Effects of Underwater Ship Sound and Urban Noise on Voluntary Feeding and Growth Response of Fish

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Research Article

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Abstract

The drastically increase of human population and urbanization in waterfronts has boosted the shipping industry along the coast line of urbanized areas. In the present study, impacts of rising noise pollution in coastal areas due to intense urbanization at waterfronts and ship sound from harbors on possible acclimation response of fish through the assessment of voluntary feeding and growth performance have been evaluated. During the initial 15-days of sound exposure, fish growth was almost stable with a linear growth trend. However, an increasing trend was noted from day-30 onwards over the following 60 days until the end of the study (day-90), which could be linked to a time-dependent acclimation of fish to ship sound and urban noise. A remarkable shift towards a significant increase in growth after the first 15-days of slow-growth trend in fish exposed to underwater sound transmissions presented evidence for a “catch-up growth endeavor”, that resulted in an increased voluntary feeding, indicating that nearshore populations of fish near harbors, ferry ports and noisy intense urban waterfronts might acclimate to noisy conditions over a certain time, which was found as 15-30 days under the conditions applied in this study. These findings may support policymakers for environmental management towards an ecology-based planning of near-shore industrial development.

Introduction

Human migration from rural areas to cities, especially to waterfront areas is getting a serious problem for the world, especially when coupled with uncontrolled migration from politically and economically unbalanced countries. Considering that the world population is estimated to reach around 8 billion in 2023, 9 billion in 2037, and 10 billion people in the year 2055 (Worldometer 2020), the intense urbanization in waterfront areas along with increasing sounds of ship traffic from ferry ports and harbors may potentially influence nearshore fish populations. Human generated underwater noise has significantly increased over the last century and one of the remarkable sounds of underwater noise in the aquatic environment is caused by the ship traffic from harbors in populated coastal areas. The drastically increase in commercial shipping trade and the increasing speed of vessels has raised the level of noise that ship traffic is spreading throughout the marine environments. It has been reported that until the 1990s, underwater noise has increased nearly 2-fold every 10 years (Andrew et al., 2002; McDonald et al., 2006; Merchant et al., 2012) since the 1960s when first underwater noise levels were measured (Wenz, 1962).

Despite the fact that recent investigations gave attention on a variety of anthropogenic underwater sounds generated by marine industrial activities such as piling, bridge construction work, underwater sounds of sonar and eco-sounders, seismic explorations, as well as sounds from ship, recreational boats, or ferries (Codarin et al. 2009; Buscaino et al. 2010), the long-term trends for ship noise are still unknown for many marine areas of the world (Viola *et al.*, 2017). The level external contribution of ship traffic to the ambient noise in the marine environment and its impacts on marine life is a matter that still needs clarification, with efficient management protocols under worldwide legislations. Besides, there is no

published information yet regarding possible impacts of the increasing noise pollution from intense urbanization at waterfronts on fish populations.

Underwater noise generated by human activities is considered as sound pollution and may influence aquatic animals with harmful consequences for marine life (Tsouvalas and Metrikine 2016; Kusku 2020; Kusku et al. 2018a,b; 2020), such as behavioral disorders, species recognition, communication, mating, response to predator approach, prey search, or feeding and growth (Radford et al. 2016; Spiga et al. 2017). Studies have revealed that short term signaling acoustics influence aquatic animals (McLaughlin and Kunc 2013; Simpson et al. 2015). Also, long-term repeated sound exposures have been reported to influence behavioral responses of fish (Nedelec et al. 2016; Sapozhnikova et al. 2018; Kusku 2020; Kusku et al. 2020). It is well understandable that aquatic animals are exposed to underwater noises repeatedly and not only once throughout their life, and may show adaptive responses to new conditions (Nichols et al. 2015; Nedelec et al. 2016; Kusku 2020; Kusku et al. 2020). Hence, it is likely that the engine or propeller sounds from ships of various sizes docking in port and harbors along the coast line with intense urbanization may overlap the ambient sounds in the marine environment, and potentially affect local fish populations in waterfront areas, which are important fishing grounds of local fishermen.

