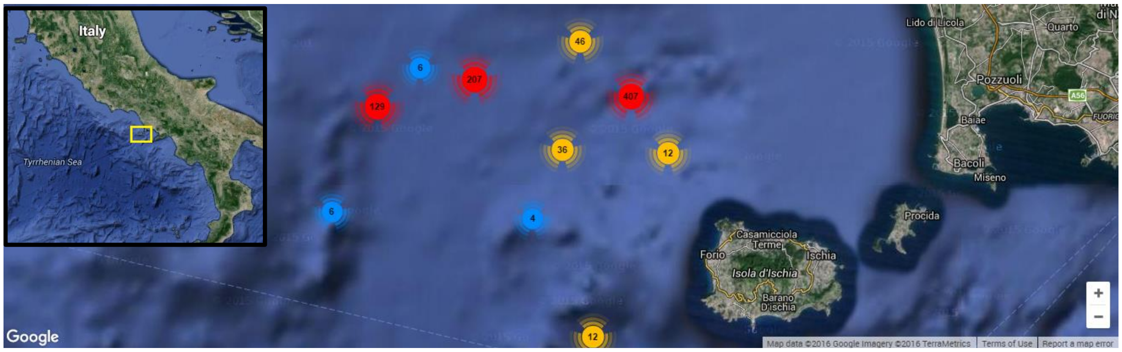

Figure 8. Locations of Transition Click Events (Map A- showing events further north). Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

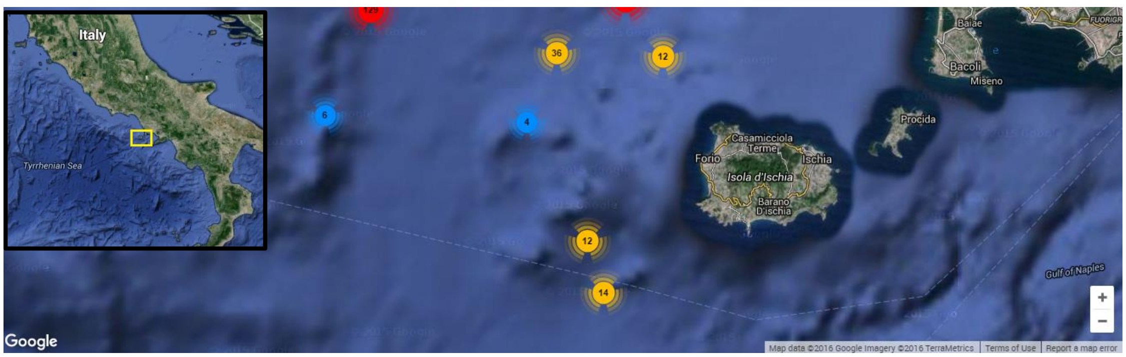

Figure 9. Locations of Transition Click Events (Map B- showing events further south). Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

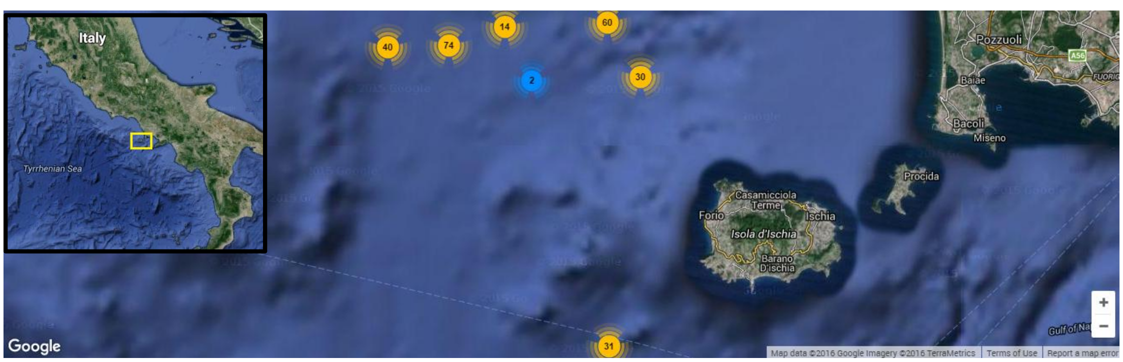

Figure 10. Locations of Creak Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

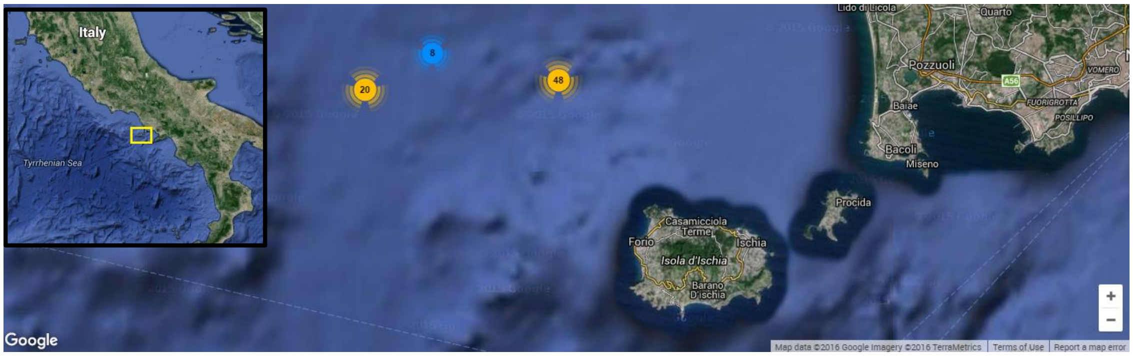

Figure 11. Locations of Rapid Click Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

