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The Sound of Silence: An Immersive Approach to Spearfishermen's Ecological Knowledge Along the Dakar Coastline

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Abstract

At the crossroads of sensory anthropology and underwater bioacoustics, this article offers an immersive approach to garner the knowledge and perceptions of Dakar underwater fishermen. Four Senegalese fishermen conveyed their extensive knowledge of the peri-urban underwater environment through the descriptions of and commentaries on the seven dives they recorded using a camera equipped with an integrated microphone attached to their heads that focused on the marine soundscape. This methodology was aimed at documenting their ecological knowledge of the underwater marine environment of Dakar concerning its growth, the modifications of the shoreline, and underwater urban extensions such as sewers, water drainage from the surface and various discharges. Notions such as “guest” fish or “social” fish, among others, are used by divers to describe the behavior of fish, highlighting the elements that allow assessing the catchability of different species. A decrease in the attractiveness of the Dakar coast for migratory fish is described in connection with urban pollution discharges, the destruction of underwater habitats, and the development of scuba-diving and night-hunting practices. In general, the information collected puts into perspective the changes perceived both in connection with the worldwide scale of global warming and the problems of over-exploitation.

Keywords:

Sonic methodology, sea soundscape, ethnoecology, spearfishermen, fish behavior, fish sound, fisherman behavior

1. Introduction

Dakar is located at the tip of the Cape Verde peninsula which is a prime fishing area as well as a corridor for many migratory fish species. In addition, the rocky nature of its coastline provides a rich habitat for demersal fish species (species living above the seabed). Before the rise of modern-day Dakar, human presence was found in the Lebou fishing villages (Balandier and Mercier 1952). Local fishermen—heirs to the Lebou culture—are expert in the marine ecosystem that they survey and exploit daily through their fishing practices, even and especially in an increasingly changing environment (Berkström et al. 2019; Mbaye et al. 2021). Spearfishing is one of the newest and, apparently, most lucrative fishing practices according to our observations in Dakar. Spearfishermen have long been exploring the peninsula's rocky coast, historically by snorkeling and increasingly with canisters of compressed air, though this is now prohibited. Their catches are often greater in size and commercial value than those of the pirogue fishermen with whom they share the coastline (Mamadou Sarr, chief of Ouakam fishermen, communication with the authors).

Dakar has nearly four million inhabitants. The consequence of its strong recent growth and economic development is increasing anthropogenic pressure on the marine ecosystem through pollution, fishing activity, and infrastructure (Belhabib et al. 2014; Deme et al. 2021; Machu et al. 2023; Sidibé

2013). Successive urbanization and human activity have affected the sea off Dakar, especially following the construction of infrastructure in the 2010's to drain water from the neighborhoods to the sea via a system of underground channels (Leclercq 2019). Professional free-diving spearfishermen mostly from fishing villages have observed underwater marine evolution and developed a store of specific knowledge of the Dakar seabed that could complement our own scientific approach to understanding this environment. Berkström et al. (2019) (see also the seminal paper of Johannes, Freeman and Hamilton 2000) insisted on “the considerable interest in combining local and scientific knowledge to achieve management objectives” within the marine conservation community. They did however note the dearth of studies about local ecological knowledge (LEK) and the complete absence of any reference on underwater knowledge. It is possible to ensure the sustainable management of natural resources such as fishing, particularly in developing countries, by promoting and using local knowledge (Cormier Salem and Bassett 2007; Cormier Salem and Roussel 2005; Heyman and Granados-Dieseldorff 2012; Mellado et al. 2014). Underwater fishermen from Dakar can thus be considered privileged observers of ecological states around the Cape Verde peninsula. This survey was conducted in collaboration with Senegalese fishermen, and therefore provides a collaborative ethnoecology of the Dakar Sea. We concur with Messias et al. (2019) when they argue that ethnoecology anal-

yses “the ecological knowledge generated from the interactions between human populations and the environment, bringing together the knowledge, practices, and beliefs that are transmitted orally through generations” (2019: 1). Our objective is to devise a methodological means to document spearfishermen’s sonic perceptions of Dakar’s underwater marine environment concerning growth, with coast-line modifications and underwater urban extensions such as sewers, drainage surface water, and miscellaneous discharges. We also aim to understand their relationship with this environment through sound perception and fishing practices, and, more particularly, their fishing techniques, and the sensorium involved by the practice of the underwater environment in free diving. Fishermen contributions to soundscape ecology has been an emerging field of research for approximately 10 years. Up to now, it was largely based on measurements of the acoustic environment (see Pijanowski et al. 2011; Lindseth and Lobel 2018). Our contribution was to produce a methodology to record sonic knowledge and experience of free divers as material for soundscape ecology and iterative knowledge circulation between scientists and fishermen. The ethical and scientific principles of “Ethnobiology 5” (Cite Hunn 2007 JOE 27(1) 1-10.) that include an engaged, sustained, and critical commitment to the perspectives of indigenous and local people was used as a basis in our study (Nabhan, Wyndham and Lepofsky 2011). In line with their proposal of a novel approach to “open-source biology and knowledge-sharing,” we designed a collaborative methodology for initiating dialogue between scholars and people in order to collect ecological data (Azzurro et al. 2019). We adopted an immersive approach intended to give more room to fishermen to express themselves through their activity.

2. Materials and Method

2.1. Data Collection

There is an advantage in working with free divers because, unlike scuba divers, they do not make much noise in the water. This allows them to remain alert to the general soundscape of the underwater environment that they rely on to hunt, and as a result they are likely to observe acoustic changes over time. Underwater fishermen are therefore able to contribute to the identification of sounds from aquatic creatures and, in addition, to help document animal behavior and the ecological evolution of the Dakar Sea. Our approach is inspired by the sensory anthropological approach taken by Battesti and Puig that was developed to document sound perceptions of the inhabitants of Cairo (Battesti 2017; Battesti and Puig 2016, 2020). We adapted the tool they used in their study, to free diving for diving descriptions (instead of urban itineraries), and to generate a discourse on the evolving underwater environment. During the survey, the spearfishermen dived with a GoPro camera (Hero Black 5) equipped with a microphone sufficiently powerful for the experiment. The sound was set to stereo mode so that we could remove the wind attenuation feature which could cause disturbing fluctuations in underwater-sound levels (mid-setting option, manual stereo audio control). We defined



