# ACOUSTIC VOCALIZATIONS OF DOLPHINS AND EFFECTS OF ANTHROPOGENIC NOISE

Undergraduate Research Scholars Thesis

by

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# ABSTRACT

Acoustic vocalizations of dolphins and effects of anthropogenic noise. (May 2014)

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The effects of anthropogenic noise on acoustic communication among cetaceans have become an increasing concern because cetaceans use acoustic communication as a major part of their interactions. Human contribution to the ocean's noise pollution is dominated by sounds from shipping, oil and gas development, defense-related and research activities, as well as many other activities both recreational and scientific. The concern is that the continuous increase of activities and volume in the ocean is masking communication among cetaceans and, in turn, can be affecting populations, foraging habits and social behavior. By analyzing acoustic recordings from populations of dolphins in the Gulf of Corinth in Greece and comparing the results with previous analyses carried out in Hong Kong, I describe potential variations among communication between local delphinids due to effects of ambient noise and propose improvements and/or regulations that can help decrease man-made noise.

# CHAPTER I

# INTRODUCTION

Delphinids exhibit a complex social structure (Janik, 2009), with intricate intra- and inter-species networks, and elaborate social behaviors. A key behavior for delphinids is their system of communication. While dolphins show a form of communication through physical gestures, a second significant form of communication used is acoustic signaling. The vision of odontocetes tends to be compromised by water clarity and other issues, and acoustic communication is primarily used for social interactions as it can readily maintain group cohesion over short- and long-ranges (Janik, 2009).

Dolphins communicate acoustically by emitting specialized signals that vary in frequency, contour and duration. The sound repertoire of most odontocetes consists of three major groupings: whistles, burst-pulsed sounds and clicks, each playing a role in social interactions (Janik et. al., 1994). Broadband clicks are generally used for echolocation purposes, while burst-pulsed sounds and whistles play key roles in intra- and inter-group communication (Azzolin et. al., 2013). Whistles are continuous, frequency-modulated signals (Papale et. al., 2013), with a bandwidth range of 800Hz and 28.5 kHz (Janik, 2009) often containing harmonic components (Papale et. al., 2013). A dolphin initiates an interaction by broadcasting a signal, encrypted with information, within a specific frequency band. The signaler then relies on a conspecific to hear and react to the sound. Hearing among delphinids ranges from about 50 Hz-150 kHz, with additional variation among species (Janik, 2009). For short-range detection, a dolphin typically uses its echolocation system, producing click sounds. In long-range communication, an individual generally produces whistles, as the signal transmits further depending on the frequency. In an ideal environment, whistle sounds produced by a common bottlenose dolphin, *Tursiops truncatus*, below 12 kHz can be detected by a conspecific at up to (outer limit) ranges of 10-20 km; higher frequencies have a shorter transmission range as they diminish faster, thus, the active space of a call 12 kHz or above is detectable up to about 4 km (Janik, 2009). Frequency, strength of the sound when first emitted, physical property of the surroundings through which the sound travels, and background noise levels, affect the maximum distance and sound level at which a signal is detected (Würsig and Richardson, 2009).

A growing concern is the increase of anthropogenic noise in the ocean and its effects on the cetaceans that can hear it and have to communicate through it (Würsig and Richardson, 2009). Ambient noise has an effect on the whistle contour and parameters of dolphins (Papale et. al., 2013). Several short-term changes in behavior result from reactions to noise pollution: shorter surface intervals, efforts to protect calves, longer dive times, faster swimming behavior, and avoidance of the area containing the sound (Croll et. al., 2001). Common bottlenose dolphins, short-beaked common dolphins, *Delphinus delphis*, (Papale et. al., 2013), and other odontocetes, alter the frequency and modulations of whistles (Papale et. al, 2013) or increase the source level of their signals to reduce the effects of masking by noise pollution (Würsig and Richardson, 2009). Typically, dolphins limit their acoustic communication to the bare minimum during times when ambient noise reaches a level where it begins to hinder the transmitted information. However, when noise levels increase abruptly, delphinids increase their calling rates. This type of response is most likely a method to better the chances of their signals being received by a conspecific. For example, when a boat approaches a group of bottlenose dolphins, the dolphins escalate the redundancy of their calls. This reaction can improve the likeliness of individuals detecting the call, which may be signaling information about an individual's location as well as where to gather once the boat has passed, helping to maintain group cohesion (Janik, 2009). Indo-Pacific humpback dolphins (*Sousa chinensis*) increase whistle rates when met with boat traffic, changing their degree of communication once a boat has passed (Sims et. al., 2011). This trend of signaling suggests that group dispersal and calling rate are directly related, as an increase in dispersal generates an increase in call rates to maintain group cohesion (Cook et. al, 2004). Furthermore, Indo-Pacific humpback dolphins located in areas with a significant level of noise pollution displayed whistles of lower frequencies and less frequency inflection in comparison to dolphins residing in areas less polluted by anthropogenic noise (Janik, 2009), indicating additional alterations in the whistle repertoire due to ambient sound.

