www.ijarp.com ISSN 2456-9992 Page: 01-18

International Journal Advanced Research Publications

Research Article

Volume: 02
Issue: 06

RESPONSE OF *SIGANUS JAVUS* TO ARTIFICIAL BIOACOUSTIC STIMULI AT DIFFERENT SOUND FREQUENCIES UNDER LABORATORY CONDITIONS

***[1]Muhammad Zuhaimi Al Mustofa, [1]Aristi Dian Purnama Fitri, [1]Hendrik Anggi Setyawan**

[1]Capture Fisheries Department, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Central Java, Indonesia.

Article Received: 29 April 2026, Article Revised: 19 May 2026, Published on: 09 June 2026

***Corresponding Author: Muhammad Zuhaimi Al Mustofa**

Capture Fisheries Department, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Central Java, Indonesia.

DOI: https://doi-doi.org/101555/ijarp.9407

ABSTRACT

The application of bioacoustic technology in capture fisheries has attracted increasing attention because sound stimulation offers a non-destructive approach to influencing fish behavior. This study aimed to analyze the behavioral response of *Siganus javus* to artificial bioacoustic stimuli at different sound frequencies under laboratory conditions, with particular attention to radius of presence, response duration, and the emergence of response. A laboratory experiment was conducted in March 2025 using an aquarium-based observation system and an artificial bioacoustic device. Two sound treatments, namely sudden sound and continuous sound, were tested at five frequencies of 100, 200, 300, 400, and 500 Hz, with nine replications for each treatment. Fish response was evaluated through spatial position relative to the sound source, duration of response, descriptive analysis, and Cochran's Q test. The results showed that 100 Hz consistently produced the strongest response in both treatments. Under sudden sound, the fish gradually approached the sound source and responded in all replications, while under continuous sound, 100 Hz generated the longest and most sustained response duration. The 200 Hz treatment still elicited detectable responses but with lower consistency, whereas 300–500 Hz produced minimal response. Statistical analysis confirmed that sound frequency significantly affected the emergence of fish response. These findings indicate that low-frequency artificial bioacoustic stimulation, especially 100 Hz, is the most effective frequency range for influencing *Siganus* *javus*behavior and may support the development of environmentally responsible fishing technology.

KEYWORDS: Fish acoustic stimulus; fish behavioral response; low-frequency sound

1. INTRODUCTION

The development of fishing technology continues to advance in response to the need for capture methods that are more effective, efficient, and environmentally responsible. Within this context, bioacoustic technology has emerged as a promising approach for influencing fish behavior through controlled sound stimulation. Bioacoustics broadly examines the production, transmission, and reception of sound by living organisms and their environments (Mutanu et al., 2022). In fisheries science, this approach has been increasingly used to understand how fish respond to acoustic cues and to explore methods for directing fish movement in a targeted manner (Fay and Edds-Walton, 2008; Popper et al., 2024). Because acoustic stimulation can modify fish distribution and swimming behavior without physically disturbing aquatic habitats, bioacoustic applications are considered to have considerable potential for supporting more selective and less destructive fishing operations (Popper and Hawkins, 2019).

The biological basis for this potential lies in the sensory capacity of fish to detect sound and vibration in aquatic environments. Fish perceive acoustic stimuli through several interconnected systems, including the inner ear, the lateral line, and, in some species, the swim bladder. The otolithic organs of the inner ear detect particle motion and enable fish to perceive sound propagation in water (Fay and Edds-Walton, 2008). The mechanosensory lateral line is highly sensitive to local water movement and vibration, allowing fish to detect nearby hydrodynamic disturbances (Webb, 2023). In addition, the swim bladder may contribute to acoustic sensitivity by functioning as a pressure-sensitive structure and, in some taxa, as part of the sound production and reception system (Rogers et al., 2023). These sensory inputs are converted into neural signals through hair cells, enabling fish to interpret sound as ecologically relevant information (Hastings and Thomas, 2025). However, auditory sensitivity is not uniform across taxa, because responses vary according to species, ontogenetic stage, body size, and the frequency characteristics of the acoustic stimulus. In general, many fish species are more responsive to lower frequencies, commonly below 300 Hz, than to higher-frequency signals (Popper and Hawkins, 2019; Hastings and Thomas, 2025).

Behaviorally, fish responses to sound may include changes in position, swimming activity, schooling pattern, vigilance, and movement either toward or away from the sound source (Pieniazek et al., 2020; Wang et al., 2023). Such responses indicate that acoustic signals can act as behavioral modifiers and, therefore, may be useful in fisheries applications where directed movement or spatial aggregation is required. Nevertheless, the outcome of acoustic exposure is strongly context dependent, as fish may exhibit attraction, avoidance, passivity, or stress-related behaviors depending on the spectral properties, duration, and repetition of the stimulus, as well as on the biological condition of the fish (Looby et al., 2023; Mauro et al., 2020). For this reason, identifying species-specific responses to particular frequency ranges remains essential before bioacoustic methods can be meaningfully applied in capture fisheries.