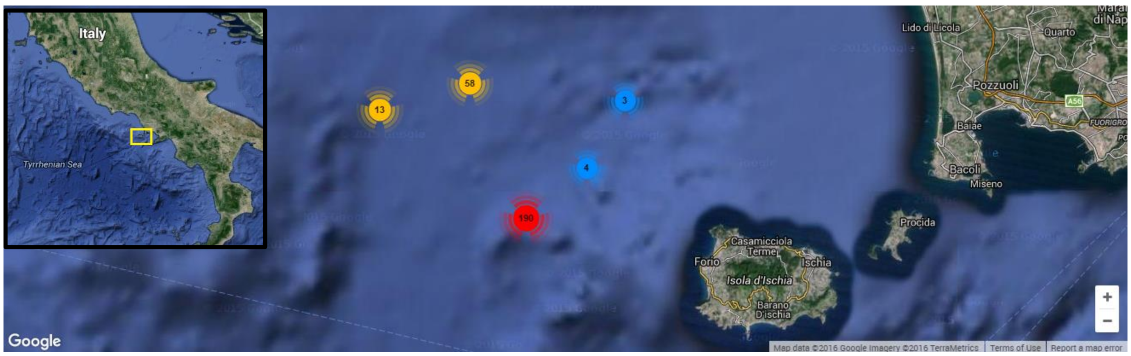

Figure 12. Locations of Coda Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

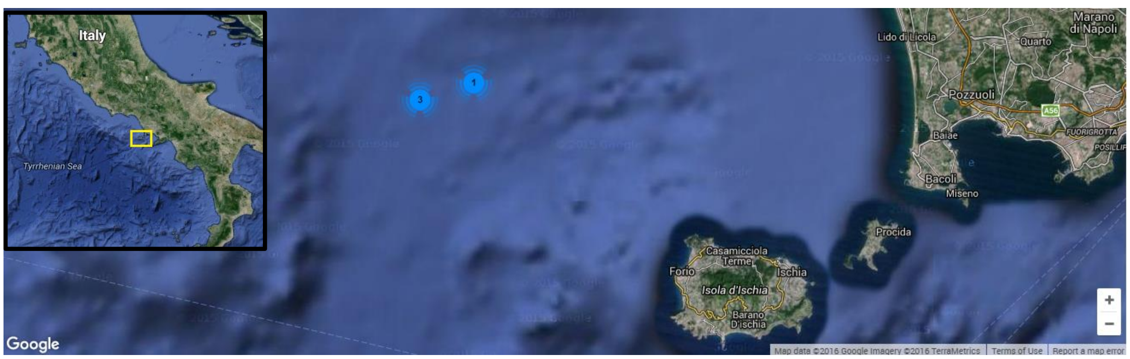

Figure 13. Locations of Coda-creak Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

Figure 14. Locations of Slow Click Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

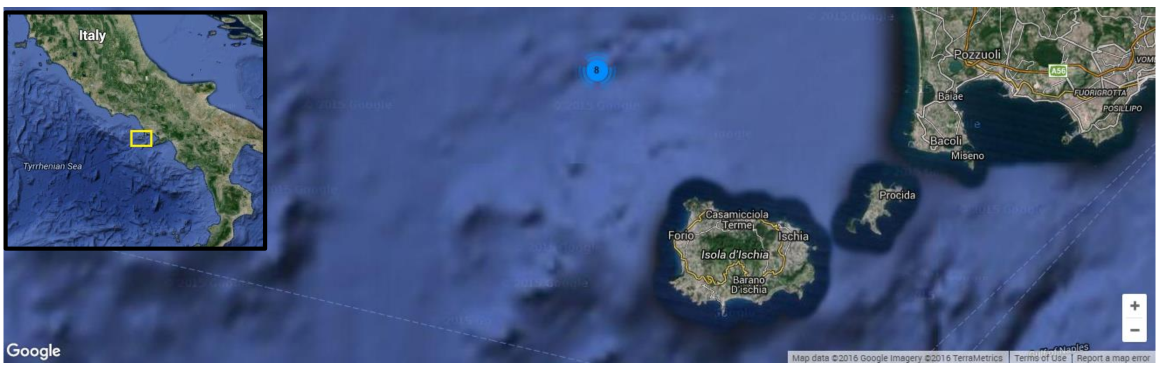

Figure 15. Locations of Squeal Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

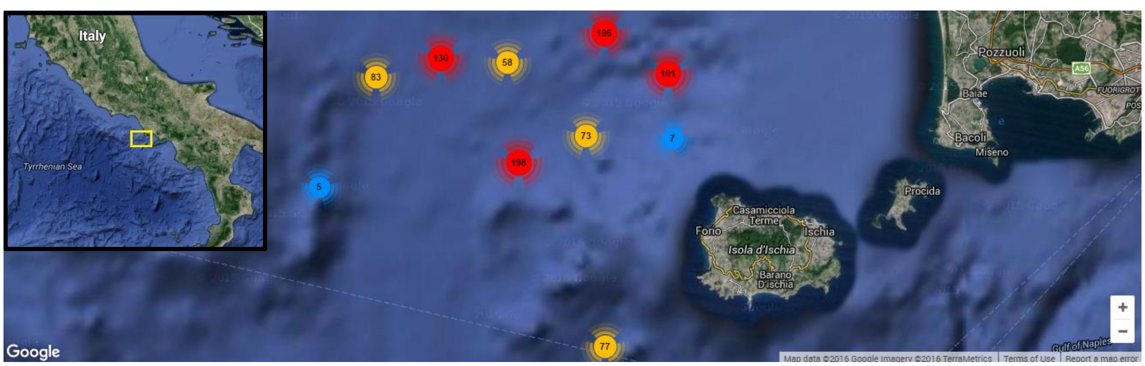

Figure 16. Locations of Silence. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