Additionally to boat traffic, there are underwater blasting, oil drilling, construction, and several other anthropogenic activities that escalate noise levels in the ocean. The intensity of masking from these man-made activities has caused deviations in migration and distribution patterns among animals, as well as unexpected animal strandings due to noise levels. Ambient noise also has a clear potential to disrupt or hinder acoustic communication between individuals (Janik, 2009). It has been suggested that there is a direct relationship between higher-frequency whistle signals in bottlenose dolphins and higher levels of ambient noise. However, it is also possible that a bottlenose dolphin differentiates its whistle contour to its surrounding environment by decreasing the frequency and modulation of its whistles in response to an increase in anthropogenic noise (Azzolin et. al., 2013). Due to the potential effects of man-made noise on delphinid behaviors such as foraging, navigating, and communicating, there can be a negative effect on the efficiency of such behaviors (Croll et. al., 2001). A change of these behaviors can have a damaging effect on population growth. Implementing strict regulations in areas where animals congregate as well as regulations limiting anthropogenic activity can aid in decreasing noise levels in the ocean. Further research on the effects of acoustic activity on delphinid communication will provide additional information on potentially adverse effects or changes in acoustic behavior directly related to underwater noise and efficiency of delphinid acoustic communication.

Analyses of delphinid whistles will help to understand dynamics of inter- and intra-population networks (Azzolin et. al., 2013). By analyzing acoustic data of dolphins, collected in the Gulf of Corinth in Greece I hope to establish a basic understanding of the representative sounds of the dolphin community. In addition, by comparing results to previous analyses in Hong Kong, I intend to obtain a better understanding of the effects of anthropogenic noise on the acoustic communication of delphinids. I hypothesize that delphinids in closer proximity to man-made noise modify the regularity at which they communicate with each other, as well as alter the frequency and duration of their acoustic signaling, so as to enhance their chances of being detected by a conspecific. Knowledge of vocal variation in the acoustic channel of delphinids due to ambient noise generated by human activity can have significant impacts on conservation views and regulations on human activity on the ocean.

# CHAPTER II

# METHODS

## Study area

For the purpose of this study, two areas of contrasting levels of anthropogenic activity were surveyed. The first area was the Gulf of Corinth in Greece, located in the northeast of the Mediterranean Sea. This area represents the zone less disrupted by boating, drilling and other ambient noise. The second area was from a previous study in Hong Kong (Sims et. al., 2011; Sims et. al., 2012), which represents the opposing extreme of a zone more intensively affected by noise pollution. All Hong Kong analysis is extrapolated from previous literature of Sims et. al., 2011 and Sims et. al., 2012.

### *Gulf of Corinth, Greece*

The Gulf of Corinth (approximate coordinates 38° N-022° E) is a small rather enclosed sea, except for two openings located at the east and west ends. At the east end of the Gulf of Corinth is a narrow passage (25m), the Corinth Canal, which opens up to the Saronic Gulf. At the west end, the Rio-Antirio straight (2-km wide) creates a passageway into the Gulf of Patras and the Ionian Sea. The Gulf of Corinth has very steep slopes along the coast, reaching a maximum depth of 935m near the center (Frantiz and Herzing, 2002). Artisanal fishing run by locals in small boats is common, but there is some presence of commercial traffic by cargo ships that pass through, as well as several fish farms located around the gulf.