Figure 1: Maguette Sarr.

the raw audio mode, allowing us to create a sound file (.wav recorded at 32 kHz) separate from the image. The camera was equipped with a waterproof case (60 m) which ensured correct operation of the device even when free divers descended below 10 m; they hunt between 4–5 m and 20 m. Like in the Cairo investigation by Battesti and Puig, the objective was to create and provide researchers with a tool for verbalization below the surface of the Dakar Sea while obtaining audio and video recordings of this environment (the recordings will be offered in open data). The device chosen was apnea with the camera. The spearfishermen dive with a GoPro camera worn on their forehead. Babacar Sy (sometimes only mentioned by his first name in the text) is a professional fisherman from the village of Ngor located on the edge of the Cape Vert peninsula. To avoid camera movements during the dive, he added a chinstrap to the camera mounting system which we decided to retain. We worked with him, and we also recruited three other underwater fishermen for their experience from different sites including Ngor, Ouakam, and Gorée. Two young as well as two experienced divers participated in the experiment: Seven dives were recorded (see Table 1). The spearfishermen were asked to dive in one of their usual fishing grounds where they stayed for 1 to 2 h. The four divers afterwards described and commented on the recorded sounds while watching the videos of their underwater expedition. The words come directly from the description of the dives since the interviews were not guided. We recorded several hours of descriptions in French and Wolof (with some specific words in Lebou) which were then translated into French, when necessary. In parallel with this experiment, we conducted interviews using different media. We interviewed one of the older spearfishermen who did not dive himself, but who commented on the video of a dive made by Babacar Sy (see Tables 1 and 2).

2.2. Data Analysis

Sequences from the spearfishermen’s whole dive recordings were extracted to obtain descriptions. This was easily done by visually checking the sound record spectrogram. Indeed, using the spectrogram made it easy to differentiate from the one at the surface level. Once the spearfishermen’s descriptions were integrally transcribed (either by the authors or by a translator), the information was classified according to themes that emerged

Table 1: Summary of dives and sound recordings used as material for comments.

#	Date and Place	Diver/sound recorder	File	Comment
1	April 21th 2019, vivier	Babacar Sy	Gopr0204.MP4	Sea urchins and sea -
2	June 27th 2019, vivier	Babacar Sy	Gopro3739 - GOPR13739.MP4	red cornetfish sound clearly identified
3	September 18th 2019, vivier	Babacar Sy	Gopr3791-2-3-4. MP4	Rain season. Commented by BS, ND et CT
4	January 16th 2020, Ouakam cliffs	Magatte Sarr	GOPRO 16459	Poor visibility along the Mamelles cliffs
5	January 17th 2020, Gorée	Maurice Kambé	GOPR6460.MP4	Dive with Nicolas Puig. Long apneas.
6	January 18th 2020, Vivier	Babacar Sy	Gopro6492. MP4	Dive with NP, Hunting and hydrophone deployment
7	January 18th 2020, Vivier	Ndiass	Gopro6477. MP4	Presence of a marine turtle
8	January 10th 2019, Bijagos	Timothée Brochier	20190110T235859.wav	Stationary hydrophone at 3m depths.
9	October, 1st 2019, Melax Buoy	Timothée Brochier	20191001T041500.wav	Stationary hydrophone on the bottom (35m depth)

Vivier : a reef in Dakar, Almadies; Ouakam cliffs : cliffs behind the Mamelles neighbourhood, Dakar;

Bijagos : an archipelago in Guinea Bissau, south of Senegal; Melax : a scientific observatory buoy anchored south of Dakar, by 32 meters depth.

from the descriptions. For the present study, we focused on information directly related to the sound descriptions. When specific fish sounds were identified from the recordings, they were extracted and computed by the spectrogram. This allowed us to classify the fish sounds with their corresponding fish species as specified by the spearfishermen. Fishermen name fish using local names. We referred to the picture in the recordings or in the two books of reference, “Les poissons d’Afrique de l’Ouest” (Seret 1981) and “Guide des ressources Halieutique du Sénégal et de la Gambie” (Bellemans and Sagna 1988) to identify the corresponding Latin names. Senegalese fish taxonomist Oumar Sadio (IRD/CRODT) helped us to identify *Batrachoides liberiensis* (Steindachner 1867), hairy toadfish (Table 2). We had subsequent conversations with the divers to develop certain elements and get their opinion on underwater sounds recorded with the hydrophone or on certain remaining unexplained sounds of the dives. They helped us to complete the comments and discussions around the recorded dives; references to these conversations are noted as open discussion (Figures 1 and 2).

Specific sounds indicated by the spearfishermen were extracted and included in the article text. For the sound 2 (distant Anglerfish), we also provided a filtered version of the sound (low pass 700 Hz) as the indicated sound was almost impossible to hear for the non-expert. Spectrograms were computed to differentiate the sound duration and frequency. To visualize long (1 s) fish sounds, we set the time window of the short-term Fourier transform to 0.256 s (Figure 3a to c) while for shorter sounds we set the time window to 0.032 s (Figure 3d to f).

3. Results and Discussion

The substantial amount of data collected and the descriptions and comments from the dives enabled us to identify four main themes related to the sea soundscape. Moreover, the method made it possible to approach themes far beyond, for example: a “crackling” sound, a constant background noise, fish sounds, fish behavior, and fishermen’s behavior. We will present here some analytical data, but we include additional data from the totality of the fishermen’s narratives collected throughout the experiment.

3.1. A Constant Background Sound of Biological Origin

All the spearfishermen highlighted a background noise along the Almadies coastline. They attributed this background sound

to crackles from different sea urchins and seashell species. The crackles are mixed but they can be differentiated. Spectrogram analysis revealed that some crackles covered the whole frequency spectrum (1–16 kHz) while others ranged from 1 to 7 kHz; this is also in line with Coquereau et al. (2016) which mentions two different crackles from sea urchins, due to either feeding or moving. Spearfishermen also mentioned that the noise intensity changes depending on the depth and the season which influences the salinity of the water and the abundance of seaweed that urchins feed on.

N: It’s sea urchins’ sound you hear like that. Everything you hear there. It’s sea urchins’ sound. That’s it; all that noise is made by sea urchins.

