INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 15, Issue 4, 2024: 1959-1970 www.ijcs.ro

DOI: 10.36868/IJCS.2024.04.25

FIRST RECORD OF SPERM WHALE DETECTION USING A HYDROACOUSTIC INSTRUMENT IN THE VICINITY OF FISH AGGREGATING DEVICES (FADs) IN THE MOLUCCA SEA

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Abstract

Knowledge of the occurrence and behaviors of formerly intensively exploited marine mammals, such as sperm whales and around fish aggregating devices (FADs) are lacking yet crucial for guiding species conservation management. FAD-based fisheries attract targeted fish such as tuna and Endangered-Threatened-Protected species like sperm whales, making these species more vulnerable. Acoustic studies are imperative to learn more about sperm whale's ecology. This study aimed to investigate the occurrences and activity patterns of sperm whales around FADs using active acoustic methods in the Molucca Sea. The 200kHz echosounder instrument was employed in this study to measure the target strength (TS) based on vertical movement patterns in the echogram. The presence of sperm whale has been observed spending around 6 hours at shallow depths during daylight over 10 days near the FADs, with depths varying from 0 to 50 meters. The temporal variations in the scattering amplitude (S_A), with the highest S_A values observed between 10:00 AM and 5:00 PM. The TS values were measured at -31dB, 34dB and -30dB for the head, tail and broadside aspects, respectively. The findings from this study are anticipated to offer crucial contributions to the ecological understanding of sperm whales, thereby establishing a foundation for more effective conservation and management efforts within the Molucca Sea.

***Keywords**: Active sonar system; Fish aggregating devices; Sperm whale; Target strength.*

Introduction

In recent years, research on the presence and behavior of marine mammals around fish aggregating devices (FADs) has increased [1-2]. The utilization of FADs is often associated with commercial fishing activities, especially for pelagic fish such as tuna [3]. However, FADs can also attract other marine species, including marine mammals [4]. Furthermore, the influence of FADs on marine animals and their interactions with these structures has not been extensively studied. FADs are essentially designed and used to attract and concentrate fish populations in specific areas, thereby increasing the efficiency of fishing operations in terms of distance and time [5]. However, in some cases, FADs can also have unintended impacts by attracting the attention of marine mammals, such as dolphins and whales [6-8].

Sperm whales are large marine mammals with long-distance migration patterns that involve traveling between polar and tropical waters [9]. They typically migrate for feeding, mating, or giving birth. For their paraffin, this whale was the target of European and American

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whaling ships for two centuries, from the mid-18th century to the early 20th [10]. Their population recovery has been slow due to the extensive commercial hunting activities in the past [11]. Currently, this species is classified as vulnerable on the IUCN Red List [12]. Some marine biota are often found around FADs for various reasons, including serving as orientation points and meeting points during migration navigation [13]. The presence of sperm whales can be detected using various approaches, including visual monitoring [14] and technology-based applications [15]. One technology that can detect sperm whales near FADs locations is underwater acoustic instruments [16]. Knowledge about the acoustic target strength (TS) of sperm whales is still limited [17-18]. Researchers have been using underwater acoustic techniques as a reliable tool to monitor the presence of marine animals around FADs to fill this information gap.

Underwater acoustic techniques are a method that utilizes sound waves to detect and monitor marine organisms in their natural habitats [19-21]. Various methods are employed for detecting sperm whales in their oceanic habitat, encompassing both active and passive approaches. The active acoustic method uses sound intentionally emitted into the water and the returning echoes help identify the presence and location of sperm whales. On the other hand, passive acoustic methods rely on listening to the natural sounds produced by sperm whales, such as their characteristic clicks and vocalizations [22-23]. Using active acoustic methods such as echosounders, high-resolution data of target biota, such as marine mammals, can be collected to observe their vertical and horizontal distribution patterns around FADs [2]. This technique allows for continuous monitoring during the observation period, thereby describing the spatial and temporal patterns in the presence of sperm whales.