The harmony of biodiversity and marine industries is an important conceptual value for the sustainability and ecology-based development. Monitoring the responses of aquatic organisms to long-term sound exposures may help to understand their tolerance levels against human made acoustic noise, that in terms may provide sophisticated information for environmental management and planning. Reports with reliable information on long-term acoustic sound impacts on fishes are limited so far (Radford et al. 2016; Spiga et al. 2017; Kusku et al. 2020). Earlier studies underlined that human made underwater sounds of seismic air-gun shootings affect caged fish in the nearby vicinity (Popper et al. 2005; Santulli et al. 1999), showing that not only natural fish populations in local coastal fisheries grounds, but also fish in cage farms might be under threat of sound pollution of ship traffic at harbors with intense urbanization or even seaside touristic facilities.

Therefore, the aim of this study was to investigate impacts of underwater ship sound and the increasing noise from intense urban waterfronts on possible acclimation response of fish through the assessment of voluntary feeding and growth performance. Taking the start from these viewpoints, findings from the present study may provide useful indications for nearshore natural fish populations as well as caged fish near harbors, ferry ports or waterfront areas, that in terms may support policymakers towards an ecology-based management of near-shore industrial development efforts.

Materials And Methods

Underwater Sound Transmission

Playbacks of underwater sound of a ship and urban noise were continuously transmitted underwater throughout the experimental period of 90 days. Underwater ship sound and urban noise were retrieved

from <https://sound-effects.bbcrewind.co.uk/search?q=underwater%20ship%20sound> and <https://sound-effects.bbcrewind.co.uk/search?q=underwater%20urban%20noise>, respectively.

All experiments tanks used in the study were equipped with waterproof hydrophone system consisting of a mini speaker with 8 Ohm, 1.5 W and 40 mm specifications, which were set 7 cm below water surface, towards the water in-flow pipe. A “Magic Voice” brand amplifier with three outputs were used for the even distribution of sounds in all triplicate groups of experimental tanks, which were installed with identical hydrophone system. Underwater sound levels were measured using a sound level meter device connected to an Benetech Gm1352 Thr228 ehy-thr228. The average ambient noise level was measured by a sound recording program (dB Sound Meter Version: 1.0.9) with a Samsung G8 model Android smartphone.

Playbacks of continued underwater sound transmissions of ship sound and urban noise have been initiated simultaneously and continued throughout the study period of 90 days without interruption. Special care was taken to avoid any possible contact of vibrating pipes with tank surface, as suggested by Davidson et al. (2007, 2009), which was especially important for accurate ambient noise levels in the experimental tanks. In order to ensure same level of sound in test containments, sound pressure levels (SPL, dB re 1 μ Pa SPL) were measured in 10-days intervals over the experimental period of 90-days. Spectrums analyses for underwater sound transmissions applied in this study, were performed for 60 sec using Spectrum Octave Band RTA (Real-Time Analyzer) program.

Experimental Fish and Study Conditions

The experiment was carried out in the research facilities of Canakkale Onsekiz Mart University, Faculty of Marine Science and Technology (Turkey). A recirculating aquaculture system (RAS) with experimental glass aquariums (70 x 40 x 40 cm) was use and the freshwater inflow rate was set to around 29.8 ± 0.3 L/min. Aeration was supplied using air stones. A total of 9 glass tanks were randomly stocked with experimental fish of Nile tilapia (*Oreochromis niloticus*) (12 fish per tank) in a triplicate design, and photoperiod followed a natural course throughout the growth trial of 90 days. Schematic diagram of the experimental setup in test containments with hydrophone output and sound-meter recording has been illustrated in Figure 1.

In order to ensure a suitable environment for the experimental fish, water quality parameters of temperature, ammonia, dissolved oxygen, nitrate, nitrite, and pH was recorded bi-weekly applying an automatic water quality measuring device (brand of YSI), and resulted as respectively: $22.04 \pm 1.16^{\circ}\text{C}$, 7.3 ± 1.3 mg/L, 0.01 ± 0.001 mg/L NH_3 , 0.025 ± 0.010 mg/L, 2.19 ± 0.18 mg/L, and 7.3.