ComNdiass, January 15, 2020

M: Sounds are only sea urchins and seashells. It’s a slight sound because of the shallow depth but also because, since it’s fresh water, there is no seaweed. Seaweed does not survive in fresh water; it dies. And sea urchins are in difficulty until the rainy season is over. Then, it’s back. 4: 40: Here you hear more echoes because it’s deeper. But sea urchins are there, violet ones are there, but there is not much seaweed. It’s like that at the beginning of the rainy season; it has always been like that. 6 :00: Sea urchins, seashells, those who make a lot of noise because there’s not much else.... We used to have more fish before. 6: 58: If you could see how much the water is polluted down there! That also affects species living underwater.” Babacar January 14, 2020 If there is a lot of depth you can’t hear the sea urchins, they are not stones. It’s sand. It’s quicksand; there is sand over there in Vivier; there are rocks but there is also sand. (...) It’s sea urchins tictic . Maguette, January 15, 2020

Babacar also identifies a particular species of sea urchin he calls “electric sea urchins,” with longer spines (radiolae) and whose shell is iridescent blue (his description corresponding to that of *Diadema Savignyi*, Audouin, 1809).

B: It’s electric sea urchins or seashells that you hear (SOUND 1). In my opinion, the movement of their spines allows them to detect what they have around

Table 2: Summary of Audio/video comments and open discussions.

Fisher's name	Date and place	Support, lasting	Description and Comment
Babacar Sy	January 14th 2020 – Almadies – Restaurant	Comments video file #1 (French), 6 :51	Sea urchins and shells, "electric" sea urchins
Babacar Sy	January 20th 2020	Comments video file #2 (French), 7 min	Trumpet sound in the distance. Sounds of swell, sand, rocks and currents. Typical rain season sound description.
Babacar Sy	January 14th 2020	Comments video file #3 (French), 45 min	Season identified thanks to the seabed. Swallow fish sound description. Historic evolution of fish sounds abundance and diversity. Parrot fish migration behavior. Difference between sea shells and sea urchins sounds.
Ndiass	January 15th 2020 – Almadies – Restaurant	Comments video file #3 (Wolof), 10 : 47	Rocks, guest/immigrant fish, sea urchins
Mamadou Touré	January 15th 2020 Almadies (Mbarou Babacar)	Comments video file #3 (French/Wolof), 7:11	Contrast between relative silence today Vs numerous sounds at the time he dived.
Maguette Sarr	January 16th 2020	Comments video file #4 (French/Wolof), 23:26	Behavior of goldblotch grouper, white grouper, fin's sound, concept of guest/immigrant fish.
Babacar Sy	January 20th 2020 – Almadies – Restaurant	Comments video file #6 (French), 12 :03	Electric sea urchins sounds and biology – clicking sounds
Ndiass	January 18th 2020 – Almadies – Restaurant	Comments video file #7 (Wolof), 7 : 10	Sea hyenas, currents ...
Maurice Kambé	January 17th 2020	Comments audio file #8 (French), 35:33	Crustacean noise. Identified sounds: blow of tail of Sars, blackbar hogfish and non-identified scary fish.
Ndiass	January 18th 2020 – Almadies Mbarou Babacar	Comments audio file #8 (French/Wolof), 2:11	"Sea Hyena" sound and fish description
Babacar Sy	January 20th 2020 – Almadies – Restaurant	Comments audio file #8 (French), 10 :06	Sea hyena seasonal sounds, hunting methods of whales and dolphins, orcas
Babacar Sy	January 14th 2020 – Almadies – Mbarou Babacar	Open discussion (French), 47 :18	Fish migrations, monkfish, mystic, toponymy of the coast
Babacar Sy	January 14th 2020 – Almadies – Mbarou Babacar	Open discussion (French), 8 :49	Fish's movements near the coast or at sea, effect of pollution on a specific diving site
Babacar Sy	January 20th 2020 – Almadies – Mbarou Babacar	Open discussion (French), 43 :59	Biology and name of the fish
Babacar Sy	January 20th 2020 – Almadies – Mbarou Babacar	Open discussion (French), 6 :11	Concept of invited or immigrant fish.
Ndiass et Babacar Sy	January 18th 2020 – Almadies – Mbarou Babacar	Open discussion (French/Wolof), 42 :01	Dakar free diving history- compressed-air tanks – fish behavior- Pollution
Mamadou Touré	January 15th 2020	Open discussion (French/Wolof), 14:20	Beginning of free diving in Dakar, then arrival of compressed-air tanks and arrival of industrial boats.
	Almadies (Mbarou Babacar)		



Figure 2: Ndiass Mbéguéré watching, listening, and commenting on his dive.

them. And they move very quickly. They are poisonous. Only Chinese eat them. Babacar January 18, 2020

- B: The sound made by electric sea urchins is different from the sound made by other urchins. Electric sea urchins move their spines in a different way. They cross them like someone sharpening two chopsticks. That makes a sound like pssss, you have to get closer to hear that sound. 4: 57: They're electric sea urchins, filmed in Ngor on a plateau around 6 - 12 m. Babacar, January 14, 2020

According to Babacar Sy and Ndiass, during the rainy season, background noise would be lessened because during that season there is less seaweed and, therefore, fewer sea urchin sounds since most of the background noise comes from when they are eating seaweed. They say that this can be explained by the fact that, during the summer months, the seaweed that this species feeds on becomes rare (sound would therefore be made during feeding phases). Crackling is also weaker in certain highly polluted areas where rocks and sand are described as "dead," meaning they no longer have seaweed or microorganisms that fish can feed on; these zones are described as silent deserts and one of the participants in the survey prefers not to go to these zones because they make him "sick" (Babacar, January 18, 2020) Sensitivity of urchins to pollution was doc-

umented, although the effect of the pollution described by the Dakar spearfishers primary impact seaweed then urchins and fish while it affects only the urchins in Brittany, leading to a proliferation of seaweed (Guillou, Grall and Connan 2002).

The pollution issue was recurrent. Ndiass and Babacar point to white rocks visible in the diving video.

NDIASS: They now put channels in places where we used to dive to catch; the rocks are no longer alive. You can tell if rocks are alive when they have seaweed stuck to them. At a certain point, all the seaweed died. If you see the rocks now, they have turned white; all the rocks turn white like that.