Experimental research on TS values for marine animals like fish is typically conducted in laboratories with variations in different angles representing the natural swimming behavior of the fish [24-26]. Regarding large animals like whales, there have been limited reports of TS measurements primarily due to the challenging technical aspects involved in conducting such measurements on unrestrained animals in the open ocean. Additionally, the body of sperm whales has complex structures and compositions, especially in their heads and lower jaws. Different parts of the whale’s body, such as the head, fins and tail [27], can have different TS values (dB re 1 m^2) due to differences in shape, density and composition. These body parts determine the acoustic instrument’s average detected TS value.

Accurately measuring the TS value for sperm whales is challenging because it depends on various factors and can vary among individuals. Moreover, there is variation in the weight and length of sperm whales, which can reach up to 12 meters in length and weigh 15 tons for females and up to 15 meters in length and 45 tons for males [27]. This variation in length and weight can also affect the TS value. This research aims to investigate the detection of the presence and activity patterns of sperm whales around FADs using active acoustic methods in the Molucca Sea. By using information visualized on echograms, the results of this study can be utilized to identify distinctive signs of sperm whales, including their vertical movement patterns, to map the distribution and behavior of sperm whales concerning FADs.

Materials and Methods

Acoustic Data Acquisition and Study Area

The single-beam echosounder instrument SIMRAD EK15 with a 200 kHz frequency was mounted on a pole on the ship 1 meter below the sea surface. The echosounder was calibrated using a sphere following the standard echosounder calibration procedure [28], which includes the pulse duration setting of 0.512ms, transmit beam angle of 26° and time-varied gain (TVG) function set at 20 log R. Raw data from the echosounder were processed using Echoview software with a threshold range from -48 to -25dB. The SIMRAD EK15 instrument was configured for acquisition according to Table 1.

Table 1. SIMRAD EK15 acoustic instrument settings during data acquisition.

Parameter	Values
Frequency (kHz)	200
Maximum detection range (m)	200
Ping rate (Hz)	40
Pulse duration (ms)	0.512
Power (W)	45

Breadth refers to the width of the area or horizontal coverage that can be monitored by this instrument, which is 8 meters at a depth of 50 meters or 16 meters at a depth of 200 meters. Meanwhile, the maximum detection range refers to the maximum distance from the device underwater at which it can still detect objects or marine organisms, up to 200 meters (Fig. 1).

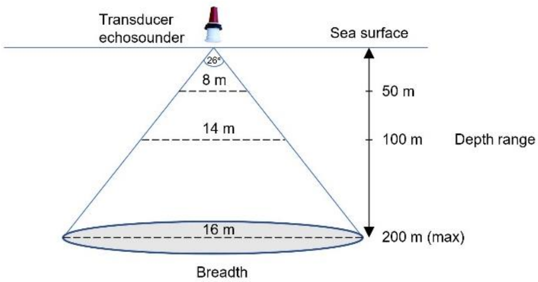

Fig. 1. Distance and detection width of sound wave formation by the SIMRAD EK15 with a frequency of 200kHz

The combination of this coverage width and maximum range allows the SIMRAD EK15 to provide crucial information for understanding the distribution and behavior of marine mammals, especially sperm whales, considering that sperm whales have long and large bodies with acoustic characteristics that differ from other objects in the water column.

The survey was conducted in April 2015 around FADs in the Molucca Sea (Fig. 2). During the experiment from April 19 to April 29, 2015, sperm whales approached the FADs. These sperm whales were observed using a combination of direct visual observation with cameras and acoustic methods.