A commercial diet containing 2.7% lipid and 21% crude protein were used during the growth trial and experimental fish with initial weight of 7.26 ± 0.06 g was fed once daily at 10 am, for 10 minutes for e total of 90-days. Feeding was withheld when fish refused the pellets, which was accepted as a sign of satiation.

Calculation of Voluntary feeding, Feed efficiency and Growth Data

Voluntary feed intake, feed efficiency and growth performance data for fish exposed to underwater sounds of ship and urban noise were calculated using following equations:

Wet weight gain (WWG, g) = final biomass (g) – initial biomass (g)

Relative WWG (RWWG, %) = WWG (sound treatment group) x 100 / WWG (control group)

Specific growth rate (SGR, %/day) = 100 x (ln final weight - ln initial weight) / days

Relative SGR (RSGR, %) = SGR (sound treatment group) x 100 / SGR (control group)

Voluntary feed intake (VFI, g) = dry feed intake (g) / [(initial biomass (g) + final biomass (g)) / 2]

Feed conversion rate (FCR) = feed consumption (g) / wet weight gain (g)

Relative growth rate (RGR, %) = [(final biomass (g) - initial biomass (g)) / initial biomass (g)] x 100

Statistical analyses

Data presented in this research have been indicated as $\pm$ SD. After meeting homogeneity and usual data distribution, Tukey Multiple Range Test was applied in order to assess the data of growth performance. In case of homogeneity however no normally distributed data, Kruskal-Wallis test was preferred, while the Tamhane test was used for any data with no homogeneity, through SPSS 19 (IBM SPSS Statistics 19) Statistical Software. Critical significance limits were set at $P < 0.05$.

Results

The decibel sound pressure levels (dB re 1 μ Pa SPL) measured for the control, ship sound, and urban noise groups are given in Figure 2. The average SPLs in the control group without external sound treatment at all was recorded as 51.42 ± 1.73 dB re 1 μ Pa SPL (range 49-58), which represents the ambient noise conditions with no additional sound treatment. Average SPLs for experimental groups exposed to underwater sound transmissions were 86.00 ± 1.07 (range: 84-88) dB re 1 μ Pa SPL, 85.29 ± 2.54 (range: 81-89) dB re 1 μ Pa SPL for the ship sound and urban noise groups, respectively. In both sound treatment groups, the ambient noise was overlapped by the external sound transmissions. A spectrum analyses of 60 sec for the ship sound, urban noise sources, using Spectrum Octave Band RTA (Real-Time Analyzer) program is illustrated in Figure 3, where the control group represents ambient noise without additional underwater sound transmission.

The control group without sound treatment performed highest growth, while experimental fish exposed to underwater sound treatments of ship -and urban noise presented lower growth compared to the control ($p < 0.05$). A similar trend was seen for the relative growth rate (RGR) and feed conversion rate (FCR) which were lower in the groups exposed to underwater sound transmission, either ship sound or urban noise.

Voluntary feed intake values over the entire study period of 90 days were significantly higher in the sound treatment groups over the control group. Lowest growth and feed utilization were found for the group exposed to urban noise, followed by the ship sound group, with significant ($p>0.05$) difference among the sound treatments. Voluntary feed intake, feed utilization and growth performance of fish exposed to underwater sound treatments of ship -and urban noise are given in Table 1.

Table 1
Voluntary feed intake, feed efficiency, growth, and survival of Nile tilapia (*Oreochromis niloticus*) exposed to acoustic sounds of ship sound and urban noise. Data (mean $\pm$ standard deviation) with same superscript letters in the same line are not significant different ($p>0.05$).