7.2 Behavioral Associations

Behavioral associations to acoustic types were made based on published literature (Backus and Schevill, 1966; Norris and Harvey, 1972; Gordon, 1987; Mullins et al., 1988; Weilgart and Whitehead, 1988; Weilgart, 1990; Goold and Jones 1995; Møhl et al., 2000; Jacquet et al., 2001; Madsen, 2002; Whitehead, 2003; Miller et al., 2004; Oliveira et al., 2013; NOAA Northeast Fisheries Science Center, 2015). Usual Clicks, Transition

Clicks, and Creaks have all been associated with orientation/searching/foraging click types. Rapid Clicks, Codas, Coda-creaks, and Slow Clicks have been associated with socializing click types. For analysis purposes in this section, Trumpets and Squeals were grouped into "Other Acoustics/ Silence" category due to the lack of data in the literature assigning a behavior. Silence was also grouped in this category because there is no specific behavior currently associated with this acoustic code.

Table 3 documents that sperm whale Bachelor Groups spend the vast majority of time displaying orientation/searching/foraging behaviors versus socializing behaviors; 20 hours, 24 minutes, and 48 seconds vs. 17 minutes and 10 seconds (Table 3). Overall, sperm whale Bachelor Groups spent 77.87% of the analyzed time engaging in orientation/searching/foraging behaviors (Figure 17).

Table 3. Behavioral associations of click types and time spent. (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence and H= Hour, Min= Minute, Sec= Second).

Type	Time Spent (h/min/sec)
Orientation/Searching/Foraging Click Types (UC, TR, CR)	20:24:48
Socializing Click Types (RC, CO, CC, SC)	0:17:10
Other Acoustics/ Silence (SQ, TP, SL)	5:31:00

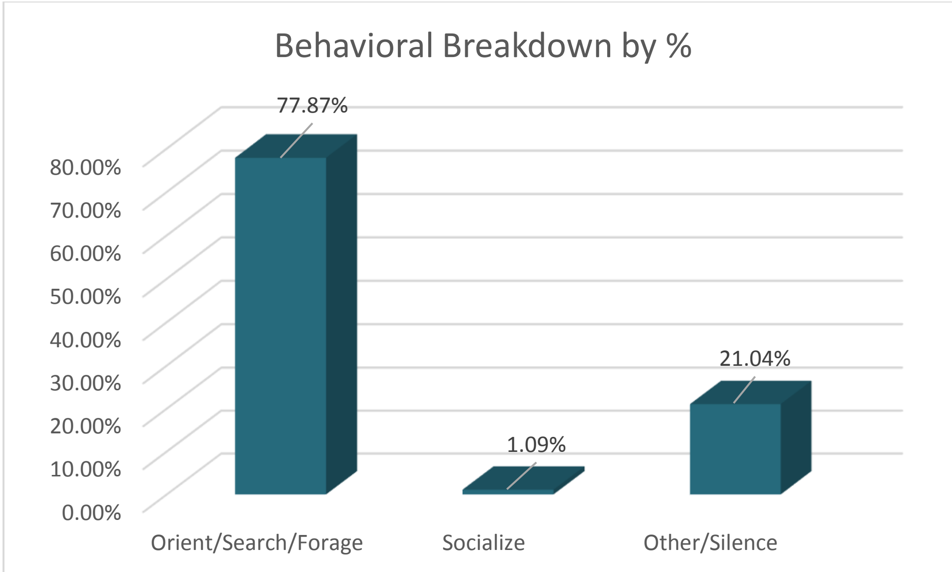

Figure 17. Percentage of time spent in behavioral categories.

The two behavioral categories were plotted on maps based on GPS coordinates. While the event numbers for orientation/searching/foraging click types were larger than the event numbers for socializing click types, there was no obvious difference in the locations of the two types (Figures 18 and 19).

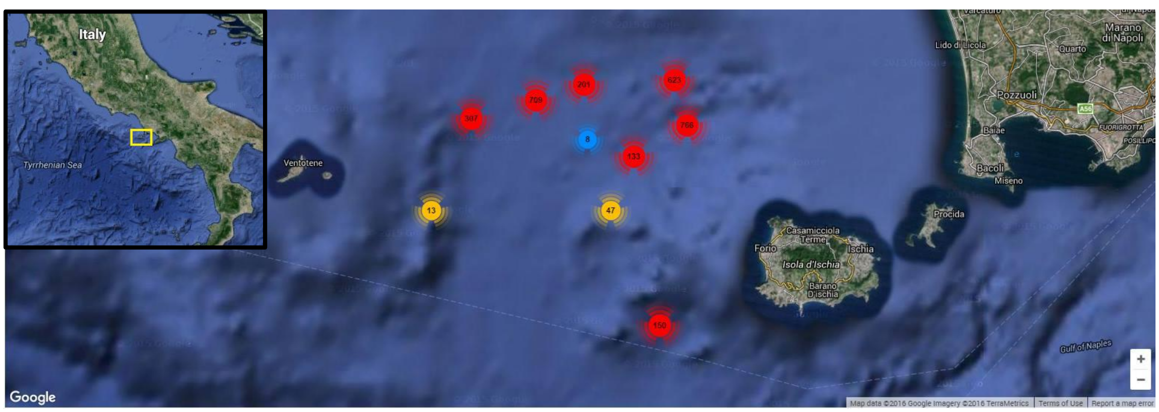

Figure 18. Locations of Orientation/ Searching/ Foraging Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High