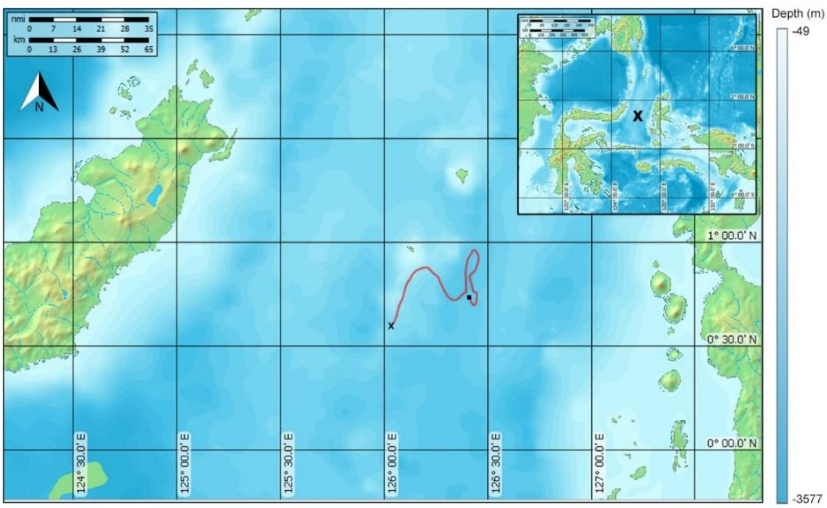

Fig. 2. Acoustic sounding position (red line) with starting (■) and ending (X) points around FADs in the Molucca Sea

Processing and Analysis of Acoustic Data

The TS value is a highly variable depending on the type and size of the object as well as the specifications of the acoustic instrument [29]. TS analysis uses a threshold of -45 to -25 dB re μPa to facilitate acoustic observations. Variations in TS values based on the angle of arrival are used to estimate the azimuth and elevation of the received echo relative to the direction of sound propagation from the transducer. The angle of arrival of the transmitted pulse to the object is estimated by calculating the angle relative to the acoustic transducer axis as the object approaches and moves away from the acoustic system due to successive changes in the distance to the whale in the returning echo. As the distance increases, the whale is assumed to be near the tail aspect and as the distance decreases, the whale is assumed to be near the head aspect. Similar methods have been used by *C. Levenson* [17], *I. Lucifredi* and *P.J. Stein* [21] and *J. Xu et al.* [20].

Information about time, position, depth, ping count and average TS is analyzed to obtain the behavioral patterns of sperm whales when detected by the echosounder [30]. The average TS is calculated for each acoustic signal that appears on the echogram using the following equation [31]:

$$TS_{avg} = 10\ log_{10}(\frac{\Sigma\sigma_{bs}}{n_i}) \qquad (1)$$

where temporal observations were conducted by observing changes in the estimated biomass of the target biota, expressed as S_A ($m^2\ nmi^{-2}$) or the Nautical Area Scattered Coefficient (NASC) [32], before, during and after sperm whales approach the FADs at different times [2]. The S_A equation is written as follows:

$$S_A = 4\ \pi\ (1852)^2\ S_a \qquad (2)$$

where S_a represents the backscattering coefficient ($m^2\ m^{-2}$), which can be written as follows:

$$S_a = \int_{z1}^{z2} S_v\, dz \qquad (3)$$

The value of S_v represents the volume backscattering coefficient (m^{-1}), obtained using the following equation:

$$S_v = \Sigma\sigma_{bs}/V \qquad (4)$$

where σ_{bs} represents the backscattering cross-section (m^2) from the information generated by the echosounder instrument and V represents the water column volume (m^3).

Further analysis was focused on the periods when sperm whales move towards the surface, move away from the surface and swim at specific depths to analyze the variation in their TS values to various angular functions [33]. Various angles when the sperm whale was swimming were analyzed, including the head, tail and broadside aspect of their bodies.

Results and discussion

Time Evidence Appearances

Regarding some of the theories proposed regarding the association of sperm whales with FADs, the results of acoustic data analysis indicate that the presence of sperm whales exhibits temporal variations contingent on the time of day. Acoustic data provides valuable insights into the behavior of sperm whales as they navigate the water column. They display a dynamic pattern, at times maintaining depths between 10 to 50 meters and at other moments executing vertical movements, ascending and descending towards the water's surface (Fig. 3).

The discovery of sperm whales around FADs further proves that FADs serve not only to collect economically valuable target fish species such as tuna, skipjack and bonito in a specific area but also have the potential to attract the attention of other species. Several government regulations regulate the installation of FADs through the Indonesian Minister of Marine Affairs and Fisheries Regulation No. 18 of 2021, where FADs are categorized as auxiliary fishing tools and their quantity, distribution and associated fishing vessel types are regulated. The allocation of the number of FADs that can be deployed for fishing grounds in Zone III (>12 nautical miles) in each fisheries management area has also been regulated in the Indonesian Minister of Marine Affairs and Fisheries Decree No. 7 of 2022, where the allocated number of FADs in the Molluca Sea within fisheries management area 715 is 75 units.