	Experimental groups		
	Control	Ship sound	Urban noise
Initial weight (g)	7.31 $\pm$ 0.05	7.25 $\pm$ 0.08	7.22 $\pm$ 0.05
Final weight (g)	21.72 $\pm$ 0.21 ^c	19.17 $\pm$ 0.17 ^b	17.44 $\pm$ 0.10 ^a
Wet weight gain (g)	14.42 $\pm$ 0.25 ^c	11.92 $\pm$ 0.14 ^b	10.22 $\pm$ 0.13 ^a
Initial Biomass (g)	87.67 $\pm$ 0.58	87.00 $\pm$ 1.00	86.67 $\pm$ 0.58
Final Biomass (g)	260.7 $\pm$ 2.52 ^c	230.0 $\pm$ 2.00 ^b	209.3 $\pm$ 1.16 ^a
Relative growth rate (%)	197.4 $\pm$ 4.61 ^c	164.4 $\pm$ 2.76 ^b	141.6 $\pm$ 2.56 ^a
Voluntary feed intake (g)	0.36 $\pm$ 0.01 ^a	0.42 $\pm$ 0.01 ^b	0.40 $\pm$ 0.01 ^b
Feed conversion rate	1.46 $\pm$ 0.03 ^a	1.78 $\pm$ 0.07 ^b	2.05 $\pm$ 0.05 ^c
Survival rate (%)	100 $\pm$ 0.00	100 $\pm$ 0.00	100 $\pm$ 0.00

During the research, fish exposed to ship sound and urban noise showed remarkably lower ($p<0.05$) wet weight gain (WWG) in contrast to the control. By the end of the 90-days experimentation, significant difference ($p>0.05$) for WWG was found between sound exposure groups. Regarding the control group with no sound treatment, growth performance showed a rather linear trend contrast to those exposed to ship -or urban noise over the 90-days growth study. Fish in the sound treatment groups showed a stable growth trend during the first 15 days, and shifted to a rapid growth period afterwards, showing a growth endeavor from day-30 until the end of the study that was terminated after 90 days of sound exposure in total (Figure 4).

After termination of the 90-days growth trial, relative wet weight gain in the ship -and urban noise groups were negative (-) 17.3% and (-) 29.1%, respectively, lower than the control group with no sound treatment (Figure 5). A similar trend was also noted for the SGRs with considerably lower rates ($p < 0.05$) in fish exposed to ship -and urban noise compared to the control group. During the 90-days growth period, fish exposed to ship -and urban noise showed negative (-) 10.8%, and (-) 19.1% lower relative SGRs than the

control (Figure 6). On the other hand, when excluding the first one month and considering growth performance after the stable period, namely between 45 to 90 days, the SGRs presented rather higher rates for the underwater sound-exposed groups contrast to the control, with 11% (ship), 13% (urban) higher RSGRs over the control, respectively (Figure 7).

Discussion

The present study evaluated human generated underwater sounds of ship -and urban noise caused by industrial development and urbanization in nearshore areas with long-term impacts on voluntary feeding, feed utilization and growth performance of fish. Not only natural fish populations of nearshore fishing grounds, but also cultured fish species for example in cage farms might be influenced by sound pollution of several acoustic noise types near ferry ports, harbors or coastal urban areas, as well as touristic facilities along the coastline. However, only few reports evaluated the impacts of underwater noise on voluntary feeding, feed efficiency, fish growth, physiological responses, and survival in fish. To our knowledge so far, no any published information is available regarding possible effects of the increasing noise pollution from intense urbanization at waterfronts on fish populations of nearshore marine environments. Terhune et al. (1990) underlined that reduced growth performance was recorded in Atlantic salmon (*Salmo salar*) exposed to underwater sound higher than the ambient sound level. Sun et al. (2001) reported that acoustic sound pollution influences physiology and welfare of fish such as reduced growth performance in carp (*Cyprinus carpio*). In contrast, some other investigations underlined that survival, growth performance and disease resilience of rainbow trout (*Oncorhynchus mykiss*) were not influenced by noisy farm conditions of machinery noise up to 149 dB re 1 μ Pa (Davidson et al. 2009), or 150 dB re 1 μ Pa SPL (Wysocki et al. 2007) in a recirculating aquaculture facility by long-term treatment. A limited number of available studies, however provided evidence that European seabass (*Dicentrarchus labrax*), northern pike (*Esox lucius*) and lake-chub (*Couesius plumbeus*) grown in net cages were influenced by underwater seismic air gun shootings (Santulli et al. 1999; Popper et al. 2005). Further, disturbance effect was seen in steelhead and caged salmon exposed to pile driving noise during a bridge construction work in the marine environment (PIDP 2001). It indicates that sounds of underwater caused by industrial activities not only manipulate natural populations of aquatic animals but also aquaculture facilities such as cage farms under influence of coastal urbanization and ship traffic.