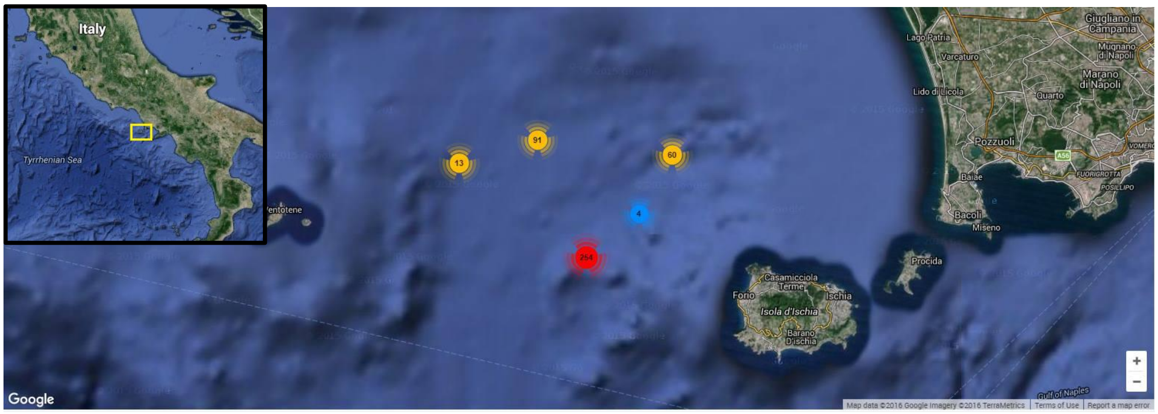

Figure 19. Locations of Socializing Events. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

7.3 Single Code vs. Combination Code Events

Events where multiple acoustic codes were heard simultaneously were labeled as 'Combination Codes'. In total, 14 different Combination Codes were created from the recorded time analyzed for this project. 85.71% of the Combination Codes were made-up of two acoustic codes and 14.29% of the Combination Codes were made-up of 3 acoustic codes. No events were recorded showing more than 3 acoustic codes simultaneously. Usual Clicks were part of 57% of the Combination Codes. Usual Clicks/Transition Clicks were the most frequently heard Combination Code in the Ischia sperm whale Bachelor Group acoustic repertoire representing 73.74% of the analyzed Combination Code time (Table 4).

Table 4. Composition of Combination Code events, time spent and percentage of time. (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence and H= Hour, Min= Minute, Sec= Second).

Combo Code	Time Spent (h/min/sec)	% of time
UC/TR	1:09:30	73.74%
UC/SQ	0:00:02	0.04%
UC/SC	0:04:47	5.08%
UC/RC/SC	0:00:04	0.07%
UC/RC	0:00:57	1.01%
UC/CR	0:16:30	17.51%
UC/CO	0:01:19	1.40%
UC/CC	0:00:03	0.05%
TR/SC	0:00:20	0.35%
TR/RC/SC	0:00:01	0.02%
TR/RC	0:00:11	0.19%
TR/CR	0:00:08	0.14%
SC/CO	0:00:22	0.39%
RC/SC	0:00:01	0.02%

Comparisons of Single Code events versus Combination Code events were performed for each of the 9 acoustic codes. The Silence acoustic code was not part of this analysis since the Silence code cannot be heard in combination with any other acoustic code. Single Codes represented 17 hours, 33 minutes, and 31 seconds of the total time analyzed (Table 5) and Combination Codes represented 1 hour, 34 minutes, and 15 seconds of the total time analyzed (Table 4). Silence represented 5 hours, 30 minutes, and 52 seconds (Table 5). Single Codes accounted for 71.25% of the total time analyzed in this project.

Table 5. Single Code vs Combination Code (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence and H= Hour, Min= Minute, Sec= Second, N= Number of observations).

Code	N for Single Code	Time Spent- Single Code (h/min/sec)	N for Combination Code	Time Spent- Combination Code (h/min/sec)	Time Difference (h/min/sec)
UC	1827	15:46:28	622	1:33:12	14:13:16
TR	567	1:33:33	333	1:10:10	0:23:23
CR	83	0:04:47	168	0:16:38	0:11:51
RC	13	0:00:18	66	0:01:14	0:00:56
CO	191	0:03:12	99	0:01:41	0:01:31
CC	1	0:00:02	3	0:00:03	0:00:01
SC	35	0:05:05	39	0:05:35	0:00:30
TP	0	0:00:00	0	0:00:00	0:00:00
SQ	6	0:00:06	2	0:00:02	0:00:04
SL	928	5:30:52	N/A	N/A	N/A