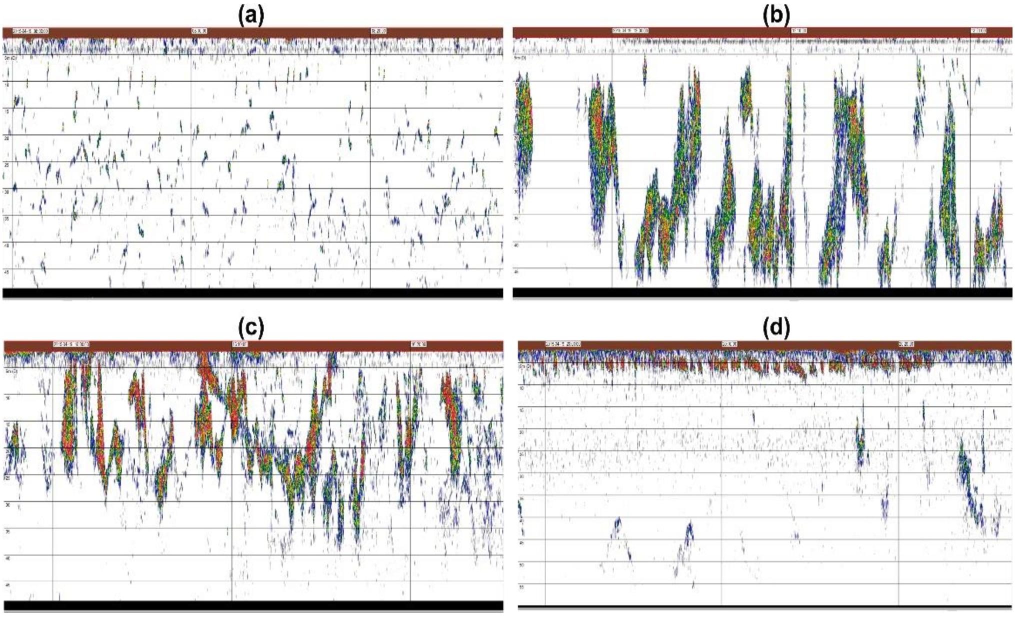

Fig. 3. Sperm whales were detected acoustically around FADs at (a) morning (08.00), (b) noon (12.00), (c) afternoon (16.00) and (d) evening (20.00)

At least a few assumptions can be discussed based on the findings of the association of sperm whales with the presence of FADs. The first assumption is that the FAD deployment area is a migration route for sperm whales, so sperm whales regularly pass through that route. The second assumption is that sperm whales are attracted to swim around FADs for several reasons, such as meeting points [13] and food sources [33]. Based on the latter assumption, there is a theory that the FAD deployment area can potentially become an ecological trap for some fish species if FADs are placed in non-optimal areas or low productivity. This theory is supported by the fact that many tunas are caught under less-than-ideal conditions, including empty stomachs and thinner body conditions [34-37].

The documented image was captured in the morning precisely at ten on a specific date, offering a vivid portrayal of sperm whales breaching the sea’s surface. This phenomenon is unmistakably discernible through the robust acoustic signals generated by the reflections from the sperm whales. The echosounder’s acoustic signals are adept at detecting sperm whales within their range of sound emission. The exact location of the detected presence of sperm whales by the acoustic instrument was pinpointed at coordinates 0°53’29" N - 125°49’36" E on April 19, 2015. The sperm whales surfaced close to the research vessel, as documented in Figure 4.