One species for which such information remains limited is *Siganus javus*, a herbivorous marine fish of the family Siganidae. This species is widely distributed in tropical coastal waters, including Indonesian waters, and inhabits seagrass beds, estuaries, and shallow coastal environments where algae and other marine vegetation are abundant (Dananjaya and Paris, 2023; Zarco-Perello et al., 2024). Siganids are also recognized as important macroalgal grazers in Indo-West Pacific reef systems, indicating their ecological significance in coastal food webs (Zarco-Perello et al., 2024). In addition to their ecological role, siganids possess economic value in coastal fisheries and are commonly associated with diurnal activity patterns, with catches often reported to be higher in the morning than in the afternoon (Suardi et al., 2019). Despite this relevance, bioacoustic studies have focused predominantly on pelagic species, commercially cultured fish, or model species, while the acoustic responsiveness of siganids, particularly *S. javus*, has received far less attention.

The scarcity of research on *S. javus* is notable because recent evidence suggests that rabbitfishes are capable of responding to low-frequency acoustic stimuli. Behavioral work on rabbitfish has shown that members of the group can detect and respond to sound frequency variation, with stronger responsiveness often observed at lower frequencies (Zhang et al., 2024). This pattern is consistent with broader findings in fish bioacoustics showing that low-frequency sound can alter swimming performance, spatial positioning, and collective behavior (Mauro et al., 2020; Wang et al., 2023). However, the extent to which *S. javus* exhibits comparable responses under controlled artificial bioacoustic exposure remains insufficiently documented. This gap limits both the biological understanding of the species and the practical evaluation of bioacoustic tools for capture fisheries targeting herbivorous coastal fish.

To evaluate acoustic responsiveness in a measurable way, two behavioral parameters are particularly relevant: the radius of fish presence relative to the sound source and the duration of the observed response. The radius of presence reflects the tendency of fish to approach or avoid the acoustic stimulus, thereby providing a spatial indicator of behavioral attraction or repulsion. Response duration, meanwhile, indicates how long fish maintain a detectable behavioral reaction after exposure to sound. Together, these parameters provide a useful basis for assessing the relative effectiveness of different sound frequencies in eliciting behavioralchange. In laboratory fish studies, spatial distribution and persistence of behavior have been widely used to interpret responsiveness, including distinctions between active approach, erratic movement, passive behavior, and wall-oriented stress behavior such as thigmotaxis (Schnörr et al., 2012; Horka et al., 2024).

2. METHODOLOGY

2.1. Time and Location of the Study

This study was conducted in March 2025 at the Fishing Gear and Materials Laboratory, Department of Capture Fisheries, Faculty of Fisheries and Marine Science, Universitas Diponegoro. The research was designed as a laboratory-scale experiment using an aquarium as a controlled observation medium to examine the behavioral responses of *Siganus javus* to artificial bioacoustic stimulation. A laboratory setting was selected to ensure a more controlled evaluation of fish behavior under sound exposure, particularly with respect to differences in response to low- and moderate-frequency stimuli, which are known to shape fish movement, vigilance, and spatial positioning (Popper and Hawkins, 2019; Wang et al., 2023). This controlled design was considered appropriate for isolating the influence of sound frequency on fish behavior while minimizing environmental variability that commonly occurs under field conditions.

2.2. Experimental Design and Acoustic Treatments

The study employed an experimental method with artificial bioacoustic stimulation as the principal treatment. Two sound-exposure patterns were used, namely sudden sound and continuous sound. The sudden sound treatment was delivered for 10 s followed by a 120 s silent interval, whereas the continuous sound treatment was delivered for 300 s followed by a 300 s silent interval. Each sound pattern was tested at five frequency levels, namely 100, 200, 300, 400, and 500 Hz, with nine replications for each frequency. These frequency ranges were selected because fish generally exhibit greater sensitivity to lower-frequency acoustic signals, especially those below 300 Hz, although responsiveness may vary across species and experimental contexts (Popper and Hawkins, 2019; Hastings and Thomas, 2025). The use of repeated trials at each frequency level was intended to improve the reliability of behavioral observations and to facilitate comparison of response consistency across treatments.

The experimental design focused on post-stimulus behavioral observation of *Siganus javus* after each acoustic exposure. This approach follows the general principle in fish bioacousticstudies that sound may function as a behavioral cue capable of inducing attraction, avoidance, altered swimming patterns, or stress-related responses depending on the acoustic characteristics and biological sensitivity of the species (Pieniazek et al., 2020; Looby et al., 2023). Because previous studies have shown that rabbitfishes and other teleosts may respond differently across frequency gradients, the present design was structured to evaluate whether variation in artificial sound frequency would produce measurable differences in the response pattern of *S. javus*.