BABACAR: Actually, there is all that now killing everything down there. So, that means that as soon as the fish can't feed themselves there, they leave.

NDIASS: Even the sand, it even kills the sand. (...) You know that sand is alive. That sand is good when you pour water the sand absorbs it. But when the sand is dead, if you pour water, nothing moves because the sand has become rotten; it looks like powder. Sand is white but when it dies it becomes black. Babacar January 18, 2020

The fishermen corroborated the existence of a constant background noise that they perceive during their dives, but they gave variable explanations about its origin even if they mostly believed that sea urchins were the source of this back-ground sound. This constant background noise, observed in many temperate marine environments, was described and studied for the first time during World War II from submarines (Everest, Young and Johnson 1948; Johnson, Everest and Young 1947). The background sound has been attributed to a particular shrimp species—the snapping shrimps—that can be found all around the world in waters with depths lower than 55 m and a temperature above 11 °C. Thus, after listening to the crackling recorded in the Almadies, a bioacoustics expert suggested that the sound came from an elevated presence of these snapping shrimps ("a lot of snapping shrimps!," David Mann, Loggerhead, pers. com.). Radford et al. (2008) high-lighted the sound made by sea urchins while feeding. However, these sounds

were more frequent at dawn and dusk; this time-based variability was not reported by the divers in our study. Thus, in line with Coquereau et al. (2016), LEK suggested that these cracklings may be an indicator of the health of marine ecosystems as they become exposed to numerous sources of stress.

3.2. Fish Sounds and Fishermen's Imagery

These crackling sounds now dominate the soundscape, but older free divers recall a time when fish sounds were much more present in the soundscape. Their observations point to the drop in fish abundance, but might not also be a nostalgic expression of a "golden" age? The recordings capture unusual fish sounds, and yet, free divers describe nearly twenty characteristic sounds that are associated with local species. The fish sounds that the free divers describe can be linked to different behavior. Certain species' "vocalizations" can be a bit fear- some and could be related to their reproduction or a way of marking out their territory. One example is the frightening chorus of "Sea Hyenas" [Bukki Geej, wolof/Lebu name, hairy toadfish, *Batrachoides liberensis*, associated with bad hunting conditions and can mark the end of the hunt. However, the causes largely remain a mystery for the divers.

m: The more the sea is murky, the more you hear it. Sometimes there's just one so it makes a noise that can go on for up to 5 seconds. Usually, you hear it when you're between the sand and the rocks. You never hear it on shipwrecks. It can be anytime, but most of all when cold water arrives, around November, December. Maurice, January 10, 2020]

But other divers who identify the species [i.e., Ndiass] say that this chorus is harmless. This harmless fish that emits strange cries between 50 and 700Hz with basic low harmonics between 50 and 150 Hz, gives rise to many comments from free divers, as indicated in Figure 3a. Babacar Sy stated that the sounds made by Hyena fish relate to a social function. He learned to recognize its specific sound by differentiating it from the sound of whales. His observation of Hyena fish enabled him to describe precisely how it makes the sound.

b: It's like a sort of communication between them. But at the beginning, before I understood it was them, I thought they were whales. But later on I realized, by looking through the holes that they weren't whales. I watched how they made the sounds and how they communicated with each other (...). They don't cry by opening their mouth; they do it with their throat. they don't move. You can see them between 4 and 5 m. But you can only hear them during the summer, when there are many of them. That means they communicate (with each other). How? Why? We still have to delve further into this to find out why they do this. But they do it during the summer. (...). The mouth is a little bit bigger but, but apart from that, this fish has a tail like a Guitarfish. It is shaped like the Guitarfish except that its hind tail is a fin, like

a normal fish. Like the White Grouper, it also has two wings on its back. (...) It is not dangerous. It has no teeth; its teeth look they have been filed down. I don't know how it eats, but in general it digs so it can bury itself beneath, or under the rocks. If you don't pay close attention, you won't see it. Many divers won't be able to tell you what it is (...)." Babacar, January 18, 2020

Ndiass heard and identified a Hyena fish during his dive. He pointed out that this fish sound can frighten some inexperienced divers. Ndiass describes the Hyena fish as:

n: ...a yellow colored fish with no scales and is smooth. It is audible from up to 1 km away. They are everywhere, many, and frequent: Yoff, Almadies, Mbour. There are more in Mbour.

Then, there are the predator Goldblotch Grouper or White Grouper, silent in normal times but they give powerful fin blows when attacking or fleeing, generating a specific sound that can be recognized from far away by free divers looking for these prime targets and thus, predators reveal their presence even in murky waters [Maguette Sarr]. For the divers, each fish has a specific sound, and without seeing the fish, the sound indicates that there could be a big fish. For Babacar Sy, "Sounds are very important for hunting" Babacar Sy, September 2021 According to Babacar Sy, swell is a marker for fish arriving that operates like a "bell":

b: It goes like waves, like here; it makes a kind of bell. Then it's the beginning. You tell yourself, 'Oh, today is the start!' and so you see Goldblotch Grouper, White Grouper, Spotted Grouper; stuff like that arrive. That's how it works". With the swell, you can hear different noises under the water, and that, that makes the fish move.

For Babacar, in a calm sea the fish don't move but the swell brings currents that carry fish like Monkfish. In Senegal this common name refers to Tetraodontidae, *Sphoeroides* spp. which announce the arrival of other fish; that's why it is called "the front-runner (or spearhead) fish." He identified many fish species during his dive. He recognized the sound of a Red Cornetfish, which he caught soon after and which makes new cries when wounded by the arrow (see spectrogram in Figure 3c). The sound has the same characteristics in terms of duration and frequency, but it first rises and then falls once the fish is wounded. Babacar later identifies the very discreet sound of an Anglerfish ("an Anglerfish, there you heard one"), which illustrates his acquired competence to perceive and discriminate fish sounds (Figure 3b and c). Even though the sounds made by the Red Cornetfish can be recognized and their identification was confirmed by the video, we weren't able to authenticate this. As Babacar says, the first sound is indeed the cry of the Red Cornetfish, and the second made by the Anglerfish and, even if these two sounds differ, around 100 Hz for the first and 200 for the second, they could actually come from two species.