In this study, growth performances of fish exposed to ship -or urban noise playbacks were lower than the control group after long-term exposures of 90 days. This was similar with the earlier findings of Lagardère (1982) in brown shrimp (*Crangon crangon*), Radford et al. (2016) in European seabass (*D. labrax*), Anderson et al. (2011) in lined seahorse (*Hippocampus erectus*), Kusku (2020) and Kusku et al. (2020) in Nile tilapia (*O. niloticus*) with damaging effects of underwater sound pollution on fish growth response. Considering the lower growth performance of fish exposed to urban noise treatment compared to those of the ship sound treatment group could be attributed to the irregularity of repeated “impulsive sound” of urban noise comprising a playback of a mixture of traffic noise, sounds of several motor

vehicles such as cars, bus, train, lorry, truck, operations of both building or road construction machineries, etc. whereas ship sound was a more regular “continued sound” type of noise generated by the propeller of a vessel, which is also supported with the 60 sec spectrum analyses in the present study.

Different than our study, Radford et al. (2016) did not observe increasing response of physiological movements when fish was exposed to a constant ship noise playback in comparison to the control group with no sound treatment. However, Radford et al. (2016) reported that fish initially increased physiological and behavioral response of ventilation rate in European seabass (*Dicentrarchus labrax*) after exposure to impulsive pile driving or seismic air gun noises, with declining response over long-term exposure. Fish did not show any further response after 12-weeks period. This was also supported by Kuskü (2020) and Kuskü et al. (2020) who reported a startle response in Nile tilapia, but fish did not respond with an elevated ventilation to the same noise after 12 weeks (90 days) of exposure. Similarly, to our findings in terms of long-term response of fish with growth indications, or earlier reports with physiological and behavioral responses, Nedelec et al. (2016) reported decreased level of behavioral responses or physiological in coral-reef fish after one week exposure to underwater motorboat noise transmission, which also support our results showing that fish may evolve tolerance to repeated acoustic noises after a certain time. The declining response of fish after repeated or continuous exposure to underwater sound transmissions could be attributed to the development of tolerance or changes in hearing threshold as was also reported earlier by Kuskü et al. (2020).

Growth of experimental groups exposed to underwater sound treatment was linear and almost stable for the first 15 days, and did not show any increase. Thereafter however, growth trend shifted forward with almost similar growth performance with the control group that received no sound treatment. This was more remarkable after day-30, and during the feeding period between day-30 to day-90, the SGRs of fish exposed to underwater ship sound or urban noise were higher than the control group, a strong sign of adaptation to the new and stressful conditions. This can be accepted as a remarkable-evidence that fish showed acclimation to noisy environment with a strong “catch-up growth endeavor” from day 30 onwards. Higher voluntary feed intakes in fish exposed to underwater sound treatments over the control group in the present study, might be attributed to the acclimation of fish that in terms presented a catch-up growth endeavor, which resulted in an accelerated growth trend over the following 60 days of the study that lasted for 90 days in total. The finding of the present study in terms of acclimatization to noise-induced environments without influence on growth after a few weeks of exposure is in close agreement with earlier reports (Wysocki et al. 2007; Davidson et al. 2009; Nedelec et al. 2016; Radford et al. 2016; Kuskü et al. 2018b, 2020; Kuskü 2020). When underwater sound transmission was initiated, a startle response was triggered on tilapia, which was in correspondence with Spiga et al. (2017) who noted instant response in European seabass (*D. labrax*) with the start of underwater sound playbacks. Similarly, Kuskü et al. (2020) reported physiological change as a startle response in tilapia exposed to underwater sounds of marine industrial constructions such as drilling or piling, and growth was depressed during the first 4-5 weeks of exposure, but increased thereafter, which is in close agreement with the findings in this study. Overall, our findings in terms of almost linear growth followed by an increasing trend after 3-4 weeks of sound pollution exposure overlaps with earlier reports underlining elevated respiratory rates for

the first 4 weeks of exposure, with a gradually declining physiological response over a long-term sound exposure in tilapia (Kusku 2020; Kusku et al. 2020).