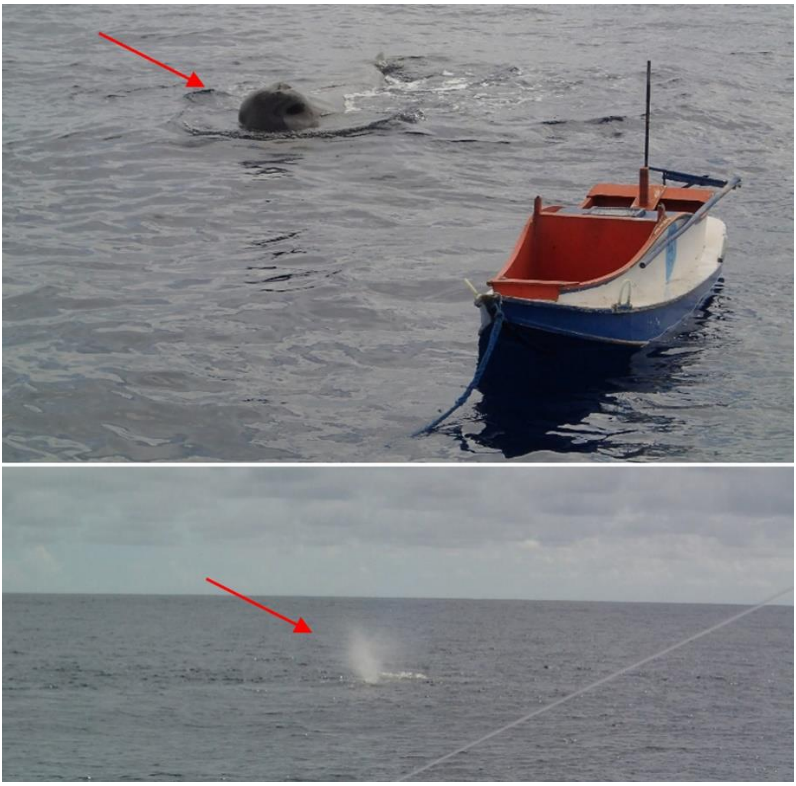

Fig. 4. Surface photo of a sperm whale approaching a FAD. Visual identification was carried out with the help of surface images and it was identified as a sperm whale (*Physeter macrocephalus*)

Acoustic Detection of Sperm Whale

For a more significant detection of the results, the S_A (m^2 nmi^{-2}) method was used from the acoustic raw data as layered water column analysis [38]. The study analyzed temporal variations in SA around the FADs by averaging S_A values per hour, delineating the water column into elementary sampling units (ESUs) at 50-meter depth intervals. Each ESU served as a representative of the mean S_A value for one hour. The presence of sperm whales near the FADs was achieved by comprehensively examining temporal fluctuations in the S_A. The analysis identified gray-shaded areas in the dataset, signifying the presence of sperm whales. The highest S_A values were consistently observed between 10:00 AM and 5:00 PM at depths ranging from 0 to 50 meters, as illustrated in Figure 5.

In the morning, the presence of sperm whales tends to be more challenging to observe as the acoustic instruments in this study do not detect them. This makes sperm whale detection more difficult in the morning because they are rarely seen at the surface. During the daytime to late afternoon, sperm whales stay near the surface for rest or socializing [39]. Vocalizations accompany this activity and can last hours [27], increasing detection success through acoustic instruments. The previous research aligns with the findings of this research, where the maximum detection of sperm whales through acoustic instruments occurred during the daytime to late afternoon hours (Fig. 3b and 3c). During the night, acoustic data did not show the presence of observable sperm whales on the echogram. This may be because sperm whales are known to exhibit feeding behaviors, primarily on giant squid, in deep-sea environments during the night [40].