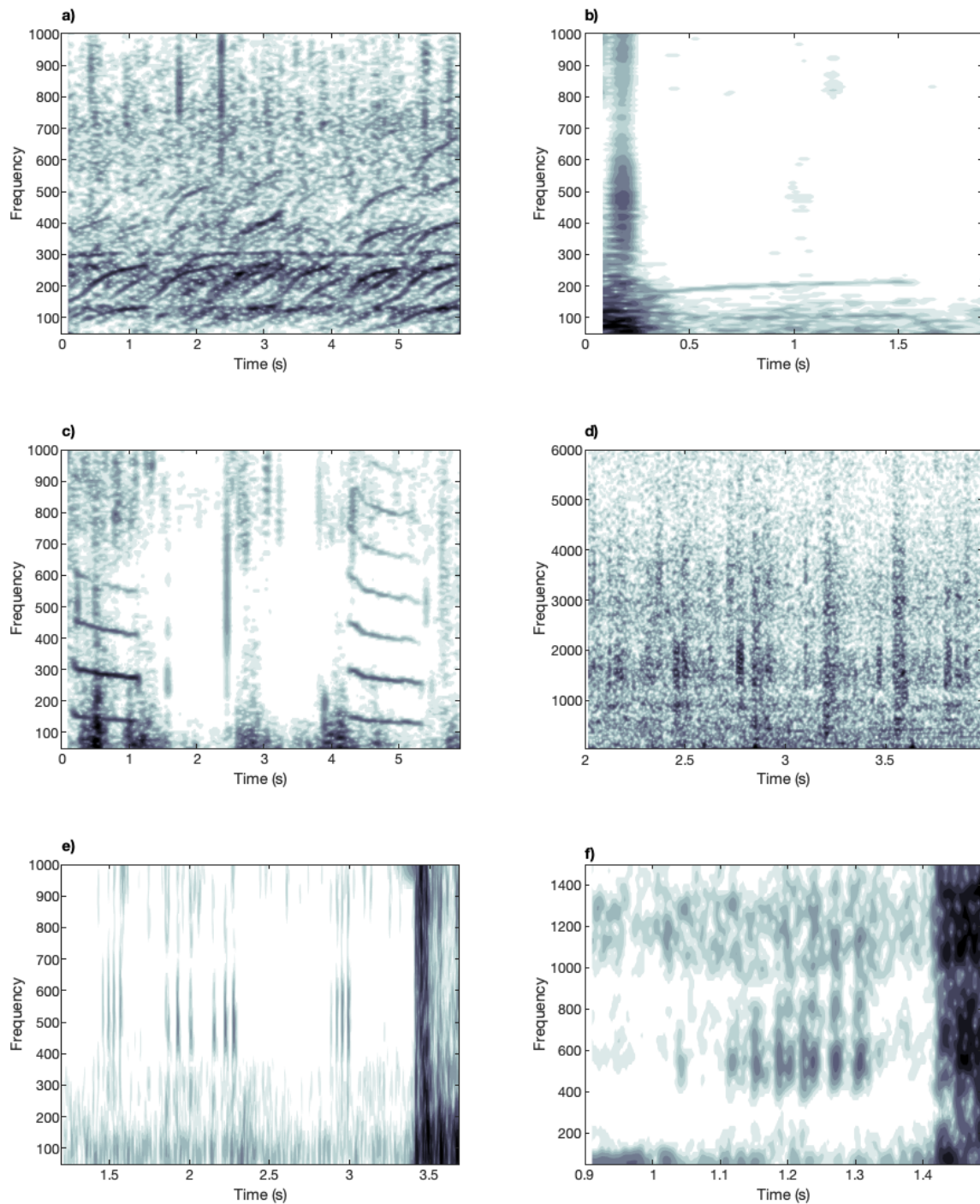


Figure 3: (a) A sound identified by divers as “Hyena fish”—a type of African monkfish. (SOUND 2); (b) A sound identified as an Anglerfish (SOUND 3). The Anglerfish is more audible after application of a low-pass filter at 700 Hz. (SOUND 4); (c) The sound of Red Cornet fish (*Fistularia petimba*, Lacepède, 1803 (SOUND 5); (d) Blackbar Hogfish, grunts are visible on the spectrogram as a succession of vertical (SOUND 6); (e) A sound made by a Caranguidae attempting to escape, visible in the spectrogram between 400 and 700 Hz just before being hit by the spear fishermen’s arrow which triggers the noise visible around 3.5 s (SOUND 7); (f) Babacar shooting a Guinean Parrotfish. The fleeing fish make a sound that is visible on the spectrogram between 400 and 800 Hz for a period of 1.1 to 1.32 s, and the shot is fired at 1.41 s (SOUND 9).

While commenting, Babacar insists on the sound made by the Red Cornetfish:

B: You can hear it up to 10-15 m but you have to listen carefully. This means that, during this dive, someone must have hit a Red Cornetfish, 10-15 m away. If you hit it or if someone else hits it a little further, you hear it, like someone blowing on a trumpet. That's the only fish you can hear from far away, and if they are fighting each other. Babacar, January 14, 2020

Sound emissions made by animals when a predator is nearby or when they are captured are well-observed phenomena, but their function for the fish remains undetermined (Ladich 2022). Maurice, who dives offshore off Gorée Island, identifies the sounds of several Sars, and then some Blackbar Hogfish sounds recorded offshore off Dakar (Figure 3d):

M: That grunt is made by the Vieilles [Blackbar Hogfish, *Bodianus speciosus*, Bowdich, 1825] what we call Parrotfish but you call them Vieilles. I don't know whether they make those sounds with their nostrils or with their teeth. Maurice, January 10, 2020

The spearfishermen identify only a few sounds and fish cries during the experiment. Nevertheless, all their various comments describe an underwater world full of different sounds. They use several onomatopoeias to translate their sounds/cries, giving "voices" to the fish: "tac" (fish running away, C. Touré), "tac-tactac," (Maguette, "small stones near the coastline that move a lot with the waves and they make that noise"), "kékékéké" (C. Touré : Leerfish "there were shoals of 1000 ! You see them and while coming they bring their noise "kékékékékékékékéké"), "cococo" (Babacar: "Look there, that's a Hironnelle [a fish from the Carangidae family]. It's escaping, look... you see? That makes a sound like "cocococo," like a hen. They come at the beginning of the rainy season". This sound of escaping was recorded during the experiment (Figure 3e). Among the fish mentioned by the spearfishermen, there are also the sounds from whales and dolphins they use for herding their prey or for forcing their prey against the edge, depending on the species' hunting strategy. Spearfishermen mentioned a whale sound that was actually recorded by a hydrophone placed offshore of Ouakam and identified by a spearfisherman (SOUND 8). However, this sound is not present in the recorded dives. LEK provides a step forward for identifying fish sounds and associated fish behavior for bioacoustics monitoring of the marine environment (Ladich 2019, 2022). This may contribute to the current development of underwater acoustic monitoring in Senegal (Kammegne et al. 2023).

