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Evaluating the Effects of Increased Anthropogenic Noise on the Reproductive Success of *Poecilia reticulata*

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Abstract

Noise pollution, or more specifically, increased anthropogenic noise, in aquatic ecosystems has been increasing as humanity progresses in size and innovation. Very little research has been conducted to investigate the effects of noise pollution on the biotic factors in these ecosystems. The research that has been conducted has produced results that vary extensively depending on the organism and region, with some alluding to no noticeable effects, and others indicating fatality upon or after exposure. The lack of cohesiveness in these findings are what prompted the purpose of this research paper: to evaluate the effects, if any, of increased anthropogenic noise (IAN) on the reproductive success of *Poecilia reticulata*, or guppies. Guppies were chosen as the subjects for this study due to their classification as hearing generalists, fish with poor hearing sensitivity. Though this logic may seem counterintuitive, this classification makes them good candidates for this study because many of the fish the human population relies on for food are hearing generalists. Additionally, it could be argued that if exposure to anthropogenic noise negatively affects fish with poor hearing sensitivity, then it could also and to a greater degree affect fish with well adapted hearing capabilities. Thus, the results yielded by this study could potentially be applied to a greater population of fishes. For the purposes of this experiment, reproductive success is defined as the number of offspring produced by a female guppy.

To do so, two tanks were set up with ensured controls; one was constantly exposed to increased anthropogenic noise in the form of two different recordings merged, each played at random intervals; the other was not. Each tank had a camera placed in front of it to record the happenings of the tank. Data was collected for a month, the time it takes for one full gestation cycle (Yang, 2021). At the end of the gestation period, data was evaluated to determine results and conclusions.

At the end of the experiment, the tank that was not exposed to IAN produced offspring, while the tank that was exposed to IAN did not. This result supported the initial hypothesis that IAN can negatively affect the reproductive success of guppies.

Evaluating the Effects of Increased Anthropogenic Noise on the Reproductive Success of *Poecilia reticulata*

Many ecosystems and the biota that live in them are being affected by anthropogenically induced changes to their environment (Kunc & Schmidt, 2019). More widely known changes include habitat destruction, light and air pollution, as well as the introduction of invasive species. However, one source of anthropogenically induced change that is often overlooked is noise pollution. As industrialization and globalization have risen exponentially in the last century, so has noise pollution, or anthropogenic noise. The World Health Organization states that anthropogenic noise is a hazardous form of pollution and has become omnipresent in aquatic and terrestrial ecosystems (World, 2025). Berkhout et al. states that it has been found that anthropogenic noise can interfere with crucial behaviors such as habitat occupancy, feeding efficiency, and reproductive behavior (2023).

In this study, the term “increased anthropogenic noise” (IAN) was chosen to describe noise pollution for multiple reasons. First, the term “anthropogenic” is defined as “originating from human activity” (Oxford Languages, 2022). Thus, simply using the term “anthropogenic noise” could refer to sneezing, coughing, and many other small-scale noises produced by humans. Omnipresent factors in the environment of where this experiment was conducted prompted the need for the term IAN to be used for the sake of specificity. These human-produced noises could not be completely avoided throughout the experiment. IAN, as defined in this experiment, will include noise which produces disruption in a scale beyond what, for example, a sneeze would produce.

Because the prevalence of IAN has grown exponentially in the past few decades, it has been added to the list of several environmental changes that species are facing (Hildebrand, n.d.). The primary sources of IAN include transportation, urbanization, and industrialization, all of which grow in tandem with the human population (Jerem & Mathews, 2020). The prevalence of these sources is not just apparent in terrestrial ecosystems. In fact, there are a multitude of IAN sources in aquatic ecosystems. Seismic air guns, impact pile driving, and operating wind farms, are more large-scale, commercial sources of IAN (Slabbekoorn et al., 2018). Additionally, vessel noise, whether it is produced from the operation of large cruise ships or smaller fisherman boats, though on a smaller scale than the aforementioned sources, makes up a significant part of the IAN in aquatic ecosystems (Slabbekoorn et al., 2018).