## Recording procedures

### *Gulf of Corinth, Greece*

All recordings were carried out when the following favorable parameters were met: favorable sea conditions (low sea state, at Beaufort <2), dolphins maintained a general speed of <3 knots, and no other boat than our research vessel was present in the area. Once these parameters were met, recordings were started when the dolphins were a maximum of 15-20 m away from the boat. A Novamarine, 5.8 m inflatable craft with a rigid hull, powered with a 100HP four-stroke outboard engine, was used during the surveys. When the boat was motionless, a hydrophone connected to a handy-recorder was placed into the water in the stern lateral part of the boat and was allowed to drag by a cable 11m long. The handy-recorder was an H1 200M with the following settings: WAV recording format, low cut and auto level set at "off", and the input level at 49/100. After 2 meters of the cable were in the water, recordings were started and the rest of the cable was slowly released.

During recordings, vessel engine was off, there was no talking, and any potential extraneous noises were minimized. One person was in charge of holding the cable and hydrophone while listening with the headphone (QuietComfort 15 – Bose). A second person, away from the hydrophone area, recorded with another digital recorder the following factors: time of day, behavior of surrounding animals, number of individuals, composition of the group, presence of short-beaked common dolphins, group activity, minimum dolphin distance from the hydrophone, and any possible relevant information.

When sounds were no longer audible because of the dolphins' distance from the boat, the recording was stopped, the cable and hydrophone were retrieved, and the boat was then moved to another possible recording location closer to the dolphins. Four different group follows were surveyed, each composed of one or more species: 1) Striped dolphin, *Stenella coeruleoalba*, Short-beaked common dolphin, *Delphinus delphis*, and Risso's dolphin, *Grampus griseus* 2) Striped dolphin and Risso's dolphin, 3) Striped dolphin and short-beaked common dolphin, 4) Striped dolphin. After each survey, the hydrophone and cable were carefully washed with fresh water, and the data collected were transferred with a micro-USB cable to a computer.

### Acoustic analysis procedure

Approximately 40 minutes of recordings, associated with 8 acoustic detections for 4 different group follows were taken in the month of July, 2013. A total of 400 whistles were documented and used for statistical analysis. Whistles were manually measured and analyzed based on 7 parameters: duration, minimum frequency, maximum frequency, start frequency, end frequency, frequency range, and contour. Whistle analysis used Audacity acoustic software at a scale of 0-44 kHz. Whistles that went off the scale, above 44 kHz, were not included in the statistical analysis. If a whistle was not clearly identifiable, it was also not included for statistical analysis.

A descriptive analysis was run using SPSS software establishing the mean of the six parameters measured for each whistle contour found among the delphinid repertoire in the Gulf of Corinth. A frequency analysis of whistle contours present for each group follow was conducted and compared to each other for differences in repertoire.

# CHAPTER III

# RESULTS

I categorized sound types into groups, explained here.

## Rise

The rise whistle type was a narrow-band vocalization with harmonic structure (Fig. 1 (e)). The mean duration was 0.6 ± 0.3 s (n=70) and the mean minimum frequency (7.10 ± 2.8 kHz, n=70) observed to be approximately half the mean maximum frequency (14.81 ± 2.8 kHz, n=70; Table 1).

## Down

The down whistle type was a narrow-band vocalization with harmonic structure (Fig. 1 (c)). The mean duration was 0.78 ± 0.22 s (n=27) with a mean maximum frequency of 16.07 ± 4.1 kHz (n=27) and mean minimum frequency of 7.78 ± 1.8 kHz (n=27). The mean ending and starting frequency were equivalent to the mean maximum and minimum frequencies, respectively (Table 1).

## Echolocation

Echolocation was composed of a series of clicks (Fig. 1 (h)), commonly referred to as “click trains”. This broad-banded vocalization had a mean duration of 0.57 ± 0.49 s (n=22) with a mean minimum frequency of 12.73 ± 9.8 kHz (n=22) and a mean maximum frequency of 43.59 ± 1.9 kHz (n=22), some maximum frequency of echolocation ranged greater than 44 kHz (Table1).

### Flat

The flat whistle contour was a narrow-banded vocalization with a continuous frequency with harmonic structure (Fig. 1 (a)). This whistle type had the shortest mean duration of the narrow-banded tonal signals (0.45 ± 0.28 s, n=35) and a mean frequency of 10.51 ± 4.2 kHz (n=35;Table 1).