3.2.1. Fish Behavior

Based on the divers' comments on recorded sounds, this section provides some analytical elements on how divers perceive the behavior of animals in the underwater world. When analyzing fish behavior, Dakar spearfishermen use the language of intentionality and analogy with the human world, thus, they use anthropomorphous categories to be able to construe their

common relationship. By conferring human intentions to fish ("foreign fish," "fish solidarity"), spearfishermen integrate them into a large social inter-species system. Referring to Descola (2005), we can make the hypothesis of the presence of a kind of analogical reasoning, which is combined with other registers (Islamic/technological), when it comes to underwater causalities—establishing connections between things, distinct events and attributing intentionality to animals and fish (See also Simon 2020). Such is the case of the very special type of interaction established between the spearfisherman and the "curious" fish which comes unsuspectingly to stand before the fisherman's harpoon. Here is how Maguette describes the situation about the "guest" fish:

M: When the water is clear, you go down and wait on the rocks, and the fish comes towards you; here people call that a "stranger" fish [wolof, gane, guest]. It doesn't know the area that well, and that's why it comes towards you.

NP: Is it the same word you use when referring to human beings?

OUSSEYNOU SENE (TRANSLATOR/SOCIOLOGIST): Yes. GANE, a guest. He says sometimes you can go to a place where you can find fish. It's their asylum; they've been there for like a year. As soon as they see you, they flee. Although there are other newcomers, he calls other "gane" so I guess it's a shoal of fish or something like that just came in. They don't know the area and so, when they see you, they come to you. So, it's the difference between the fish living in the area and foreign fish. The spear fishermen go to dive in the area of the 'foreign' fish." Maguette, January 16, 2020

Babacar confirms the analogy and the existence of this specific category of fish, "gane," that is recognizable by its behavior:

B: A Thiof comes in front of the loaded harpoon, and looks at it like this. Do you see? But if it's a fish that knows the spear well, it won't wait for you to shoot it. So all this is called, in Lebou "Badèche u gan"[Goldblotch Grouper] or "Thiof u gan" [White Grouper]. Babacar, January 20, 2020

Anthropomorphic projection is directly related to a human-fish interaction, even if it is minimal: proximity/curiosity of the fish and attack. It is part of the scheme defined as follows by Airenti: *Anthropomorphism has two fundamental characteristics: 1. As an expression of a basic teleological thinking, it's a way of representing non-humans by associating them with humans, by attributing perceptions, beliefs, intentions, and emotions to them. 2. It manifests itself mainly during interactions (2012, 46).*

From the social behavior of the fish, the fishermen then extend their representation to their migrations. Spearfishermen have detailed knowledge of the seasonal migrations of fish. According to them several factors explain seasonal variations of fish stocks in Dakar Bay. Ndiass, commenting on his dive,

pointed out the declined fish stock in the sea, and related this to climate change:

N: No fish came in. There are only sea urchins. The noises you hear are made by sea urchins, but there is nothing apart from them. I hope that fish will come in soon. Because during this month of January, we used to catch a lot of fish. But if there is no fish in January, they will come back in February. Every year, there is a delay because of climate change; that's the reason why. But in November we used to catch fish; but you see, now, you won't see fish in November. You won't see fish in December. But in January, yes. Perhaps in January and even in February, because every time there is a delay of a month. Last year we caught fish up to December. It was in December that fish came in here in abundance. You see since December we have been tracking them but we're not able to see them. It's because of the time lag, every year a delay of a month, a bit more than a month or two months.

Babacar uses lunar monthly cycles to evaluate the presence of fish, in respect to the changing tides and sound modifications:

B: As soon as the tide starts to rise, all the animals in the water move. You hear the sounds differently. Seashells, sea urchins, fish... it's like you when you sleep you don't make any noise. As soon as the sea starts to rise there is more noise, and when it starts to fall you hear the same thing. There are moments where noises become much more intense. You can't catch it in the 'normal' calendar, but you can catch it in the Muslim calendar: from the first to the 10th there are no high tides. From the 10th to the 15th high tides begin to rise. 15th, 16th, 17th, the moon is full which means good fishing. Then from 22nd to 26th, there is also good fishing. Apart from that when the moon is in the hole [new moon], it is not good. For example, the 1st day is no good because you can only fish for like thirty minutes; the 2nd day you fish for 60 minutes; the 3rd day is better; the 4th is even better. From the 5th day on it is stable, and so on. Babacar, January 14, 2020

The concept of "gane" (guest/immigrant/foreign) versus local Grouper is in line with previous observations that have suggested the existence of both migrant and sedentary Grouper populations around the Cape Verde peninsula, and thus reinforces this hypothesis (Cury and Roy 1988). The lag of migrating fish arrival in Dakar during the transition between the rainy and cold seasons is in line with recent oceanographic research (Lopez-Parages et al. 2019) that links the migratory behavior of a typical migratory species performing migrations between Senegal and Mauritania (*S. aurita*) to global climate indices. Climate change scenarios generally predict a weakening of the upwelling in Senegal (Sylla et al. 2019); this could further increase the migration lag for the species mentioned by spearfishermen, and, according to the order of migration they



Figure 4: Out of the water. Babacar. January 2022.

describe, some of the migratory species may not reach Dakar anymore.

3.2.2. Fishermen's Behavior

Two different aspects became clear from the commentaries on fishermen's behavior. The first one relates to hunting techniques established specifically in relation to the different underwater animals. The use of lures, particularly sound lures, is common (Artaud 2013). Underwater sound is ambivalent insofar as it can make some species flee while attracting others. Fishing nets make some fish flee by the noise they make "like the sound of a whistle, or the wind blowing through the net." Babacar, January 14, 2020.