From an overarching perspective, IAN may have many potential effects on fauna. In fish, IAN may cause hearing and orientation impairment, mask vocalizations, disrupt instinctive behavior like foraging and reproduction, and in some cases, fatality (Slabbekoorn et al., 2018; Popper & Hawkins, 2019). All the previously mentioned effects could not only impact fish, but also the surrounding ecosystems that rely on them for predation, consumption, parasitization, and other natural relationships. Humans are also a part of these surrounding ecosystems, as billions of people worldwide rely on fish for "food, jobs, and life satisfaction" (Loring et al., 2018). Quite a wide gap in the existing knowledge of IAN and its effects on fishes are what prompted this study and its aim to investigate the effects of IAN exposure on the reproductive success of guppies.

Literature Review: Evaluating Previous Research for Gaps

Arthur N. Popper and Mardi C. Hastings, two research professionals at the University of Maryland and The Pennsylvania State University, respectively, pinpointed some key issues with conducting and analyzing research for the purpose of coming to a general conclusion about the effects of IAN on any animal. First, it is hard to conduct any sort of experiment to investigate this topic because of numerous factors researchers must account for. In the wild, conducting experiments is particularly difficult because of how hard it is to ensure controls even with copious amounts of funding and equipment. In a lab environment, replicating the conditions that the fish would be exposed to in the wild is an equally strenuous task. Moreover, the effects of IAN have not been heavily studied until recently, thus there is not much information to go from when attempting to conduct further research (Popper & Hastings, 2009).

Given the difficulties in conducting experimental studies with appropriate controls, most published literature invoices meta-analyses (Kunc & Schmidt, 2019). The issue with this approach is that some species or circumstances are not given attention, further contributing to the wide gap in this field of research. A study conducted in 2019 sought to analyze the holistic effects of IAN on animals. The study used a table to assess previous research that had investigated its effects on animals to base their research on. In the table, only 25 out of 102 studies were about the impact of IAN on fish (Kunc & Schmidt, 2019). That itself urges the pursuit of further knowledge regarding the specific effects of IAN on fish.

Moreover, little research has been done regarding the hearing of fish. Though most can hear to an extent, some fish fall under the category of hearing generalists, meaning that they have poor hearing sensitivity (Popper & Hastings, 2009). Hearing specialists, on the other hand, "have special anatomical structure" that allow them to hear higher or lower frequencies of sound, a notable example being humans (Popper & Hastings, 2009). However, that does not mean that generalists cannot hear at all, only that they do not have the heightened hearing capabilities that hearing specialists do. Additionally, it is important to recognize that researchers of marine and aquatic bioacoustics advise that the two aforementioned terms should not be regarded as strict guidelines for the hearing capabilities of fishes, as there are "clear gradations in hearing capabilities" (Popper et al., 2021). However, because of the lack of more specific terminology, this experiment will refer to species as either generalists or specialists. Cod and salmon, for example, can be considered generalists, and it is extremely important that the effect of IAN on these species is determined. Not only are these fishes crucial to their respective ecosystems, but they are also heavily consumed by humans (NOAA Fisheries, 2000; NOAA Fisheries, 2020).

If such species are being negatively impacted by IAN, then two separate concerns arise. First, if IAN can negatively affect fish with poor hearing sensitivity, then logically, it could have quite severe effects on fish with well adapted hearing capabilities. Second, as previously mentioned, humans have developed a reliance on several hearing generalist fish for consumption purposes. If IAN were to harm those fish, it would indirectly harm the fishing industry and communities whose primary source of nutrition is fish. One study assessing the effects of high-speed boating on fish communities found that the hearing specialists (perch, in the case of this study), could perceive boats up to two hundred meters, while the hearing generalists (whitefish) could only detect boats up to thirty meters away (Amoser et al., 2004). Though this difference appears to be quite significant, it still signifies that hearing generalists could potentially be affected by nearby sources of IAN, and that their well-being should not be discarded from this conversation. This experiment looks to assess the effects of IAN on hearing generalists for these reasons.