2.3. Observation Arena and Behavioral Parameters

The observation arena was divided into three spatial zones to assess the radius of fish presence relative to the sound source. This zoning system was established to facilitate behavioral interpretation based on the position of the fish during acoustic exposure. Zone 1 represented the area closest to the sound source at a distance of 0–43 cm, Zone 2 represented the intermediate area at 44–86 cm, and Zone 3 represented the farthest area at 87–130 cm. The observation arena measured 130 cm in length and 60 cm in width, with the sound source positioned at one side of the aquarium. The zonal configuration used in this study is presented in Figure 1.

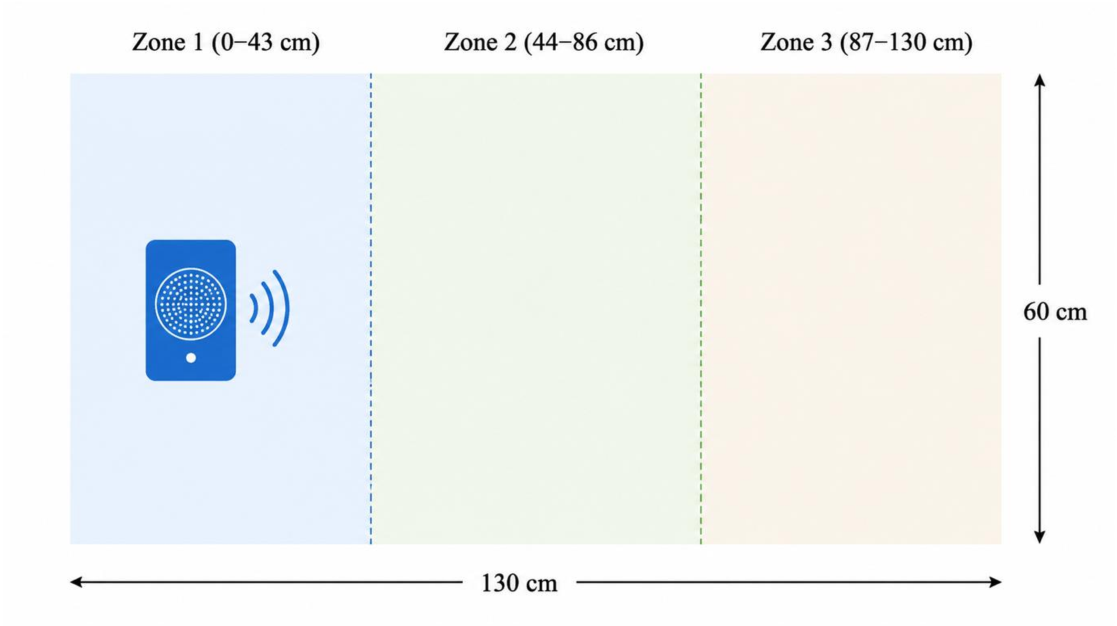

Figure 1. Observation area used to assess the positional response of *Siganus javus* to artificial bioacoustic stimulation.

The radius of fish presence was used as a spatial parameter to evaluate whether the fish tended to approach or remain distant from the sound source. In addition, response duration was recorded as the length of time during which the test fish exhibited a detectable behavioral reaction following sound exposure. The combined use of spatial position and response duration was intended to provide complementary evidence of acoustic responsiveness. In behavioral studies on fish, spatial distribution within an arena and persistence of reaction are widely used to identify attraction, avoidance, erratic movement, passivity, or anxiety-related behavior such as thigmotaxis (Schnörr et al., 2012; Horka et al., 2024). Accordingly, these two parameters were considered appropriate for describing the behavioral pattern of *S. javus* under different sound frequencies.

2.4. Artificial Bioacoustic Device

Artificial acoustic stimulation was generated using a specifically assembled bioacoustic device consisting of a chassing unit, an ESP32 DevKit V4 microcontroller, an AD9833 DDS function generator, an AD828 pre-amplifier, a TDA2003 amplifier, a 12 V 8 ohm speaker, a 3S 18650 battery, an LM7809 voltage stabilizer, and an LM2596S step-down voltage regulator. The device was designed to produce controlled sound stimuli at the specified frequency levels used in the experiment. The technical specifications of the artificial bioacoustic system are presented in Table 1.

The chassing unit measured 21 cm × 15 cm × 15 cm. The ESP32 DevKit V4 measured 5 cm × 3 cm × 0.5 cm, while the AD9833 DDS function generator measured 2 cm × 1 cm × 0.1 cm. The AD828 pre-amplifier measured 3.2 cm × 2.5 cm × 0.7 cm, and the TDA2003 amplifier measured 4.5 cm × 3.5 cm × 2.5 cm with a power capacity of 100 W. The 12 V 8 ohm speaker measured 10.7 cm × 10.7 cm × 5.6 cm with a diameter of 4 cm and a power capacity of 100 W. The 3S 18650 battery measured 6.5 cm × 1.6 cm × 1.6 cm with a diameter of 1.6 cm and a capacity of 1,500 mAh. The LM7809 voltage stabilizer measured 5 cm × 2.5 cm × 1.8 cm, while the LM2596S step-down voltage regulator measured 6.5 cm × 3.5 cm × 1 cm. The use of a programmable and portable acoustic device enabled precise control of stimulus frequency and exposure pattern, which is essential in behavioralbioacoustic experiments that aim to distinguish species-specific responses to different sound regimes (Fay and Edds-Walton, 2008; Popper et al., 2024).