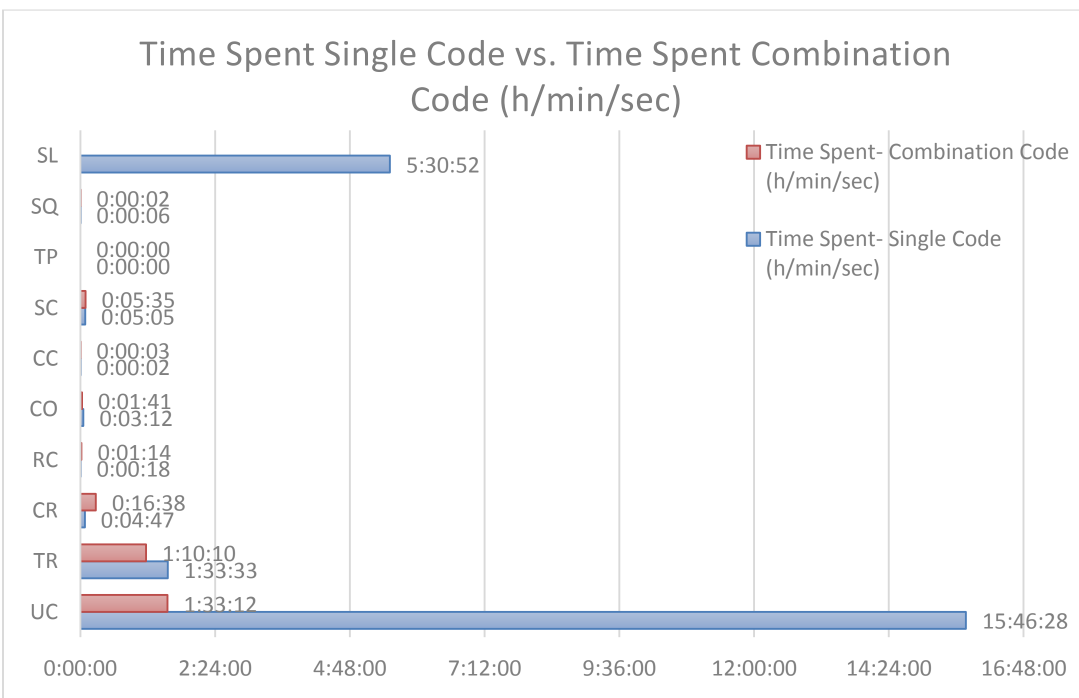

Figure 20. Time spent in Single Code events vs. time spent in Combination Code events, per acoustic code. (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence and H= Hour, Min= Minute, Sec= Second).

For the Usual Click acoustic code, time spent in Single Code versus time Spent in Combination Code resulted in a significant difference when tested at the 99% significance level (Table 6). Usual Clicks were heard in Single Code events 82.07% of the time versus 17.93% of the time in Combination Code events. Squeals also showed a significant difference between Single Code event time and Combination Code event time when tested at the 99% significance level (Table 6).

Table 6. Results of Pearson's Chi Square test at the 99% significance level. Each acoustic code was tested for significant difference between Single Code vs. Combination Code event time. (UC= Usual Click, TR= Transition Click, CR= Creak, RC= Rapid Click, CO= Coda, CC= Coda-creak, SC= Slow Click, TP= Trumpet, SQ= Squeal, SL= Silence).

Code	Significant Difference: Time Spent Single Code vs. Time Spent Combination Code
UC	Significant
TR	Not Significant
CR	Not Significant
RC	Not Significant
CO	Not Significant
CC	Not Significant
SC	Not Significant
TP	Not Significant
SQ	Significant
SL	N/A

7.4 Regno di Nettuno MPA

All acoustic code events analyzed in this study were plotted on a map according to GPS coordinates. A comparison of the events map (Figure 21) with a map of the Regno di Nettuno MPA (Figure 22) shows that the large majority of sperm whale acoustic events take place outside of the MPA territory.

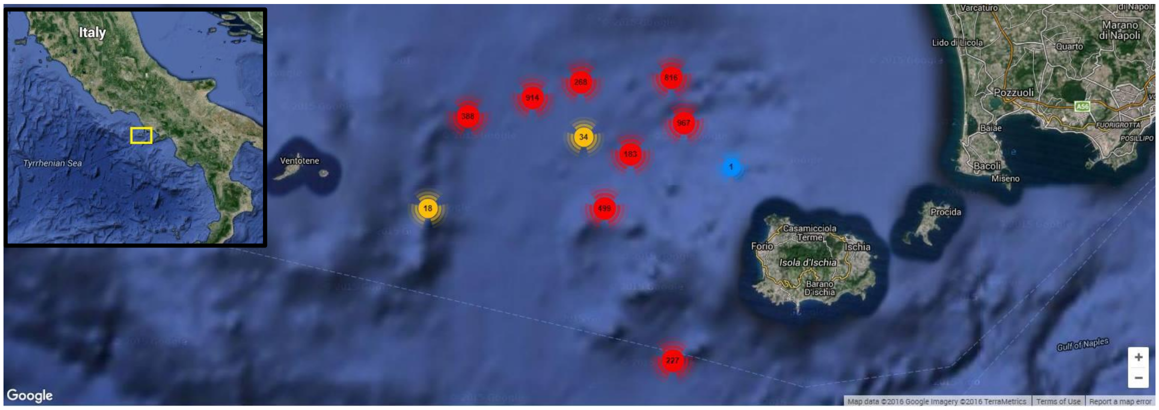

Figure 21. Locations of all acoustic code events surrounding Ischia, Italy. Colors indicate number of events; Blue= Low, Yellow= Medium, Red= High.