Another pressing issue that the lack of respective research contributes to is that there have not been solid sound exposure criteria (SEC), "the sound levels where a specified level of damage or response is likely to occur," set for many organisms such as fishes (Slabbekoorn et al., 2018). It is incredibly difficult to set SEC for fishes because there is so much variation in the physical and behavioral characteristics between species (Slabbekoorn et al., 2018). Furthermore, it is hard to determine which aspect of the IAN would be affecting fishes, not only because of the vast species diversity, but also because there are many parts of a sound. Apart from noise, IAN may create sound pressure, vibrations, or particle motion (Slabbekoorn et al., 2018). Because SEC has not yet been set for many species of fish and there is a general deficit in information regarding their hearing capabilities, this experiment will generalize IAN and its attributes to simply the way its presence affects reproduction.

Guppies are a beyond sufficient species for studying the effects of IAN on fish. First, they are hearing generalists, which allows for many of the findings of this research to contribute to the body of knowledge regarding fish species such as the aforementioned cod and salmon, fishes that are critical for human consumption as well as the broader marine ecosystem. Second, guppies are incredibly useful in regard to measuring reproductive success as they are livebearers, meaning that they give birth to live offspring after retaining eggs internally (Evans & Magurran, 2000). This makes it easier to record how many offspring are born using camera footage, as opposed to trying to count the number of eggs produced while ensuring to account for eggs that have been eaten by other fish in the tank. Another quality of guppies that eased the experiment process is their ability to develop visual signs of pregnancy. A few weeks into its pregnancy, a female guppy will develop a dark patch near the back of its abdomen (BYA Editorial Staff, 2021). This allowed possible pregnancies to be tracked. Additionally, female guppies can become sexually mature as early as eight weeks, making it easier to acquire guppies that are able to reproduce. Females also can store sperm for several months at a time and produce multiple litters from a single insemination, increasing overall efficiency for this experiment (Evans & Magurran, 2000). Finally, guppies were financially and locally accessible for the purposes of this experiment.

Summary

Guppies are species that are often overlooked in the scientific realm as they are thought to be of little significance to prevalent topics of concern compared to other species. However, it is pertinent that their reproductive capabilities are recognized and taken advantage of when investigating how the fertility of fishes can be impacted by factors such as IAN. This experiment sought to answer this question: to what extent does exposure to increased anthropogenic noise affect the reproductive success of guppies? Because of the previously mentioned lack of research and knowledge about the effects of IAN on aquatic life, any research, even a small-scale experiment, can provide a good starting point to narrow gaps in the field. The methods in this experiment can be used as guidelines for future experiments and can be replicated with more advanced equipment and financial support, providing the field with more in-depth data.

Experiment Design and Methodology

Research Method

An experimental research method was chosen for this study because it assesses the effects of a change on test subjects. In the case of this experiment, the change would be the IAN exposure, and the test subjects would be the guppies. Initially, two tanks were prepared, and four guppies were placed into each in a ratio of three females to one male. This specific ratio was followed because male guppies can sometimes be aggressive towards females and outnumbering them using a ratio is a safety precaution taken for the health of the females (Betta Care Fish Guide, 2020). The use of and procurement of guppies for this experiment was approved by an IRB. Guppies were purchased from a local pet store, and proper ethical procedures for care and maintenance of the fish were followed.