Noise levels in the aquatic environment may vary in a range between 5 and 50 dB, with higher sound pressure frequencies in shallow waters close to the shore (between 50-95 dB) (Wenz 1962). Hence, underwater sound levels may differ depending on environmental conditions such as weather, currents, or waves (Lagardère 1982). In this study, the ambient sound level of the control group was recorded as 51.42 ± 1.73 dB (min - max: 49 - 58), which was rather lower than the ship (86.00 ± 1.07 dB re 1 μ Pa) -or urban sound (85.29 ± 2.54 dB re 1 μ Pa) treatment groups.

Gibson and Mathis (2006) observed different levels of opercula beat rates in fish exposed to various kinds of stimuli and underlined that increased opercula rates in fish might be accepted as a behavioral response to predators. Further, Kusku (2020) and Kusku et al. (2020) revealed strong relation between sound pollution stress and opercula beats or pectoral wing rates. Additionally, Kusku et al. (2020) underlined a correlation between opercula or pectoral wing rates and growth performance with a linear trend initially, then showing a catch-up growth endeavor thereafter, a sign of attenuation to sound transmission. These findings overlap with our findings in the present study, as well as those of Wysocki et al. (2007), Davidson et al. (2009), Nedelec et al. (2016). The reason for tolerance development and reduced response to underwater sound generated by external sources may be illustrated through habituation impact, an indication that the aquatic animal become familiar to the noise type with no hazard impacts (Bejder et al. 2009), which might also explain the increased growth performance with a catch-up growth endeavor by fish after 45 days of exposure in the present study, that was also supported in an earlier study on Nile tilapia (*Oreochromis niloticus*) by Kusku et al. (2020).

Conclusion

Findings in the present study highlight evidence that fish can attune and habituate to noisy environment above the ambient sound level over a long-term exposure period. An initial slow-motion growth was followed by a “catch-up growth endeavor” until the end of the study for 90 days. Acoustic sound experimentations in tank conditions may not directly or clearly replicate natural marine conditions, and field experimentations in the oceans may surely provide more realistic information. However, till then, the findings in this study provide useful information about fish populations schooling at nearshore marine areas, near harbors, ferry ports and intense urbanized shores, especially touristic facilities with recreational speedboat activities at waterfronts. Results of the present study may provide useful indications for policymakers in environmental management of irrepressible growing industrial water world.

Declarations

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Author contribution : Designed study, analysed data, drafted paper (Conceptualization, Methodology, Investigation, Writing)

Ethics approval: Regulations of Animal Behavior Society Guidelines have been followed throughout the experimental procedures of the present study, approved by the Ethical Committee of Canakkale Onsekiz Mart University via Ethical Commission Approval Number: 2021/04-09.

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Figures

Figure 1

Schematic illustration of experimental setup of the test containment with hydrophone output and soundmeter recording.

Figure 2

Average decibel sound pressure levels (dB re 1 μ Pa SPL) measured for the control (a), ship sound (b), and urban noise (c) groups. The control group represents ambient noise with no additional sound treatment

Figure 3

Spectrum analyses of 60 sec for ship sound and urban noise sources using Spectrum Octave Band RTA (Real-Time Analyzer). Control group represents ambient sound without additional underwater sound transmission.

Figure 4

Growth performance of fish exposed to underwater sound transmission of ship sound and urban noise for 90 days

Figure 5

Wet weight gain (WWG) and relative WWG (% of the control group) for fish exposed to ship sound and urban noise for 90 days. Data are means $\pm$ SD, and bars with same superscript letters are not significantly different ($P < 0.05$).

Figure 6

Specific growth rate (SGR) and relative SGR (RSGR, % of the control) in fish exposed to ship sound and urban noise for 90 days. Data are means $\pm$ SD, and bars with same superscript letters are not significantly different ($P < 0.05$).

Figure 7

Specific growth rate (SGR) and relative SGR (RSGR, % of the control) in fish after 30-days of underwater sound exposure (between days 30-90). Data are means $\pm$ SD, bars with different letters are significantly different within groups ($P < 0.05$).