Figure 22. Regno di Nettuno MPA. Area inside of the colored boxes depicts MPA territory; regulation varies per zone according to color and resident or non-resident status (see Figure 23)

The Regno di Nettuno MPA is divided into various zones with differing restriction in each zone. Figure 23 displays each of the MPA zones and the various restrictions for each zone, according resident or non-resident status. The zones on the map in Figure 22 correspond directly to the zones listed in Figure 23.

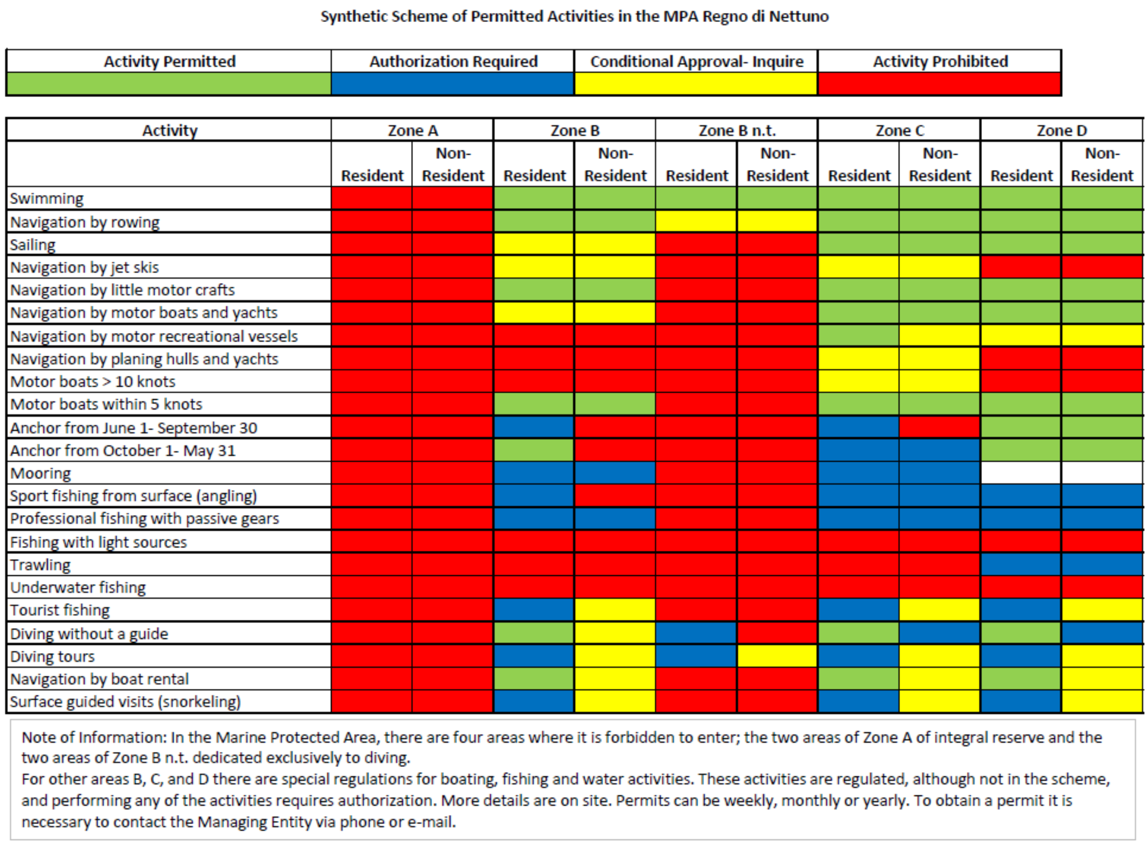

Figure 23. Regno di Nettuno MPA regulations by zone (translated from Italian).

8. DISCUSSION

8.1 Acoustic Repertoire and Behavioral Associations

Acoustics provide important insight to the behavior and lives of sperm whales below the surface, where they spend the large majority of their time. Studies have also shown that populations of sperm whales can be genetically different by location and can exhibit social, acoustic, and behavioral differences (Notarbartolo et al. 2012; Gero et al., 2014; Gero et al., 2016). Furthermore, acoustic and behavioral differences can be seen among the various social groups within a population (Breeding Groups, Bachelor Groups, and solitary adult males). Due to these complexities, it is critical to study each of the groups separately when working to protect an entire population of an area. This study provides data on the acoustic repertoire, behavioral associations, and habitat-use of sperm whale Bachelor Groups in the waters surrounding Ischia, Italy.

The acoustic repertoire in this study is described by using percentages of the time spent performing various acoustic types. This methodology has been used to describe a variety of acoustic repertoires for sperm whales, as well as other marine mammal species (Madsen et al., 2002; Whitehead, 2003; Watwood et al., 2006; Webster and Dawson, 2011; Mathias and Thode, 2012; Oliviera et al., 2013).

Results documented that the majority of the acoustic repertoire was comprised of Usual Clicks; representing 66.10% of the time analyzed. This study corroborates earlier studies on various sperm populations which show Usual Clicks as the main acoustic type (Madsen et al., 2002; Whitehead, 2003; Watwood et al., 2006). It is known that Usual Clicks are used as a form of searching echolocation/sonar to scan for potential prey and, therefore, it can be inferred that sperm whale Bachelor Groups in this area are spending a significant amount of time using echolocation and scanning for potential prey items (Backus and Schevill, 1966; Norris and Harvey, 1972; Gordon, 1987; Weilgart, 1990; Goold and Jones 1995; Møhl et al., 2000; Jacquet et al., 2001; Madsen et al., 2002; Whitehead, 2003).