One tank was exposed to IAN through a speaker, while the other was not. The IAN consisted of two different sounds, the sounds of a full high school cafeteria during lunch time and the sounds of a competitive marching band show. The specific sources of IAN were less important to this experiment than the way they were played because this experiment assesses the effects of the presence of IAN as opposed to IAN from a specific source. This is another aspect of this experiment that sets it apart from prior experiments, which assessed the effects of specific sources of IAN (ie: Amoser et al., 2004: powerboats; Hawkins et al., 2014: pile drivers; Radford et al., 2016: seismic sounds). What was crucial, though, was that both sounds were played in a way that they would disrupt the audible environment around them. The rooms the tanks were stored in were relatively quiet, as most of the time, there were no people in them. But unlike other similar experiments, which used experiment sites such as the ocean or sound controlled labs where there can be no sources of anthropogenic noise at all, the rooms already had some pre-existing sources of anthropogenic noise. The few times people were in the room, they would be producing AN. Additionally, the hum of the air conditioning system inside the room was also a source of AN. To account for this, the sounds needed to be increased anthropogenic noise, drastic enough to where they could be distinguished from the already existing AN in the rooms. The noise from a loud cafeteria and the noise of a marching band fit these requirements sufficiently. Because this researcher was not able to eliminate all AN in the room (ie: people talking, air conditioning, etc), ensuring that the sound the fish were exposed to would be louder and more prominent than all other sources of AN in the room would differentiate the experiment noise from any other noise that could not be controlled, reduced, or avoided. For the same reason, the sounds were played on a loop and at different intervals. This was made possible through audio editing software. The two sounds were spliced together in a manner where one sound would play for an ‘x’ amount of time, and vice-versa. By doing this, there was some variation in the IAN source, but it is important to mention that the intervals in which the two sounds played were not completely random because both sounds were on the same loop. Additionally, because they were on a loop, both sounds were played at the same volume.

A reserve tank was set up containing extra fish in case a fish in one of the two test tanks died. This tank was placed near the control tank, which was not being exposed to any IAN. This was pertinent because if the reserve tank was exposed to the IAN and an extra fish needed to be placed into the control tank, that fish would already have been exposed to IAN and therefore could possibly interfere with the results. Cameras were set up in front of each tank (excluding the reserve tank) to monitor the fish. The presence of the cameras was prudent, especially after signs of pregnancy were noticed, because guppies are known to eat their young almost immediately after giving birth to them. These cameras were also used prior to noticed signs of pregnancy to have visual information in the event of a fish’s death. The number of guppies in each tank was recorded daily, once again to note the death or birth of a fish. Additionally, other relevant details were also recorded, such as the first time a gravid spot could be observed in a female and if the fish were or were not tolerating each other’s presence in the tanks. While these details were not relevant to the conclusion and implications that were derived from the results of this experiment, they were helpful for the researcher to keep track of the happenings in each tank and ensure the health and safety of the guppies. Once a guppy gave birth, the number of offspring was recorded. Camera footage was reviewed to count how many offspring were born, and counting was done three times to reduce any error. Following that, data was reviewed and recorded, conclusions were made, and the experiment ended. The fish were either humanely euthanized with clove oil or given away to other people.

Controls

Controlling various factors was integral to the success of this experiment and was done to the best of this researcher's ability. Both tanks were ten gallons in size, which is the recommended tank size for guppies. Each tank had the same gravel, plants, filter, heater, light, and water conditioner. The tanks were kept at 78°F in accordance with the recommended temperature range, and the guppies were fed the same food on the same schedule. Each tank was placed in a room with very little foot traffic and anthropogenic noise present. To reduce the impact that vibrations generated from nearby sources such as walking and talking, each tank was placed onto a piece of thick foam that was slightly larger in area than the tank, and approximately four inches in width.

Hypothesis

In this experiment, it was hypothesized that the tank exposed to IAN would have a lower rate of reproductive success. This conclusion was drawn from the pre-existing research relevant to this experiment. Noise emissions produced by powerboats have been found to "interact with other sound sources" (ie: sounds from prey or predators), and other "acoustic signals relevant" to fish (Amoser et al., 2004). If IAN may affect instinctive behavior like moving from feeding sites and traveling through migration routes, then it very well may disturb other instinctive behavior such as reproduction (Slabbekoorn et al., 2018).