Table 1. Specifications of the artificial bioacoustic device used in the experiment.

Part	**Size (cm)**				**Power**
	Length	**Width**	**Height**	**Diameter**	
Chassing	21	15	15	-	-
Microcontroller ESP32 DevKit V4	5	3	0.5	-	-
DDS Function Generator AD9833	2	1	0.1	-	-
Pre-Amplifier AD828	3.2	2.5	0.7	-	-
Amplifier TDA2003	4.5	3.5	2.5	-	100 W
Speaker 12V 8Ohm	10.7	10.7	5.6	4	100 W
Battery 3S 18650	6.5	1.6	1.6	1.6	1.500 mAh
Voltage Stabilizer LM7809	5	2.5	1.8	-	-
Step Down Voltage LM2596S	6.5	3.5	1	-	-

2.5. Data Collection and Analysis

Behavioral observations were conducted after each application of the acoustic stimulus. The primary data consisted of the positional distribution of fish within the three observation zones and the duration of response displayed after exposure to the sound treatment. These observations were used to describe the tendency of *Siganus javus* to remain near, move toward, or stay away from the sound source under each treatment combination. The radius of presence and response duration were first analyzed descriptively to identify response tendencies at each frequency level and under each sound pattern.

To determine whether variation in sound frequency significantly affected the occurrence of fish response, the data were further analyzed using the non-parametric Cochran's Q test with a significance level of α = 0.05. This statistical procedure was used to evaluate whether the presence or absence of response differed significantly among the tested frequencies under repeated experimental conditions. The use of a non-parametric approach was considered suitable because the observed response variable was interpreted categorically in terms of response occurrence across repeated treatments. The results of this analysis were then used to determine whether differences in sound frequency had a significant effect on the behavioral response of *Siganus javus* to artificial bioacoustic stimulation.

3. RESULT AND DISCUSSION

3.1. Radius of *Siganus javus* Presence in Response to Sound Stimuli

The spatial distribution of *Siganus javus* during exposure to artificial bioacoustic stimuli is presented in Tables 2 and 3. The observation arena was divided into three zones, where Zone 1 represented the nearest position to the sound source (0–43 cm), Zone 2 represented the intermediate position (44–86 cm), and Zone 3 represented the farthest position (87–130 cm), as shown previously in Figure 1. This zonal arrangement allowed the behavioral response of the fish to be interpreted in terms of approach or avoidance relative to the acoustic source. In fish behavioral research, positional shifts within an observation arena are widely used to detect attraction, avoidance, vigilance, and stress-related patterns under controlled stimuli (Pieniazek et al., 2020; Schnörr et al., 2012; Horka et al., 2024).

Table 2. Zone of fish presence under the sudden sound treatment.

Replication	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
1	3	2	3	3	3
2	3	2	3	3	3
3	3	3	3	3	3
4	3	3	3	3	3
5	3	3	3	3	3
6	2	3	3	3	3
7	2	3	3	3	3
8	2	3	3	3	3
9	1	3	3	3	3

Based on observations of six individuals, only two fish showed the most dominant response to the sound stimulus, whereas four individuals did not exhibit a clear reaction during the treatments. This pattern may indicate an adaptation-related stress response expressed as thigmotaxis, namely a tendency to remain near the corners or walls of the aquarium rather than moving through the central open space (Schnörr et al., 2012; Horka et al., 2024). Under the sudden sound treatment, the clearest positional shift occurred at 100 Hz. During replications 1–5, the responsive fish remained in Zone 3, then shifted to Zone 2 during replications 6–8, and finally reached Zone 1 in replication 9. This gradual movement toward the sound source suggests an increasingly responsive swimming pattern at the lowest tested frequency. Such a result is consistent with the general auditory tendency of fishes to respond more strongly to lower frequencies, especially below 300 Hz, because their inner-ear hair cells and associated sensory systems are more effective at detecting low-frequency particle motion and vibration (Popper and Hawkins, 2019; Hastings and Thomas, 2025; Webb, 2023). It is also in line with observations that siganids are responsive to low-frequency signals, with behavioral sensitivity being particularly evident below 200 Hz (Suardi et al., 2019; Zhang et al., 2024).