### Buzz

The buzz vocalization, similar to echolocation, was composed of a series of broad band clicks (Fig. 1 (i)). Though this call type had a shorter mean duration (0.13 ± 0.16 s, n=52) than echolocation, its frequency range was larger (44 kHz), with clicks exceeding 44 kHz (Table 1).

### Hill

The hill contour was a narrow-banded, frequency modulated vocalization with harmonic structure (Fig. 1 (g)). The mean duration was 0.97 ± 0.3 s (n=97) and the mean starting frequency (9.13 ± 2.93 kHz, n=97) and mean ending frequency (8.89 ± 2.39 kHz, n=97; Table 1) were observed to be approximately similar.

### Hole

The hole contour was a narrow-banded, frequency modulated whistle with harmonic structure (Fig. 1 (f)). This whistle type had the shortest mean duration (0.94 ± 0.33 s, n=13; Table 1) of the frequency modulated whistles.

### Sine

The sine contour was a narrow-banded, frequency modulated whistle with harmonic structure (Fig. 1 (b)). This contour had the most modulation and the longest mean duration (1.12 ± 0.29 s, n=51; Table 1) of the frequency modulated whistle types.

### Quack

The quack sound was a broad-banded, burst pulse call with harmonic structure (Fig. 1 (j)) and short in duration, comparable to the quack defined by Parijs and Corkeron's (2001) study with Pacific humpback dolphins, *Sousa chinensis*. This call type had the lowest mean minimum frequency (3.12 ± 0.64 kHz, n=8) of the tonal signals and the shortest mean duration (0.06 ± 0.02 s, n=8; Table 1) of all vocalizations.

### Plateau

The plateau contour was a narrow-banded, frequency modulated whistle with harmonic structure (Fig. 1 (d)). It had a mean duration of 0.82 ± 0.31 s (n=25) with a mean maximum frequency of 16.16 ± 3.95 kHz (n=25), mean minimum frequency of 7.72 ± 2.6 kHz (n=25), mean starting frequency of 10.52 ± 5.7 (n=25), and mean ending frequency of 13.24 ± 4.67 kHz (n=25; Table 1).

**Table 1.** Descriptive statistics, showing mean ± SD whistle contour duration (seconds), maximum frequency (kHz), minimum frequency (kHz), range (kHz), starting frequency (kHz), and ending frequency (kHz) for rise, down, echolocation, flat, buzzes, hill, hole, sine, quack, and plateau..

| Whistle Contour | | Duration (Sec) | Max Freq (KHz) | Min Freq (KHz) | Range (KHz) | Start Freq (KHz) | End Freq (KHz) |
|---|---|---|---|---|---|---|---|
| Rise | Mean | .6061 | 14.81 | 7.10 | 7.71 | 7.10 | 14.81 |
| | N | 70 | 70 | 70 | 70 | 70 | 70 |

**Table 1.** (Continued)

| Whistle Contour | | Duration (Sec) | Max Freq (KHz) | Min Freq (KHz) | Range (KHz) | Start Freq (KHz) | End Freq (KHz) |
|---|---|---|---|---|---|---|---|
| Rise (Continued) | Std. Deviation | 0.3089 | 2.82 | 2.855 | 2.979 | 2.855 | 2.82 |
| Down | Mean | 0.7852 | 16.07 | 7.78 | 8.3 | 16.07 | 7.78 |
| | N | 27 | 27 | 27 | 27 | 27 | 27 |
| | Std. Deviation | 0.22596 | 4.132 | 1.805 | 3.811 | 4.132 | 1.805 |
| Echolocation | Mean | 0.5709 | 43.59 | 12.73 | 30.86 | | |
| | N | 22 | 22 | 22 | 22 | | |
| | Std. Deviation | 0.4929 | 1.919 | 9.847 | 10.339 | | |
| Flat | Mean | 0.4571 | 10.51 | 10.51 | 0 | 10.51 | 10.51 |
| | N | 35 | 35 | 35 | 35 | 35 | 35 |
| | Std. Deviation | 0.28164 | 4.28 | 4.28 | 0 | 4.28 | 4.28 |
| Buzz | Mean | 0.1375 | 44 | 0 | 44 | | |
| | N | 52 | 52 | 52 | 52 | | |
| | Std. Deviation | 0.16913 | 0 | 0 | 0 | | |
| Hill | Mean | .9740 | 16.86 | 7.92 | 8.94 | 9.13 | 8.89 |
| | N | 97 | 97 | 97 | 97 | 97 | 97 |
| | Std. Deviation | .30504 | 2.901 | 2.515 | 2.809 | 2.936 | 2.397 |
| Hole | Mean | .9446 | 16.31 | 9.62 | 6.69 | 16.54 | 15.46 |
| | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | Std. Deviation | .33296 | 4.939 | .870 | 4.750 | 4.754 | 2.696 |
| Sine | Mean | 1.1255 | 17.37 | 8.14 | 9.24 | 12.33 | 10.67 |
| | N | 51 | 51 | 51 | 51 | 51 | 51 |
| | Std. Deviation | .29829 | 2.884 | 1.357 | 2.495 | 3.303 | 4.126 |
| Quack | Mean | .0625 | 10.50 | 3.125 | 7.37 | | |
| | N | 8 | 8 | 8 | 8 | | |
| | Std. Deviation | .02816 | 0.925 | 0.640 | 0.916 | | |