This result does not necessarily mean that sperm whales are spending an equivalent amount of time capturing prey. On the contrary, Creaks have been associated specifically to prey capture attempts due to their short-range echolocation signal (Jacquet et al., 2001; Whitehead, 2003; Miller et al., 2004; Oliveira et al., 2013; NOAA Northeast Fisheries Science Center, 2015). In this study, Creaks only represented 1.36% of the time analyzed. While Creaks display strong evidence of prey capture attempts, they should not be used as the sole indicator of foraging success among sperm whales since it is possible that sperm whale foraging success could occur without the use of Creaks.

Following Usual Clicks, Silence represented the second most frequent acoustic code with 21.03% of the analyzed time. The acoustic recordings were generally made after the sighting of a sperm whale(s) in the near vicinity or hearing sperm whale acoustics via the hydrophone array. Due to this measure, it is plausible that even during Silence acoustic code periods, there were sperm whales present and within audible range of the hydrophones. It has been shown that sperm whales go silent during certain intervals of foraging dives, as well as during periods at the surface (Whitehead, 2003; Watwood et al., 2006). It is also possible that the silence of the sperm whales could have been attributed to the presence or arrival of the research vessel.

Transition Clicks are a newly named acoustic category identified during the acoustic recording analysis in this study. Transition Clicks maintain an ICI in between that of the slower Usual Click and the much faster Creak. Transition clicks are emitted during dives, occasionally at the surface, and seemingly utilized as an orientation/searching form of echolocation. While it appears that many studies have combined this acoustic type together with the Usual Click, it could prove beneficial to separate its occurrence due to its difference in ICI. The data in this study reveals complexities and possible patterns for the shifts of Transitional Clicks back and forth from other acoustic types and further research could reveal finer details of the prey search and foraging process of sperm whales. This study also shows that Transitional Clicks are prominent and important in the orientation/searching/foraging process as they accounted for 10.41% of the time analyzed and represented the third most frequent acoustic code.

Behavioral associations can be assigned to most of the acoustic codes and, in doing so, it allows us to gain a better understanding of how sperm whales are utilizing the area. Usual Clicks, Transition Clicks, and Creaks have all been associated to orientation/searching/foraging behaviors. Rapid Clicks, Codas, Coda-creaks, and Slow Clicks have been associated with socializing behaviors. The behavioral association for Silence, Squeals, and Trumpets remains relatively unknown.

Through these behavioral associations to acoustic types, this study showed that 77.87% of the time Ischia sperm whale Bachelor Groups were engaged in orientation/searching/foraging behaviors and 1.09% of the time they were engaged in socializing behaviors. A number of possibilities could exist for this overwhelming statistic. The groups of whales in this study are Bachelor Groups and not near female counterparts during recordings. It is possible that Bachelor Groups place more emphasis on hunting cooperatively when together and do not require high levels of socialization during this time. Additionally, it is possible that socialization acoustics and behaviors from males would be observed more frequently in the presence of females for the potential of mating/courtship. Finally, in addition to the identified acoustic types for socialization, it is possible that other acoustic types are being used to socialize.

8.2 Single Code vs. Combination Code Events

The analysis of sperm whale acoustics presents a number of obstacles when listening to more than one whale at a time, as was the case in this project while studying Bachelor Groups. However, it was found that the acoustic types could be categorized into one of two groups rather than attempting to separate individual acoustic types and risk destroying the true nature of the event. Single Code and Combination Code events were used to describe situations in which whales were either performing a single acoustic code or multiple acoustic codes simultaneously. It was found that 71.25% of the events analyzed consisted of Single Codes. This finding indicates that although Bachelor Groups are comprised of a number of different whales, the majority of the time the group either engages in the same acoustic code or some whales are silent while one or more whales engage in a single acoustic code.

A comparison between time spent in Single Code versus time spent in Combination Code for each of the acoustic codes showed a significant difference for Usual Clicks. This demonstrates that Usual Clicks were heard significantly more in Single Code events than in Combination Code events and indicates that Bachelor Groups tend to perform Usual Clicks simultaneously or remain silent while other whales in the group perform Usual Clicks. This could reveal an importance in the function of Usual Clicks being performed without the disruption of other acoustic types.

Squeals also revealed a significant difference between time spent in Single Code and time spent in Combination Code; however, the N-value for Squeals was extremely small (Table

5) and further data collection should be performed in order to get a more accurate understanding of this difference.

The composition of Combination Codes showed that the large majority were made-up of two acoustic codes rather than three. No events were recorded where more than three acoustic codes were heard simultaneously. Additionally, the Combination Code for Usual Click/Transition Click represented 73.74% of the Combination Codes observed. The differences between a Usual Click and Transition Click are minor changes in ICI and both acoustic codes are seemingly associated with orientation/searching echolocation.

It is suggested that sperm whale Bachelor Groups spend a large majority of the time producing one acoustic code simultaneously or remaining silent while a member of their group produces one acoustic code. Additionally, even in a situation where a combination of different codes is heard simultaneously, the large majority of these instances consist of acoustic codes which are similar in both composition and function. These results, although not conclusive, could indicate a strong, collaborative structure in the use of acoustics among sperm whale Bachelor Groups. The observed cause and effect could suggest that communication is occurring to guide collaboration. A variety of reasons could exist for Bachelor Groups to work together in the production of acoustics, including the reduction of inefficient clicks and background noise and the effectiveness of foraging or socializing cohesively.