Limitations

Before assessing the data results, it is important to address the limitations of this experiment. First, although precautions were taken to reduce the amount of foot traffic and noise in each room, there were instances where they could not be avoided. For that reason, this experiment centers around increased anthropogenic noise, where one tank was exposed to more IAN than the other through the sources created by this researcher. Additionally, there were instances where the IAN stopped playing through the speaker. This is not thought to have affected this experiment's integrity, however, because IAN does not have to be and usually is not constant. For example, seismic drilling in the ocean does not happen constantly. It may happen for a few consecutive days without stopping, but it is not constant. Similarly, a motorboat may have an extensive voyage on the ocean, but there are no known motorboats that have the capability to go on forever and, thus, are not constantly operating. Considering this, the few occurrences that the IAN did stop is thought to have had no effect on the results of this experiment.

Another issue in the early days of this experiment was the death of multiple fish, four females and one male across both tanks. This occurred in both tanks, so it is highly unlikely that the IAN exposure had anything to do with the fatalities. The problem this posed was that if one tank had more fish than the other, specifically females, at the end of the gestation period, the number of offspring produced might be skewed. To be more specific, if every single female was to reproduce, a tank with two females would likely have less offspring compared to a tank with three females. Additionally, if a pregnant female died, then the replacement female would have to "catch up" to get pregnant and may only reproduce after the month it would have taken the original female to reproduce, meaning that the duration of the experiment would need to be extended to account for that data. A male death was less problematic. Indeed, a male could also be immediately replaced, but furthermore, the replacement would not have to "catch up" in the sense of getting pregnant. This issue was combated by ensuring that the population in each tank was balanced after a death, whether it was buying more fish the same day or removing fish and putting them into the reserve tank and no longer including them in the experiment. An effort was made to ensure that removed females were not pregnant to not affect conclusions. After a week and a half, fatalities and consequential replacements made it so that each tank had two fish, a male and a female.

Moreover, the volume at which the IAN was played was restricted to an extent because the room in which the exposed tank was located was in between two classrooms. The IAN could not be too loud, as it would interfere with the ongoing lessons in each class.

Also, it is possible that the guppies, especially the offspring, were miscounted despite multiple rounds of counting. Guppy fry, or the offspring of guppies, are very small and may have been missed during the rounds of counting.

Next, there is always a chance that animals in captivity do not show the full range of behavior observed in their non-captive counterparts (Benhaïm et al., 2012, as cited in Popper & Hawkins, 2019). More drastically, animals in captivity have the potential to display completely different behaviors from their non-captive counterparts (Garner, 2005). To reduce this issue, all measures that could be taken regarding water and tank parameters were done so in a way that ensured that the conditions in the tank could replicate natural conditions as closely as possible (ie: water temperature, vegetation, and food). Additionally, through the course of the experiment, no such abnormal behaviors were observed. The males displayed guppy mating behavior; they would swim and flare their fins around the female. This occurrence lowered the concerns brought about by the aforementioned source.

Lastly, time constraints limited the number of trials that could have taken place to only one. Ideally, this experiment calls for several trials to ensure that conclusions and implications derived from the results are as consistent and accurate as possible.

Results

To reiterate, this experiment defines reproductive success as the amount of offspring produced by a female guppy. After twenty-five days, the tank without IAN exposure had one female that gave birth. However, the experiment did not end after the birth occurred because the gestation period of a guppy lasts for approximately one month, and the duration of this experiment was set based on that timeframe (Yang, 2021). This meant that the other tank still had time and therefore potential to produce offspring. The experiment was left to run for six additional days so that the gestation period could end. At the end of the gestation period, the tank that was exposed to IAN did not produce any offspring, and the experiment ended. These results support what was hypothesized prior to the start of the experiment, which was that IAN would negatively affect the reproductive success of the guppies.