At 200 Hz, *S. javus* occupied Zone 2 during the first two replications and shifted back to Zone 3 during replications 3–9, indicating that the response was weaker and less stable than that observed at 100 Hz. At 300, 400, and 500 Hz, the fish remained entirely in Zone 3 throughout all replications, indicating that these frequency levels did not induce an approach response. This reduced responsiveness at higher frequencies is consistent with the broader literature on fish hearing, which notes that auditory sensitivity declines as frequency increases beyond the range most relevant to the sensory ecology of many teleost fishes (Fay and Edds-Walton, 2008; Popper et al., 2024). Moreover, exposure to sound that is not behaviorally meaningful may instead reduce movement motivation and promote passive behavior, including decreased exploratory swimming and reduced feeding-related activity (Mauro et al., 2020; Wang et al., 2023).

Table 3. Zone of fish presence under the continuous sound treatment.

Replication	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
1	3	3	3	3	3
2	2	2	2	2	2
3	2	2	3	3	3
4	2	2	2	3	3
5	2	2	3	2	3
6	2	3	3	3	3
7	2	2	3	3	3
8	1	3	3	3	3
9	2	3	3	3	3

Under the continuous sound treatment, the strongest positional response was again observed at 100 Hz. The responsive fish were initially recorded in Zone 3 during the first replication, then moved into Zone 2 during replications 2–7, reached Zone 1 in replication 8, and remained relatively close to the source thereafter. This finding indicates that continuous low-frequency stimulation promoted a more sustained approach tendency than the higher tested frequencies. Hastings and Thomas (2025) explain that fish possess internal auditory systems composed of hair cells that are especially sensitive to low-frequency vibrations, while still permitting some responsiveness at frequencies approaching 1,000 Hz. Even so, behavioral responsiveness tends to be strongest within lower frequency bands when stimuli remain within the most sensitive hearing range of the species (Popper and Hawkins, 2019; Popper et al., 2024). The present result is also consistent with evidence that prolonged low-frequency exposure can alter swimming performance and schooling-related behavior in fishes, thereby increasing the likelihood of detectable spatial repositioning (Veith et al., 2024; Wang et al., 2023).

In contrast, at 200, 300, 400, and 500 Hz the fish were predominantly distributed in Zone 3, with only occasional temporary movement into Zone 2. These results indicate that continuous exposure at frequencies above 100 Hz did not consistently attract *S. javus* toward the sound source. Taken together, the positional data show that 100 Hz was the most effective frequency for inducing approach-oriented spatial behavior in both sudden and continuous sound treatments. This pattern strengthens the inference that low-frequency artificial bioacoustic stimulation has a greater capacity to influence the movement behavior of *S. javus* than higher-frequency stimuli, a finding that agrees with current knowledge of fish sensory ecology and rabbitfish acoustic responsiveness (Looby et al., 2023; Suardi et al., 2019; Zhang et al., 2024).

3.2. Duration of *Siganus javus*Response to Sound Stimuli

The duration of behavioral responses observed under sudden and continuous sound exposure is presented in Tables 4 and 5. Response duration was used to quantify how long fish maintained a detectable reaction after the onset of the acoustic stimulus. In bioacoustic studies, persistence of response is a useful indicator of stimulus salience because it distinguishes brief reflexive reactions from more sustained behavioral modulation (Pieniazek et al., 2020; Wang et al., 2023).

Table 4. Duration of fish response under the sudden sound treatment.

Replication	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
1	10	8	0	0	0
2	10	6	2	0	0
3	10	6	0	0	0
4	8	6	0	0	0

5	6	8	0	0	0
6	8	8	0	2	0
7	7	6	0	0	0
8	7	4	0	0	0
9	10	10	0	0	2
Total responses	9	9	1	1	1

At 100 Hz under the sudden sound treatment, *S. javus* exhibited responses in all nine replications. The response duration reached the full 10 s during replications 1–3, fluctuated between 6 and 8 s during replications 4–8, and returned to 10 s at replication 9. These observations indicate a consistently strong behavioral reaction, accompanied by progressive movement from Zone 3 toward Zone 2 and, eventually, toward Zone 1. This pattern suggests an observative and directed response, which may be associated with the fish's ability to detect acoustic and vibrational stimuli through integrated inner-ear and lateral-line systems (Fay and Edds-Walton, 2008; Webb, 2023). Experimental work on juvenile fish has similarly shown that sound stimulation can induce clear behavioral responses when the stimulus falls within the species' effective sensory range (Wang et al., 2023).

At 200 Hz, responses were also detected in all nine replications, but the duration pattern was more fluctuating, ranging from 4 to 10 s. Although fish initially showed movement from Zone 3 toward Zone 2, later responses were characterized by movement back toward Zone 3 and, in the final replication, movement toward the corner of the aquarium. This behavioral pattern suggests that while 200 Hz remained capable of eliciting a response, the quality of that response was less stable and may have involved erratic behavior. Erratic swimming in fish is generally characterized by sudden and irregular changes in speed and direction in response to stimuli that trigger fear or discomfort (Tan et al., 2022; Horka et al., 2024). By comparison, 300, 400, and 500 Hz produced only a single response each, with very short durations of approximately 2 s, indicating that these frequencies were largely ineffective in sustaining behavioral activation under sudden sound exposure.