These findings demonstrate the possibility that sperm whale Bachelor Groups near Ischia could be working as a team while foraging and possibly engaging in communication in order to coordinate efforts. These speculations would be consistent with an effective strategy for evolutionary success. Foraging as a team could prove to be much more effective than foraging as a single whale. If populations can evolve to increasing foraging success through coordinated efforts, then it would ultimately increase the success and survival of the population.

It has been shown in the previous literature that Bachelor Groups in Ischia show strong site fidelity and exhibit social behaviors, such as socializing at the surface and forming social bonds; both behaviors considered exceptionally rare among males and only thought to exist in Breeding Groups of females and calves (Whitehead et al., 1992; Jaquet et al., 2000; Carpinelli et al., 2014; Mussi et al., 2014; Pace et al., 2014). This behavior has yet to be observed in any other population sperm whales. However, the findings of this study strengthen the prospect that Ischia sperm whale Bachelor Groups form social bonds by demonstrating that they may also exhibit cooperative acoustic behavior.

8.3 Regno di Nettuno MPA

The Regno di Nettuno MPA, established in 2007, was put into place to protect marine biodiversity. The more pelagic area of the MPA was modeled after the area identified as critical habitat for the endangered short-beaked common dolphin (Pace et al., 2012). The Mediterranean sperm whale subpopulation is also considered 'endangered' (Notarbartolo et al., 2013). In order to identify critical habitat for sperm whale Bachelor Groups in this study, the locations of all acoustic events were plotted in event maps and areas of high activity were identified.

Figures 18 and 19 show no obvious difference between areas of orientation/searching/ foraging acoustics and socializing acoustics. However, the maps do reveal areas of higher concentration for acoustic activity to the northwest of Ischia, in some of the deepest parts of the submarine Canyon of Cuma. The findings document that this 'hotspot' for acoustic activity of sperm whale Bachelor Groups occurs mostly outside of the MPA boundaries. Acoustic activity has been correlated to both orientation/searching/foraging and socializing behaviors. Consequently, it can be inferred that sperm whale Bachelor Groups are foraging and socializing in the waters surrounding Ischia, Italy and that the 'hotspot' for sperm whale activity could be considered a critical habitat.

Previous studies are similar to these results, revealing high encounter rates for sperm whales in the waters to the northwest of Ischia (Mariani et al., 2009; Mussi et al., 2014). Moreover, these studies have found that sperm whale encounter rates increased with increasing distance from the coast. It has been suggested that the sperm whales are being pushed further offshore by the disturbance of heavy boat traffic and anthropogenic noise.

This potential loss of habitat is especially taxing on a species already struggling with a decreasing population.

9. CONCLUSIONS AND RECOMMENDATIONS

While the global population of sperm whales is listed as ‘Vulnerable’, the Mediterranean subpopulation of sperm whales is currently listed as ‘Endangered’ (Taylor et al., 2008; Notarbartolo et al., 2012). The Mediterranean subpopulation, which is genetically distinct, contains fewer than 2,500 mature individuals, experiences an inferred continuing decline in numbers of mature individuals, and includes all mature individuals in one undivided subpopulation. Due to these factors, assessment of the subpopulation has deemed it ‘endangered’ (Notarbartolo et al., 2012).

With a currently decreasing population, it is important not only to study and understand the ecology and behavior of sperm whales in the Mediterranean but to utilize the findings for the establishment of population-specific management strategies and regulations for the protection of the species.

The results of this study show that sperm whales are foraging and socializing in the waters around Ischia, Italy and a ‘hotspot’ of activity was identified to the northwest of island, in the deepest parts of the submarine Canyon of Cuma. This study also revealed the sperm whale Bachelor Groups spend a vast majority of their time engaged in orientation/searching/foraging behaviors, making the ‘hotspot’ a critical area for the population. While the ‘hotspot’ is located in deep, open water, an extension of the MPA or suggestion of minor route changes for shipping to avoid this area could prove beneficial to preserving the habitat.

Analysis of the acoustic repertoire of sperm whale Bachelor Groups suggests the possibility of a collaborative acoustic structure and a speculated strategy for evolutionary success among the group. Further research should be carried out in order to explore the possibilities of a tighter social structure in Bachelor Groups than previously thought. A better understanding of the behaviors and structure of the group could allow for more specific and effective management of the species. Additionally, the study revealed the existence, and prominence, of Transition Clicks in the acoustic repertoire of sperm whale Bachelor Groups. Further research could provide much finer detail of the foraging process; a process that has been fairly difficult to document due to the extreme depths that it occurs.

It is recommended that research be continued on the correlation between sperm whale Bachelor Group acoustics and the possibility of a cooperative acoustic structure. In addition, a deeper analysis of Transition Clicks and their function in the acoustic repertoire could provide much deeper insight to the foraging behavior of Bachelor Groups. It is highly suggested that precautions be taken to protect the identified ‘hotspot’ of foraging activity to the northwest of Ischia in order to avoid further habitat loss for the sperm whale population in the area. While this study has provided insight on the acoustic repertoire, behavior, and habitat-use of sperm whale Bachelor Groups in the waters near Ischia, Italy, it is crucial to not only use this knowledge for implementation of regulation but to continue the research and understanding of this highly complex and magnificent species.

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