However, this experiment aims to evaluate the extent to which IAN affects reproductive success, and to do so, an assessment of more specific numbers is necessary. To do this, the camera footage from the tank was analyzed to count the number of offspring produced. This posed a problem because the offspring were extremely difficult to locate due to their size. This was partially anticipated and addressed in the limitations section of this paper, but that was in acknowledgement to the possibility of human error and how the camera was positioned to where some of the offspring would not be able to be captured in the view of the camera. The size of the offspring itself was not thought to have been an issue before the beginning of this experiment.

Even so, a total of twelve offspring were able to be distinguished (it is important to note that all but one were eaten by their parents during the first few hours following their births). It is very likely that this low number is because of the camera quality and that there were several other offspring in the tank that were not counted. Though less likely, it is also a possibility that the female just had a very small batch of offspring. Guppies can have as few as five to as many as eighty offspring at a time (Susel, 2022). The rather small batch of fry produced could also be attributed to the health of the female or less distinguishable aspects such as oxygen levels or the tank's temperature (Gorham, 1999). Whatever the case, the results acquired from this experiment are still very significant. Because the tank that had no IAN exposure reproduced while the tank that was exposed did not, the notion that exposure to IAN can negatively affect the reproductive success of guppies is supported. The only outcome that would not support this notion is if both tanks reproduced, and more specifically, the tank that was exposed to IAN produced more offspring than the one that was not. It is important to recognize that because the issue of time constrained this experiment to only one trial, that the aforementioned outcome is possible and could be a potential result in one of several future replications of this experiment.

Discussion and Conclusions

As mentioned in the results section of this paper, the data produced by this experiment supports the initial hypothesis that exposure to IAN would negatively affect the reproductive success of guppies; the tank with no IAN exposure reproduced, while the tank with IAN exposure did not reproduce at all. However, the correlation between IAN exposure and weakened reproductive success does not necessarily imply causation between the two. After considering all the measures that were taken to ensure the controls of this experiment and that all limitations were addressed to the best of this researcher's ability, it can soundly be concluded that there is very little possibility of there being no causation and instead only implied correlation. Even so, future research is necessary to find a stronger causational relationship.

Besides just supporting the hypothesis of this experiment and narrowing the existing gap in the surrounding body of literature, the results of this experiment have several significant implications to current global happenings. As mentioned earlier in this paper, sources of IAN are growing in tandem with global technological innovations, and that it is more prevalent than ever before (Hildebrand, 2004). The results of this experiment allude to the idea that exposure to IAN in the wild can damage the reproductive success of certain species of fish. This notion has several daunting consequences. Most of the human population relies on fish for consumption and commercial purposes. Specifically, fish "provide vital nutrients for three billion people around the globe and supply an income for ten to twelve percent of the world's population" (The Nature Conservancy, 2021). Lowered reproductive success because of exposure to IAN could cause a decline in many fish populations. This would inevitably affect several groups of people, not only those who consume them, but also those who are involved with them in any commercial sense, such as importing and selling fish. On a larger scale, IAN-induced dwindling of fish populations can negatively impact global biodiversity directly and indirectly. For example, certain species of salmon eat zooplankton and are eaten by birds such as puffins. If this salmon population was to decline upon IAN exposure, then the puffin population would lose its primary source of food and start declining. Populations of zooplankton may increase because of a lack of predators, and this would disrupt the ecosystem in which these animals are inhabiting. Through this displayed interconnectedness of food chains, if IAN exposure can negatively affect the reproductive success of fish, then it will eventually indirectly affect several other species of animals.

Future Research

While this experiment was successful on the scope of this researcher's skill level and research, there are several recommended changes that would need to be implemented to make the results and derived implications stronger. It is the hope of this researcher that the results of this experiment would prompt several other studies and experiments surrounding the effects of IAN exposure on fish; ones that are, ideally, greater in size, skill, and number of trials. These future experiments and studies can aim to address some of the limitations of this experiment, which would increase the accuracy of the results that they produce.