Table 5. Duration of fish response under the continuous sound treatment.

Replication	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
1	0	0	0	0	0
2	59	4	12	20	3
3	106	34	0	0	0
4	65	107	25	0	0
5	59	32	0	36	0
6	56	0	0	0	0
7	95	122	0	0	0

8	60	0	0	0	0
9	119	0	0	0	0
Total responses	8	5	2	2	1

Under the continuous sound treatment, the longest and most frequent responses were again recorded at 100 Hz. No response was observed in the first replication, but replications 2–9 produced sequential response durations of 59, 106, 65, 59, 56, 95, 60, and 119 s. These results show that once a response emerged, it tended to persist for a relatively long period, with visible reaction beginning at approximately the 120th second of the 300 s treatment period. This finding suggests that sustained low-frequency sound can induce a prolonged behavioral state in *S. javus*, rather than merely a short reflexive response. Such persistence is compatible with the understanding that fish tend to be more sensitive to low-frequency sound and may continue responding as long as the stimulus remains within an ecologically meaningful range (Popper and Hawkins, 2019; Hastings and Thomas, 2025).

At 200 Hz, five responses were recorded, with durations of 4, 34, 107, 32, and 122 s. Although this indicates that 200 Hz could still induce detectable behavior, the frequency and consistency of the response were lower than at 100 Hz. Frequencies of 300 and 400 Hz elicited only two responses each, while 500 Hz elicited a single response, confirming a marked decline in responsiveness as frequency increased. The four fish that remained passive across treatments may again reflect thigmotaxis or anxiety-related non-response, in which individuals avoid the central arena and remain close to the aquarium boundary as a coping behavior under experimental conditions (Schnörr et al., 2012; Horka et al., 2024). This interpretation is also supported by studies indicating that fish exposed to unfamiliar or stressful stimuli may preferentially remain near walls rather than engage in exploratory movement (Tan et al., 2022).

Overall, the duration data reinforce the positional findings by showing that low-frequency stimulation, particularly 100 Hz, elicited not only the highest number of responses but also the longest response durations. This result supports the view that artificial bioacoustic signals in the lower frequency range are more effective for provoking measurable behavioral responses in *S. javus* than higher-frequency stimuli. Similar conclusions have been reported in comparative fish bioacoustic studies, where lower frequencies were more effective in altering behavior, movement, or responsiveness than higher frequencies outside the most sensitive auditory range (Mauro et al., 2020; Wang et al., 2023; Zhang et al., 2024).

3.3. Effect of Sound Frequency Variation on Fish Response Emergence

To evaluate whether variation in sound frequency significantly affected the emergence of fish responses, the occurrence data were analyzed using Cochran’s Q test. The distribution of response occurrence under the sudden sound treatment is shown in Table 6, and the corresponding test statistics are presented in Table 7.

Table 6. Distribution of response occurrence under the sudden sound treatment.

Frequency	Value	
	0	**1**
100 Hz	0	9
200 Hz	0	9
300 Hz	8	1
400 Hz	8	1
500 Hz	8	1

Table 7. Cochran’s Q test results for the sudden sound treatment.

Test Statistics	
N	9
Cochran’s Q	32.000a
df	4
Asymp. Sig.	.001

The response distribution under sudden sound clearly shows that 100 and 200 Hz each produced responses in all nine replications, whereas 300, 400, and 500 Hz produced only one response each. The Cochran’s Q test yielded a significance value of 0.001, indicating a statistically significant difference in response emergence among the tested frequencies. This result demonstrates that sound frequency had a significant effect on whether S. javus responded to the artificial stimulus. The particularly strong performance of 100 and 200 Hz supports the interpretation that low-frequency stimuli are better aligned with the effective auditory sensitivity of the species. According to Zhang et al. (2024), the frequency threshold detectable by rabbitfish varies with age and biological condition, with adults showing lower upper sensitivity limits than younger fish. More generally, fish hearing research has established that acoustic sensitivity depends on species, body size, ontogenetic stage, and the physical properties of the stimulus (Fay and Edds-Walton, 2008; Popper et al., 2024). The present findings therefore support the conclusion that frequency-specific responsiveness in *S. javus* is biologically structured rather than random.

The same pattern was evident under the continuous sound treatment, as shown in Tables 8 and 9.

Table 8. Distribution of response occurrence under the continuous sound treatment.

Frequency	Value	
	0	**1**
100 Hz	0	9
200 Hz	0	9
300 Hz	8	1
400 Hz	8	1
500 Hz	8	1

Table 9. Cochran's Q test results for the continuous sound treatment.