If you're under the net, you can't hear anything. It varies if it's a net with or without a buoy. Also, nets that catch Blackchin Guitarfish make more noise because the wire is thick. Nets that are thinner can also make a lot of noise, like an alarm, but you must be far away - 20, 25 or 30 m - to hear it. If there is no current, there is no noise. The noise goes on the side of the current. This noise makes the fish run flee. - Babacar, January 14, 2020

Conversely, spearfishermen can make sounds to attract certain fish species such as the Goldblotch Grouper:

NDIASS: Like goldblotch grouper. Goldblotch grouper, yes, sometimes you make noises. When you make noise, Goldblotch Grouper arrive and come out from of the rocks.

TB: So, you call out to them?

NDIASS: Yeah, you call them. You go like this, you hit the water, you go boom.... And then all the Goldblotch Grouper come out.

TB: And you also hear the noise made by the fish?

NDIASS: You hear it, yes. Even if the water is not clear, if there are fish you hear all of fish noise, everything. You hear everything.

NP: Yes, they're big fish?

NDIASS: Yes, big fish like White groupers, Goldblotch Grouper, Barracudas, like that, Gorean Snapper, yeah.

Babacar Sy described another technique to attract other fish of the same species; here the Bonito are intentionally injured, but not killed.

B: And here, it's a Bonito.

TB: It made a sound?

B: No. It can make a sound "caaan" but they do it if they're in a shoal, not if they're alone. Those are fish you strike on June-July. If you strike one and it's still alive, it can attract other Bonitos. That's why we strike certain fish to attract others. But if you kill them, the other fish will go away. But not all fish do that. Babacar January 14, 2020.

This hunting technique thus takes advantage of a specific behavior observed by the spearfishermen, in which the "alert cry made by the captured fish attracts its conspecifics." An alert cry is a common behavior used to fight predation in animals. It potentially has several possible functions such as attracting conspecifics to allow the transmission of information about a predator. However, scientific information that could describe this type of behavior in fish is lacking (Ladich 2022). Here, the idea of solidarity is pointed out to explain this behavior in certain species. We now move on from the "guest" fish, to the "social" fish who show solidarity, and then the shellfish:

NP: [talking about the Leerfish] And in what context does it make that noise?

B: It's when they are hunting in a shoal. If there are mullets or fish like that. When you strike one it does that, and others will come to help it; it depends on the size. That's why Leerfish like with Bonitos and Amberjack, we strike them, but we don't kill them. We leave them in the water so the shoal doesn't move away, and that way we can have 2-3 fish.

NP: It attracts the others, like for Hironnelles?

B: Yes, it's the same; they provide support to their partners [...] Yes, some fish attract other fish. For some fish, it's to make the shoal stay around you. But you must go very quickly, if you have two harpoons or one harpoon and two arrows, you can get a chance to fix that. But with some fish, it's not even worth it. It's like Lobster and Slipper Lobster. With the Red Cornetfish, if you get one you take it by the tail and you scratch it. You go "kii kii kiii" and all the Red Cornetfish that are around will come out. But if it's a Lobster, once you have the lobster like that, it makes a noise, and the others go away. That's the difference between Slipper Lobsters and Lobsters. Slipper Lobsters show a kind of solidarity but not the lobsters. Once you have a Lobster it goes "kake- keke" like that,....

NP: And the others disappear?

B: Yes. For Slipper Lobsters, if you want to know if there are others, you take a Slipper Lobster, by the tail and you scratch.

NP: And all the Slipper Lobsters come.

B: All of them! Then you let it go and then, when you watch for 5 minutes you see other Slipper Lobsters come out to see what's happening, because one of their companions has a problem, so they come out to look. (...). Lobsters, Bonitos, Hironnelles, Leerfish, ... they do the same thing.

NP: Solidarity?

B: Yeah, solidarity. But other fish, I know, don't do it. White Groupers don't do it, or Spotted grouper don't do it..." Babacar, September 1, 2021

The Dakar Sea is often murky and, in that chiaroscuro world where spearfishermen use the underwater sound dimension to increase their awareness of the environment and to improve the effectiveness of their practice: "You can hear all the fish without seeing them, and it is the sound that gives them away" (Babacar, January 2020). Several videos show that the fishermen shoot and hit prey when they are barely, or not at all visible. They rely on a sensory convergence between the barely discernible movements of the fish and the sound they produce, either by the movement itself or by their cries. This sequence is not really verbalized in the diving commentary but can be identified in the sound recording (the sound made by the fish is immediately followed by the shot, Figure 3f). While underwater sound localization may be harder than in air, due to the higher propagation velocity, psychoacoustic investigations show that experienced divers can develop such an ability (Savel and Drake 2000). Maurice is from Gorée Island and he confirms what Babacar talked about in the interview with regard to sounds, while constantly insisting on the need to listen carefully to the sea. He explains primarily that he has always heard the constant background sound of the sea; a sound he hears even when he's on the boat, and that helps to guide them when searching for rocks or shipwrecks. He then notes that, usually, fish make sounds with their tail when they flee:

If the water is not clear, every time we go down that's the noise we listen for to know if there is fish. The sound of a tail. When you hear it, you must stay still to attract the fish. Maurice, January 17, 2020

These sensory skills have been developed in connection with the properties of the environment and the creatures that inhabit it. The sound dimension is a central element for this specific environment. Free divers rely on their hearing to navigate, and they use some of the sound properties of the fish they know to hunt, thereby entering into their sensory universe. This is in the context, described by Artaud, as "the familiarity of the lure - its inclusion in the sensory world of the creature for whom it is intended - conditioning its success" (2013, p. 9). The second aspect concerns the behavior of the scuba hunters; scuba diving even if prohibited, is a widespread and tolerated practice. For most free divers, quite logically, scuba hunting is a problem. Spearfishing began in the 1970s in Dakar, while scuba hunting began in the 1990s and became concomitant with the increase in industrial offshore fishing. Mamadou Touré has witnessed damage to the underwater fauna that this causes:

- MT: Yes, young people went with air cylinders; they even took the fish habitats - “fishes house” (wolof “keuri diani”), the hiding places used by the fish - the fish holes. They took everything. They removed all the wrecks for scrap metal. There were a lot of sunken boats there, but they removed them. The fish left.
- NP: Ok. And how does it work between those who dive with cylinders and those who don’t? Do they compete?
- MT: Well, young boys saw us catch fish, and there was no work. So, they began to take off the “ker”- the barnacles. They didn’t fish, but then they bought harpoons and they began to fish That was in the 1990’s. Even my grandson... I stopped in 2010, I haven’t touched the sea ever since (...). Yes, it’s over. But there are no fish now. Because the boats came. On the lighthouse, there are fish hiding places, before there was a lot of fish over there.