First, as mentioned several times throughout this paper, time constraints made it so that only one trial of this experiment was possible. To ensure the most accuracy and depth of the results and conclusions that this experiment would produce, multiple trials would need to take place. Then, even if the results of said trials were not consistent, they could be compared and analyzed to develop a stronger research method for similar experiments in the future.

Because this experiment only studied guppies, the results that it produced cannot be extrapolated to apply to all fish. This limitation can be resolved in a couple of ways. First, future replications of this experiment can aim to determine whether a pattern can be established across many different species. With more replications of this experiment being conducted, a foundational research method along with stronger sound exposure criteria could be developed, which could then be applied to several other species of fishes. For instance, zebrafish have been used as models for human hearing and deafness (Whitfield, 2002). They could be used in a future replication of this experiment to analyze the effects of excessive anthropogenic noise exposure on humans.

The conduction of several experiments, such as the zebrafish study mentioned above, could also make it easier to develop more reliable sound exposure criteria that would only further propel and solidify research regarding anthropogenic noise and fish, and on a wider scale, aquatic bioacoustics in general.

If these future studies and experiments also find that IAN exposure can negatively impact fishes' reproductive success, then governments and major corporations who contribute to IAN sources in the wild and near ecosystems can aim to create and abide by regulations of IAN production to ensure the wellbeing not only of the fishes that are affected but also of the other animals that rely on them.

References

Amoser, S., Wysocki, L. E., & Ladich, F. (2004). Noise emission during the first powerboat race in an Alpine lake and potential impact on fish communities. The Journal of the Acoustical Society of America, 116(6), 3789–3797. https://doi.org/10.1121/1.1808219

Benhaïm, D., Péan, S., Lucas, G., Blanc, N., Chatain, B., & Bégout, M.-L. (2012). Early life behavioural differences in wild caught and domesticated sea bass (Dicentrarchus labrax). Applied Animal Behaviour Science, 141(1-2), 79–90. https://doi.org/10.1016/j.applanim.2012.07.002

Berkhout, B. W., Budria, A., Thieltges, D. W., & Slabbekoorn, H. (2023). Anthropogenic noise pollution and wildlife diseases. Trends in Parasitology, 39(3). https://doi.org/10.1016/j.pt.2022.12.002

Betta Care Fish Guide. (2020, May 8). How To Keep Male And Female Guppies In The Same Tank. Betta Care Fish Guide.

https://www.bettacarefishguide.com/how-to-keep-male-and-female-guppies-in-the-same-tank/

BYA Editorial Staff. (2021, February 5). How to Identify a Pregnant Guppy (What to Look For). Build Your Aquarium. https://www.buildyouraquarium.com/pregnant-guppy/#:~:text=This%20is%20to%20provide%20as

Evans, J. P., & Magurran, A. E. (2000). Multiple benefits of multiple mating in guppies. Proceedings of the National Academy of Sciences, 97(18), 10074–10076. https://doi.org/10.1073/pnas.180207297

Garner, J. P. (2005). Stereotypies and Other Abnormal Repetitive Behaviors: Potential Impact on Validity, Reliability, and Replicability of Scientific Outcomes. ILAR Journal, 46(2), 106–117. https://doi.org/10.1093/ilar.46.2.106

Gorham, M. E. (1999, January 23). Guppies can breed like there' s no tomorrow. Moscow-Pullman Daily News. https://dnews.com/slice/guppies-can-breed-like-theres-no-tomorrow/article_9d65ea89-65a7-561a-bea3-1975af81e9ae.html#:~:text=Why%20does%20a%20female%20guppy,female%20to%20reabsorb%20extra%20eggs.