Test statistics	
N	**9**
Cochran's Q	18.444
df	4
Asymp. Sig.	0.001

Under continuous sound, 100 Hz produced responses in eight of nine replications, whereas 200 Hz produced five responses, 300 and 400 Hz each produced two responses, and 500 Hz produced one response. The Cochran's Q test again yielded a significance value of 0.001, confirming that the variation in sound frequency significantly affected the emergence of behavioral response during continuous exposure. This statistical evidence strengthens the descriptive findings from the positional and duration data by showing that the superiority of lower frequencies was not incidental. Instead, the results indicate that *S. javus* was substantially more responsive to low-frequency artificial bioacoustic stimulation, especially 100 Hz and, to a lesser extent, 200 Hz. This is consistent with studies showing that siganids are more responsive to lower-frequency sound and may display avoidance, orientation change, or altered movement at such frequencies (Suardi et al., 2019; Zhang et al., 2024).

Taken together, the results of the present study indicate that 100 Hz was the most effective frequency in producing behavioral responses in *S. javus* under both sudden and continuous sound treatments. The species showed the clearest approach pattern, the longest response duration, and the highest frequency of response emergence at this stimulus level. These results are consistent with current understanding of fish bioacoustics, which emphasizes the dominant role of low-frequency sensitivity in shaping behavioral responses to sound (Popper and Hawkins, 2019; Hastings and Thomas, 2025). From an applied perspective, the findings suggest that low-frequency artificial bioacoustic signals may offer practical potential for behavior-based fisheries technology, particularly when the objective is to influence fish distribution or movement without using destructive capture approaches. At the same time, the passive behavior displayed by several individuals indicates that behavioral responses remain shaped by stress, adaptation, and individual variability, factors that should be considered carefully in future laboratory and field-scale studies (Looby et al., 2023; Mauro et al., 2020; Horka et al., 2024).

In broader context, these findings complement earlier descriptions of fish auditory physiology, including the role of otolith organs, the lateral line, and pressure-related acoustic structures in detecting sound and vibration (Fay and Edds-Walton, 2008; Rogers et al., 2023; Webb, 2023). They also align with the growing view that artificial bioacoustics can become a useful fisheries tool when stimulus properties are carefully matched to species-specific hearing ecology and behavioral thresholds (Mutanu et al., 2022; Popper et al., 2024; Looby et al., 2023). Thus, the present results contribute both biologically and practically by identifying an effective acoustic frequency range for *S. javus* and by providing an empirical basis for the continued development of bioacoustics applications in capture fisheries.

4. CONCLUSION

The present study demonstrates that artificial bioacoustics stimulation can produce measurable behavioral responses in *Siganus javus*, but the magnitude and consistency of that response are strongly dependent on sound frequency. Across both sudden sound and continuous sound treatments, 100 Hz emerged as the most effective frequency, producing the clearest approach toward the sound source, the longest response duration, and the highest frequency of response occurrence. The 200 Hz treatment remained capable of eliciting responses, although these were less stable and, in several cases, were associated with more erratic swimming behavior. In contrast, frequencies of 300, 400, and 500 Hz produced minimal and inconsistent responses, indicating that these higher frequencies were less effective for influencing the movement behavior of *Siganus javus* under laboratory conditions.

These findings strengthen current understanding of fish bioacoustics by providing species-specific evidence that *Siganus javus* is more responsive to low-frequency sound stimulation than to higher-frequency exposure. The study therefore contributes to the broader body of knowledge on behavioral fisheries technology, particularly in relation to the use of artificial bioacoustics as a non-destructive method for modifying fish distribution and movement.

From an applied perspective, the identification of 100 Hz as the most effective frequency provides an important scientific basis for the future design of bioacoustic-based fishing aids aimed at improving fishing efficiency while reducing ecological disturbance. Further research is needed to test these findings under larger experimental conditions and in open-water environments, as well as to evaluate the effects of fish density, acclimation period, and species-specific sensory variability on acoustic responsiveness.