This type of fishing is also highly criticized because it causes numerous accidents due to decompression, even though the Dakar firemen, among others, regularly organize training sessions. But most of the young people haven’t completed their training, and are likely to take risks for a better and more profitable hunt. “It’s like a drug,” said one of our interviewees. On the contrary, free diving is a “complete sport” [Ndiass] which presents no risks and allows you to stay in good shape. Free diving also gives you a specific hunting technique, confirmed by Babacar, that it is ethical and more respectful of nature (Figure 4):

Hunting is just like going to the forest and hunting animals. What is beautiful is that the fish have time to escape. But if you scuba dive, fish won’t have the time because they see you, escape into their holes and you take them out. That is what is different. Babacar, January 18, 2020.

At the end of the day, anthropophonic effects on the ocean soundscape are not something spearfishermen pay particular attention to, since they only spoke about the passage of a pirogue while listening to its engine in the diving commentary. Nonetheless, Maguette Sarr reported a loud sound emitted by underwater work which caused the fish to flee the area. We know about the harmful consequences that human sonic emissions have on animal sound communication (Butler, Stanley and Butler 2016; Duarte et al. 2021), but this is not in general a dimension that spearfishermen discussed.

4. Conclusion

This was the first attempt to use water-immersive collaborative methodology to gather local knowledge in the research context. Indeed, we did not find a similar methodology in the broader literature. Hind (2015) underlined five phases of collecting LEK. Our approach is close to the one he defines as “rebirth and radicalism ethnography,” that generates qualitative data, but in our case, we used a replicable methodology (the

water-immersive method). Stephanie Merchant (2011) developed a method close to the one we employed, which consists of filming underwater divers, then watching the films with them to study their submarine sensorium. But apart from the fact that the context was very different (underwater leisure), it was not the divers who recorded their own dives and then commented on it in respect to fishing hazards. Analytically, our results contrast with LEK studies about fishermen in two ways: Firstly, we consider greater detail and scale of the description of the marine environment (example: an apnea dive, or a person swimming). Secondly, these results constitute the contents and issues highlighted by fishermen themselves, rather than answers to researchers’ questions. Our water-immersive approach has provided a number of productive insights. First, the descriptions of the dives represent a detailed account of the complex ecological processes that illustrate the dynamics at play on a more all-encompassing scale. These processes concern fish behavior as related to global warming, marine pollution, over-exploitation, and coast-line urbanization issues. In that regard, spearfishermen give promising leads to better describe and understand the effects of these environmental changes with multiple impacts. Pollution is frequently mentioned when describing its chronic impacts on the underwater environment, such as seaweed depletion on fishing spots, that have a direct implication on fish presence. Comments from the divers allowed us to document the existence of increasing time lags in the arrival of fish off the Dakar coast, and modifications in the migration order. Both effects attributed to long-term patterns of climate change. Modifications of fish migration patterns would also be related, according to the spearfishermen, to local practices, industrial and artisanal overfishing, as some of these practices (e.g., scuba diving) lead to the destruction of fish habitats (holes and caves used for shelter, wrecks, etc.). At the local scale, fishermen observe the progression of the city on the coastline—where each square meter is the object of ruthless negotiation for building developments—and under the sea where it extends more and more by means of infrastructure (among which it would be necessary to also count submarine cables) and different types of discharges. This complexity still needs to be thought out in terms of detail and consequence. Concerning acoustic organization of the underwater environment, the tools we used highlighted the existence of a permanent sound layer, which envelops the fisherman and creates a background white noise. Sea urchins and shellfish would generate this. The variations in intensity of this sound layer provide indications on the health of the seabed. They can also be markers that allow fishermen to identify specific locations (rocks, wrecks). The approach of this survey has shown that the most experienced fishermen are able to discriminate very discerningly within this sound envelope, such as the emissions of two types of sea urchins, whereas other younger fishermen purportedly have a less precise idea of what causes this constant noise. This sound background corresponds, in the aesthetic language of sound world analysis, to what the composer and musicologist Murray Schafer (1993) described as keynote sounds. Within this sustained note, divers perceive sound signals that correspond to those emitted occasionally by underwater animals. Hear-

ing keynote sounds does not require much consciousness, whereas listening to signals involves a great deal of attention (Schafer 1993: 10). The latter is a class of sounds that are listened to consciously since they help in hunting in general. In the context of the subsurface Dakar Sea, the fish emit these sounds. As discussed, some non-identified sounds (like human voices) can generate anxiety. On the other hand, other sounds are well-known, and the tools we used led to the formal identification of some fish sounds, such as Red Cornetfish (*Fistularia petimba*) and hypotheses for other fish sounds as the Hairy toadfish (*Batrachoides liberiensis*), Guinean Parrotfish (*Scarus hoefleri*), Blackbar Hogfish (*Bodianus speciosus*), Leerfish (*Lichia amia*), and Anglerfish (*Lophius vaillant*). The description of the underwater marine soundscape by spearfishermen constitutes a contribution to LEK research by providing detailed observations on local processes impacting local fish distribution by water contamination and environmental changes, overfishing and climate change. This LEK can be integrated in academic research conducted on the Senegalese marine ecosystem in the form of working hypotheses and may contribute to the onset of an operational monitoring system of marine biodiversity based on underwater acoustics (Kammegne et al. 2023). This article proposes an original method—the water-immersive approach—for the joint study of underwater ecology and the practices of a specific class of fishermen who involve their hearing combined with other senses in their activity. We presented some of the most salient results of this sonic ethnoecology of the Dakar Sea. We are mindful that this is a very modest part of what remains to be documented and analyzed.

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