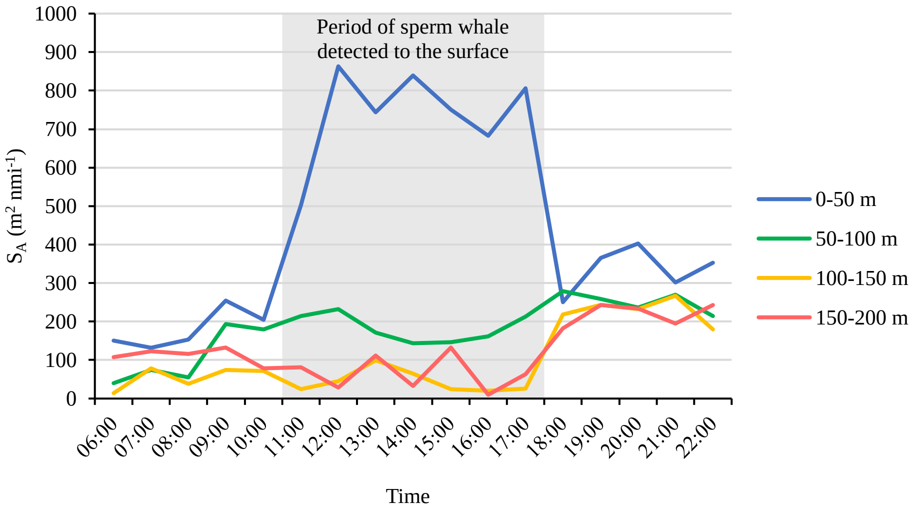

Fig. 5. Temporal variation of S_A values around FADs at 17 ESU

The S_A values, indicating the presence of marine biota detected by the acoustic instrument at various depth layers, exhibited significant variations throughout the day, from morning to night. In the morning, there were no signs of sperm whale presence around the FADs, as indicated by low S_A values. During the daytime and late afternoon, dynamic variations occurred, marked by increased S_A values at 0-50 meters depths. Maximum S_A values were observed when sperm whales were around the FADs, typically between 12:00 PM and 5:00 PM. S_A values decreased during the night, indicating that sperm whales moved away from the FADs. The average S_A values at night were higher compared to the morning, possibly due to the vertical movement of other marine biotas, such as fish, towards the surface during nighttime as diel vertical migration [41], resulting in larger S_A values.

Sperm whales typically inhabit deep-sea regions and offshore areas. However, they are known to venture near coastal zones, particularly around oceanic islands with narrow continental shelves that directly border the expansive depths of the open ocean [42]. These distinctive characteristics of sperm whale behavior and habitat preferences are readily observed in the study location, as highlighted in both Figure 3 and Figure 4.

TS of Sperm Whale as a Function of Angle

Field measurements of TS of sperm whales near FADs are generally poorly understood compared to other large whales, such as killer whales [20]. Information obtained from deploying a SIMRAD EK15 200 kHz active sonar system at the Molucca Sea in April 2015 presented a distinctive chance to calculate the TS of sperm whales. Analyzing this dataset yielded estimates of sperm whale TS across different aspects, ranging from tail to head. To elucidate sperm whale behavior and orientation, we adapted the TS of sperm whale as a function of angle method for this research. These methodologies were used to detect sperm whale orientation based on the movement of acoustic signals to the transducer. The visual representation in Figure 6 illustrates the presence and behavioral patterns of sperm whales detected by the acoustic instrument.

Figure 6 illustrates the echogram for TS analysis as a function of angle and provides histograms of TS data. The TS values were quantified at averaged -31 dB, 34 dB and -30 dB for the head, tail and broadside aspects, respectively. The distinctive feature of the sperm whale's head, which contains a hard, waxy substance known as spermaceti [27], significantly influences the TS values. The hard head of the sperm whale causes sound waves to be reflected to the acoustic device, resulting in high TS values. When the acoustic signals moved away from the transducer, it was assumed that the sperm whale was detected in its tail aspect. This assumption was supported by observations on the echogram, where the width of the reflected acoustic signal appeared narrower compared to other orientation angles.