REFERENCES

1. Dananjaya, K., & Paris, A. Y. (2023). The dominant biology of white-spotted rabbitfish (*Siganus canaliculatus*) caught in Bio-FADs installation areas in TompotanaTakalar waters. *JurnalSumberdayaAkuatikIndopasifik,* *7*(3), 309–324. https://doi.org/10.46252/jsai-fpik-unipa.2023.Vol.7.No.3.243
2. Fay, R. R., & Edds-Walton, P. L. (2008). Structures and functions of the auditory nervous system of fishes. In J. F. Webb, A. N. Popper, & R. R. Fay (Eds.), *Fish bioacoustics* (pp. 49–97). Springer. https://doi.org/10.1007/978-0-387-73029-5_3
3. Hastings, M. C., & Thomas, J. A. (2025). Fishes. In C. Erbe & J. A. Thomas (Eds.), *Exploring animal behavior through sound* (Vol. 2, pp. 223–274). Springer. https://doi.org/10.1007/978-3-031-83460-8_5
4. Horka, P., Langova, V., Hubeny, J., Vales, K., Chrtkova, I., & Horacek, J. (2024). Open field test for the assessment of anxiety-like behavior in *Gnathonemuspetersii* fish. *Frontiers in Behavioral Neuroscience, 17*, Article 1280608. https://doi.org/10.3389/fnbeh.2023.1280608
5. Looby, A., Bravo, S., Juanes, F., Rountree, R., Riera, A., Davies, H. L., Spriel, B., Vela, S., Reynolds, L. K., Martin, C. W., & Cox, K. (2023). The importance of context in the acoustic behaviors of marine, subtropical fish species. *The Journal of the Acoustical Society of America, 154*(5), 3252–3258. https://doi.org/10.1121/10.0022412
6. Mauro, M., Pérez-Arjona, I., Belda Pérez, E. J., Ceraulo, M., Bou-Cabo, M., Benson, T. T., Espinosa, V., Beltrame, F., Mazzola, S., Vazzana, M., & Buscaino, G. (2020). The effect of low frequency noise on the behaviour of juvenile *Sparus aurata*. *The Journal of the Acoustical Society of America, 147*(6), 3795–3807. https://doi.org/10.1121/10.0001255
7. Mutanu, L., Gohil, J., Gupta, K., Wagio, P., &Kotonya, G. (2022). A review of automated bioacoustics and general acoustics classification research. *Sensors, 22*(21), Article 8361. https://doi.org/10.3390/s22218361

8. Pieniazek, R. H., Mickle, M. F., & Higgs, D. M. (2020). Comparative analysis of noise effects on wild and captive freshwater fish behaviour. *Animal Behaviour, 168*, 129–135. https://doi.org/10.1016/j.anbehav.2020.08.004
9. Popper, A. N., Amorim, C., Fine, M. L., Higgs, D. M., Mensinger, A. F., & Sisneros, J. A. (2024). Introduction to the special issue on fish bioacoustics: Hearing and sound communication. *The Journal of the Acoustical Society of America, 155*(4), 2385–2391. https://doi.org/10.1121/10.0025553
10. Popper, A. N., & Hawkins, A. D. (2019). An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. *Journal of Fish Biology, 94*(5), 692–713. https://doi.org/10.1111/jfb.13948
11. Rogers, L. S., Lozier, N. R., Sapozhnikova, Y. P., Diamond, K. M., Davis, J. L., & Sisneros, J. A. (2023). Functional plasticity of the swim bladder as an acoustic organ for communication in a vocal fish. *Proceedings of the Royal Society B: Biological Sciences, 290*(2013), Article 20231839. https://doi.org/10.1098/rspb.2023.1839
12. Schnörr, S. J., Steenbergen, P. J., Richardson, M. K., & Champagne, D. L. (2012). Measuring thigmotaxis in larval zebrafish. *Behavioural Brain Research, 228*(2), 367–374. https://doi.org/10.1016/j.bbr.2011.12.016
13. Suardi, S., Wiryawan, B., Taurusman, A. Z., Santoso, J., & Riyanto, M. (2019). Dinamikahasiltangkapanbaronang (*Siganus* sp.) pada rumponhidupsecaraspasial-temporal di pesisirUlouloKabupaten Luwu. *Marine Fisheries: Journal of Marine Fisheries Technology and Management, 10*(1), 45–57. https://doi.org/10.29244/jmf.10.1.45-57
14. Tan, J. X. M., Ang, R. J. W., & Wee, C. L. (2022). Larval zebrafish as a model for mechanistic discovery in mental health. *Frontiers in Molecular Neuroscience, 15*, Article 900213. https://doi.org/10.3389/fnmol.2022.900213
15. Veith, J., Chaigne, T., Svanidze, A., Dressler, L. E., Hoffmann, M., Gerhardt, B., &Judkewitz, B. (2024). The mechanism for directional hearing in fish. *Nature, 631*(8019), 118–124. https://doi.org/10.1038/s41586-024-07507-9
16. Wang, Y., Huang, L., & Xing, B. (2023). Experimental study on the effect of sound stimulation on hearing and behavior of juvenile black rockfish (*Sebastes schlegelii*). *Frontiers in Marine Science, 10*, Article 1257473. https://doi.org/10.3389/fmars.2023.1257473

17. Webb, J. F. (2023). Structural and functional evolution of the mechanosensory lateral line system of fishes. *The Journal of the Acoustical Society of America, 154*(6), 3526–3542. https://doi.org/10.1121/10.0022565
18. Zarco-Perello, S., Martin, S. B., & Hoey, A. (2024). Biogeographical diet variation within and between the rabbitfishes *Siganus corallinus, Siganus doliatus, Siganus trispilos* and *Siganus virgatus*. *Ecology and Evolution, 14*(6), Article e11326. https://doi.org/10.1002/ece3.11326
19. Zhang, S., Zhang, X., Tang, X., & Zhang, S. (2024). Exploring sound frequency detection in the golden rabbitfish, *Siganus guttatus*: A behavioral study. *Animals, 14*(20), Article 2967. https://doi.org/10.3390/ani14202967