**Table 1.** (Continued)

| Whistle Contour | | Duration (Sec) | Max Freq (KHz) | Min Freq (KHz) | Range (KHz) | Start Freq (KHz) | End Freq (KHz) |
|---|---|---|---|---|---|---|---|
| Plateau | Mean | .8252 | 16.16 | 7.72 | 8.44 | 10.52 | 13.24 |
| | N | 25 | 25 | 25 | 25 | 25 | 25 |
| | Std. Deviation | .31290 | 3.955 | 2.606 | 3.150 | 5.709 | 4.675 |

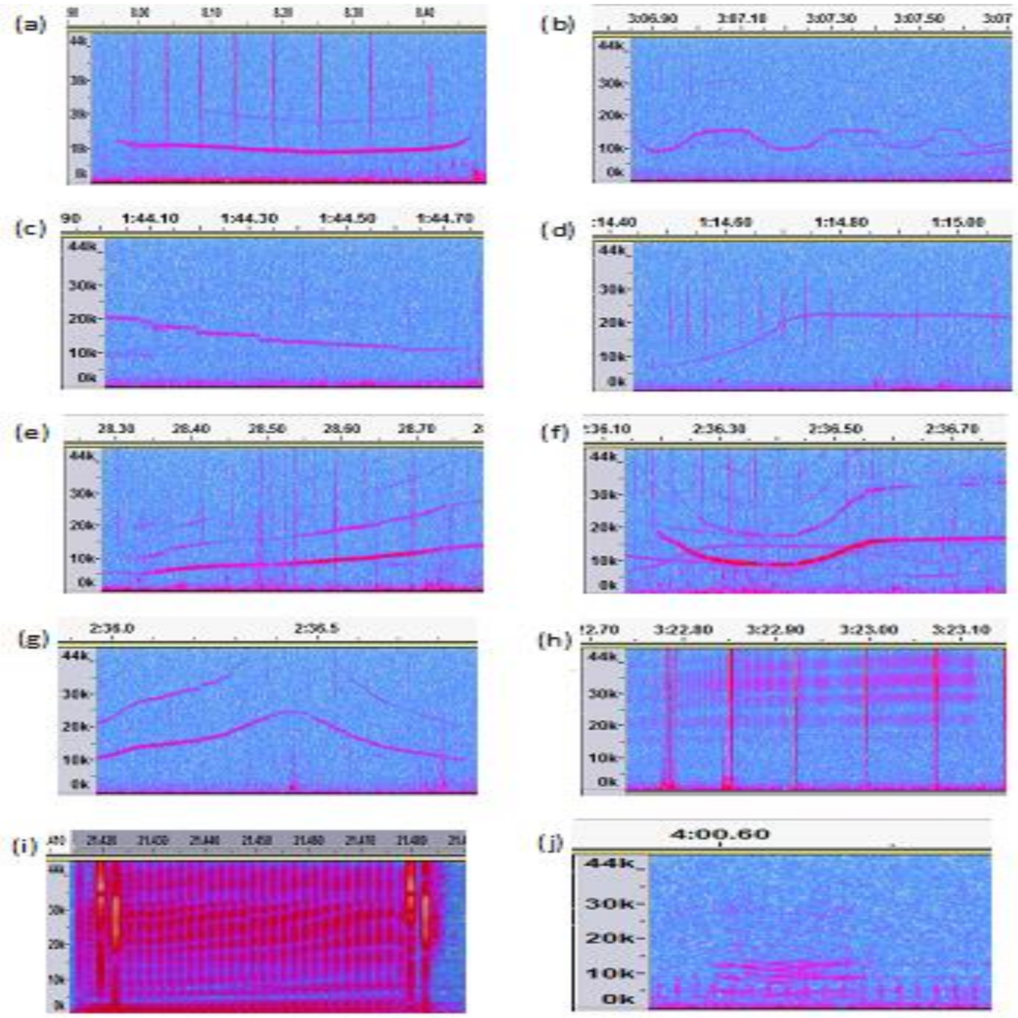

**Figure 1.** Spectrogram figures (a) – (j) illustrate the contour of each vocalization (flat, sine, down, plateau, rise, hole, hill, echolocation, buzz, and quack, respectively) recorded from Striped dolphins, Short-beaked common dolphins, and Risso’s dolphins in the Gulf of Corinth, Greece.

The mixed-species group composed of all three species (Fig. 2 (a)) and the group composed of striped dolphins and short-beaked common dolphins (Fig. 2 (c)), showed a higher percentage of hill contours, with Figure 2 (c) having the greatest percentage. The species group composed of only striped dolphins had the greatest percentage of rise whistle types (Fig. 2 (d)). The two group follows with the Risso’s dolphin present (Fig. 2 (a) and (b)), show presence of the quack vocalization. Figure 2 (b) has the highest percentages for both broad band click vocalizations.