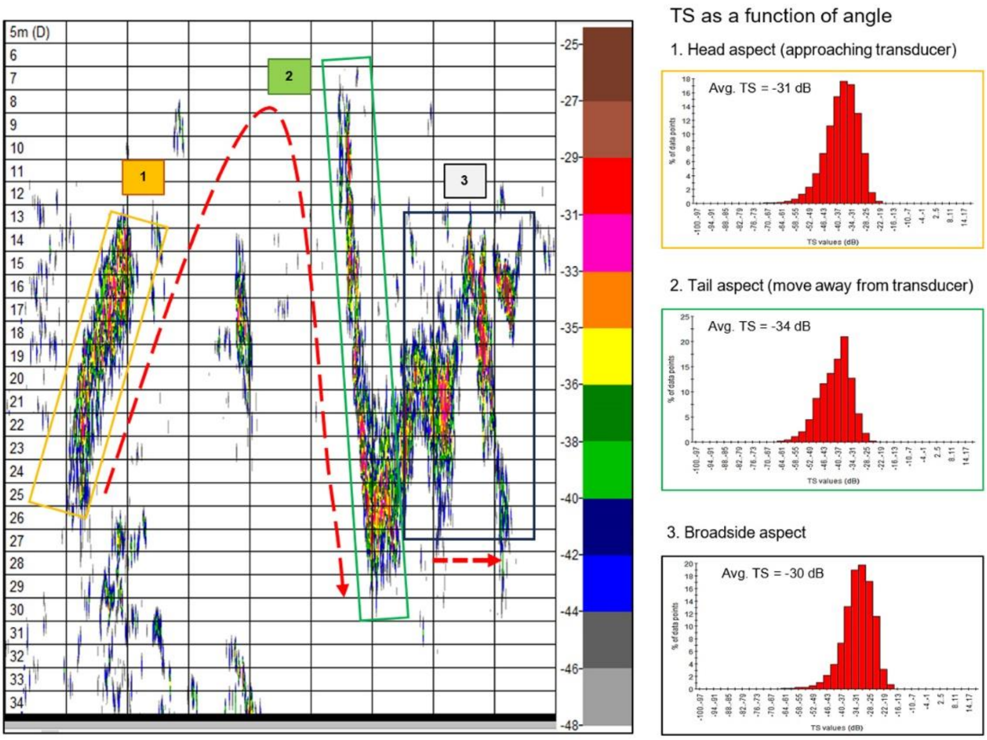

Fig. 6. Analysis of TS as a function of the angle of several aspects of the sperm whale's body to the position of the transducer

Conversely, when acoustic signals approached the transducer, it was presumed that the sperm whale was detected in its head aspect, leading to a broader width of the reflected acoustic signal. These findings align with previous research on the acoustic detection of other whales [20]. This multi-faceted approach allowed for a comprehensive understanding of sperm whale dynamics in response to acoustic signals and their interaction with the marine environment.

Sperm whales are occasionally found near FADs due to a combination of factors. While they are not typically associated with the primary targets of FADs, such as tuna, they may be drawn to these structures for specific reasons. It is important to note that sperm whales have vast migratory routes and FADs might be located along their migratory pathways, for example, in the Molucca Passage Ground [43]. Their presence near FADs, as detected by active sonar systems, can be purely coincidental as they pass through these areas on their way to other destinations. However, sperm whales are known to explore their surroundings [27]. FADs create a unique underwater structure that can attract various marine life due to the increased activity and abundance of smaller fish and organisms attracted to the FADs. Based on our findings, sperm whale was known to stay at shallow depths for approximately 6 hours during daylight over 10 days of observation, with depths ranging from 0 to 50 meters near the FADs.

In summary, while sperm whales may not specifically target FADs as a primary food source, their occasional presence near these devices could be a result of both migratory patterns and a curiosity-driven interest in the rich marine life that tends to congregate around FADs [44-45].

Conclusion

Information regarding the acoustic characteristics of sperm whales has significant implications for understanding the behavior and distribution of this species in marine waters, particularly around FADs.

This research has successfully investigated the presence and activity patterns of sperm whales using active acoustic methods in the waters of Maluku, utilizing the SIMRAD EK15 echosounder at a frequency of 200 kHz to observe the vertical movement behavior of sperm whales.

The presence of sperm whales was identified through temporal variations in the Nautical Area Scattered Coefficient (S_A) around the FADs, with the highest values occurring during the daytime to late afternoon hours. The acoustic analysis results provide deep insights into the behavior and habitat preferences of sperm whales around the FAD.

Acknowledgments

This research was funded by INREF Wageningen and WWF Coral Triangle 2016. The authors wish to thank all the local fishers from Bitung, Indonesia, for their kind support and contributions to the data collection.

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Received: February 22, 2024
Accepted: November 10, 2024