Hawkins, A. D., Roberts, L., & Cheesman, S. (2014). Responses of free-living coastal pelagic fish to impulsive sounds. The Journal of the Acoustical Society of America, 135(5), 3101–3116. https://doi.org/10.1121/1.4870697

Hildebrand, J. (2004). Sources of Anthropogenic Sound in the Marine Environment. https://www.mmc.gov/wp-content/uploads/hildebrand.pdf

Jerem, P., & Mathews, F. (2020). Trends and knowledge gaps in field research investigating effects of anthropogenic noise. Conservation Biology, 35(1). https://doi.org/10.1111/cobi.13510

Kunc, H. P., & Schmidt, R. (2019). The effects of anthropogenic noise on animals: a meta-analysis. Biology Letters, 15(11), 20190649. https://doi.org/10.1098/rsbl.2019.0649

Loring, P. A., Fazzino, D. V ., Agapito, M., Chuenpagdee, R., Gannon, G., & Isaacs, M. (2018). Fish and Food Security in Small-Scale Fisheries. Transdisciplinarity for Small-Scale Fisheries Governance, 21, 55–73. https://doi.org/10.1007/978-3-319-94938-3_4

NOAA Fisheries. (2000). Atlantic Cod | NOAA Fisheries. Noaa.gov. https://www.fisheries.noaa.gov/species/atlantic-cod

NOAA Fisheries. (2020, April 17). Sockeye Salmon | NOAA Fisheries. Noaa.gov. https://www.fisheries.noaa.gov/species/sockeye-salmon

Oxford Languages. (2022). Oxford Languages and Google - English. Languages.oup.com; Oxford University Press. https://languages.oup.com/google-dictionary-en/

Popper, A. N., & Hastings, M. C. (2009). The effects of human-generated sound on fish. Integrative Zoology, 4(1), 43–52. https://doi.org/10.1111/j.1749-4877.2008.00134.x

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

Popper, A. N., Hawkins, A. D., & Sisneros, J. A. (2021). Fish hearing "specialization" – a re-evaluation. Hearing Research, 108393. https://doi.org/10.1016/j.heares.2021.108393

Radford, A. N., Lèbre, L., Lecaillon, G., Nedelec, S. L., & Simpson, S. D. (2016). Repeated exposure reduces the response to impulsive noise in European seabass. Global Change Biology, 22(10), 3349–3360. https://doi.org/10.1111/gcb.13352

Slabbekoorn, H., Dooling, R. J., Popper, A. N., & Fay, R. R. (2018). Effects of Anthropogenic Noise on Animals. In Google Books. Springer. https://books.google.com/books?hl=en&lr=&id=jl5qDwAAQBAJ&oi=fnd&pg=PR5&dq=effects+of+anthropogenic+noise+on+animals&ots=f9ZBXrzbjr&sig=9xNF91jB_hRoluOiAq4PEBHZMws

Susel, G. (2022, February 14). How Many Babies Do Guppies Have? (Monthly & During A Lifetime). Pet Fish Online. https://petfishonline.com/how-many-babies-guppies-have/

The Nature Conservancy. (2021, January 25). A Healthy Ocean Depends on Sustainably Managed Fisheries. The Nature Conservancy. https://www.nature.org/en-us/what-we-do/our-priorities/provide-food-and-water-sustainably/food-and-water-stories/global-fisheries/#:~:text=Fish%20and%20other%20seafood%20products

Whitfield, T. T. (2002). Zebrafish as a model for hearing and deafness. Journal of Neurobiology, 53(2), 157–171. https://doi.org/10.1002/neu.10123

World. (2025). Burden of disease from environmental noise: quantification of healthy life years lost in Europe. Bvsalud.org. https://pesquisa.bvsalud.org/portal/resource/pt/who-326424

Yang, A. (2021, June 11). Pregnant Guppy Fish: How To Tell & What To Do... Aquarium Source. https://www.aquariumsource.com/pregnant-guppy-fish/