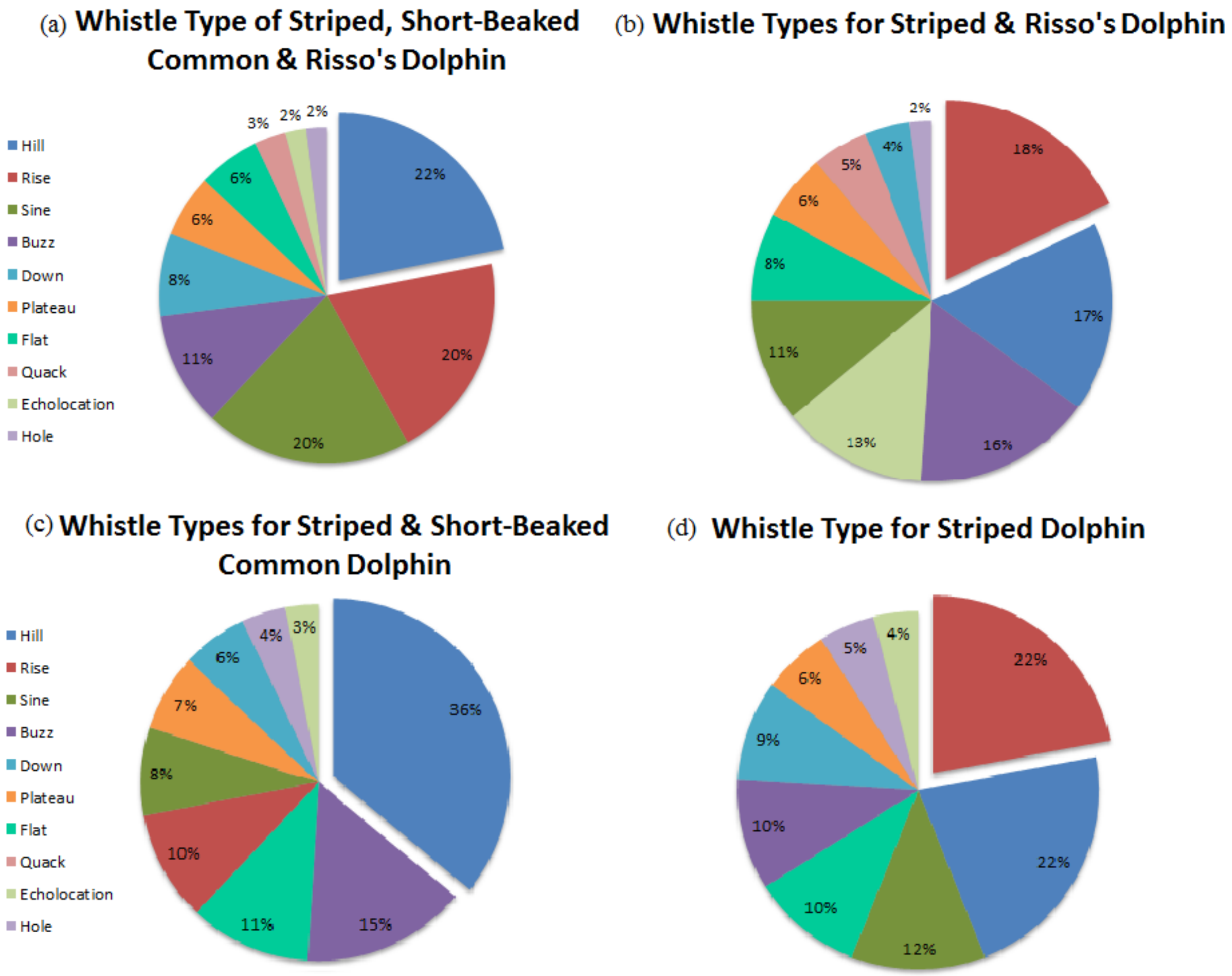

**Figure 2.** The percentage of vocalization types analyzed for all four group follows, (a) Striped, Short-beaked common, and Risso’s dolphin, (b) Striped and Risso’s dolphin, (c) Striped and short-beaked common dolphin, and (d) Striped dolphin.

# CHAPTER IV

# DISCUSSION

The results demonstrated varying proportions of vocalizations used in the 4 group follows. A noteworthy difference is the presence of the low-frequency quack in the groups only containing the Risso's dolphin. Corkeron and Parijs (2001) recorded several vocalizations produced by Australian Risso's dolphins, predominantly low-frequency sounds, ranging from 30 Hz to 22 kHz. This may signify that the observed quack was emitted by the present Risso's dolphin and could be used later as an indicator for species present in acoustic recordings. However, further study must be carried out on species' repertoire dynamics before assumptions without visual confirmation can be made.

In comparing representative sounds in the Gulf of Corinth to vocalizations observed in Hong Kong, the dominating difference was the absence of low frequency vocalizations (Sims et. al., 2011), such as the quack that was noted to present in the gulf. Sims et. al. (2011) suggest that low frequency calls were unable to be discriminated due to the high concentration of low frequency sounds generated by numerous sources of anthropogenic noise. Previous studies agrre with this assumption, determining significant deviations among whistle parameters for populations of Atlantic ocean common bottlenose dolphins (May-Collado and Wartzok, 2008), Indo-pacific bottle nose dolphins, *Tursiops aduncus* (Morisaka et. al., 2005), Indo-pacific humpback dolphins (Sims et. al., 2012), short-beaked common dolphins (Papale et. al., 2013) and several other delphinid species. However, differences in whistle variability can also be a factor of geographic variations (Azzolin et. al., 2013), different populations (Sims et. al., 2011), genotypic influences (Papale et. al., 2013), and social structure (Conner et. al., 1998).

Acoustic communication is essential in mediating mammalian social systems (Parijs and Corkeron, 2001). Creating a baseline of the characterizations of a species' repertoire provides us the possibility to study differences between species, populations, or behaviors (Vaughn-Hirshorn et. al., 2012). Comparing repertoires between species, or changes in a species' repertoire when in a mixed- species group, can advance our understanding of evolutionary relationships (Vaughn-Hirshorn et. al., 2012) and intra-species communication. Association between acoustic signals and displayed behavior can inform possible functions of vocalizations (Vaughn-Hirshorn et. al., 2012). Based on a population level, comparisons of species' repertoire can show the impact of different ecological conditions and culture on delphinid communication (Vaughn-Hirshorn et. al., 2012).

In conclusion, further research is needed on the composition of species-specific acoustic repertoires to establish a baseline of typical vocalizations, so that future comparisons can evaluate variations among whistle parameters due to changes in ecological dynamics. Acoustic studies can have substantial impacts on conservation and benefit delphinid populations by proper implementation of noise regulations specific for various regional areas around the globe. Region-specific noise regulations may be more beneficial than a global standardized regulation, as different delphinid populations and in different habitats with variable (often anthropogenic) background noises vary in communication parameters.

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