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Acoustic monitoring of wetland habitats in dry regions (Kuwait) : bird community dynamics related to migration

Sarah Obaid

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General Introduction

1.1 Arabian Peninsula and Kuwait Importance to Birds

The Arabian Peninsula is considered as a valuable geographical region for biodiversity, especially for birds. The region is situated as a link between three continents: Africa, Asia, and Europe. Its unique location and natural system helped to make it a connection of three biogeographic realms: western Palearctic, Afrotropical, and Oriental (Symes et al. 2015). The different ecosystems that exist along Arabia, make suitable habitats for birds as breeding, wintering and migratory stop-over grounds. Many soaring birds also use the coastline and associated thermals for their migration. Islands are used mostly by breeding waterbirds, while food-rich areas and remote vegetated quiet sites are good places for stop-overs and foraging (Shobrak 2011). Still despite all these biological interests in the region, there is a limited availability of information on temporal and spatial trends in avian diversity.

Kuwait is one of the most important biodiversity areas in the region, with limited studies on bird diversity as well. Kuwait is located at the North-East of the Arabian Peninsula, between Saudi Arabia at its southern borders, and Iraq at the northern side of the borders, sharing marine borders with Iran in the North-East, with the Arabian Gulf on its Eastern side. The Kuwait environment is categorized as a flat desert, covering an area of 17,818 km². However, within this fairly small area, it comprises variable ecosystems, including coastal ecosystems and 9 islands (the largest is named Boubyan), desert ecosystem, farm ecosystem, and freshwater ecosystem (Evans, 1994; Omar et al. 2000) (Figure 1). The deserts display scattered depression which serve as water pools

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during rainy seasons. Water-filled depressions have an important eco-biological value for birds because they attract migratory species.

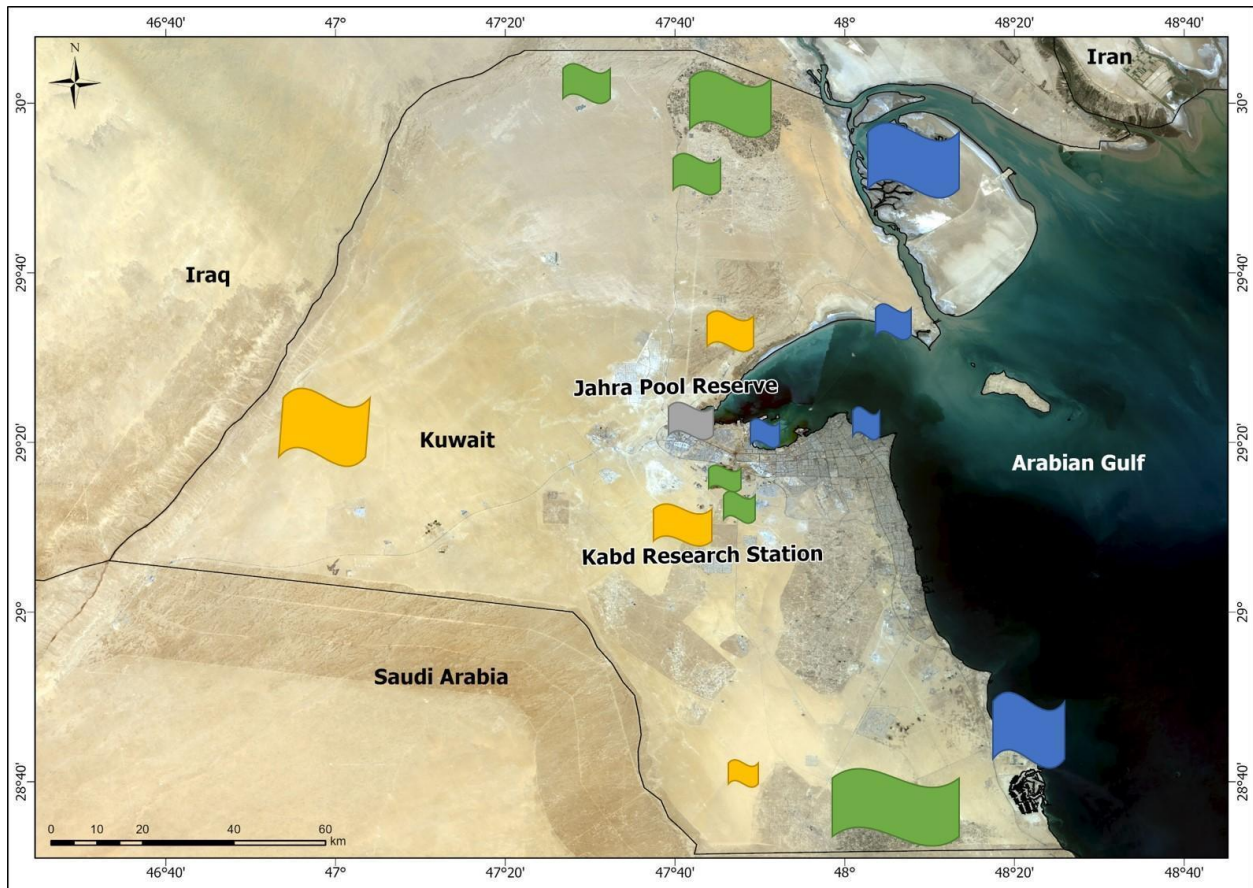


Figure 1. The different ecosystems with bird areas in Kuwait. Blue is the coastal ecosystem, Sulaibikhat bay, Gulf coast, Subiyah, Zour and Khairan. Gray is the freshwater ecosystem in Jahra Pool Reserve. Yellow is the desert ecosystem in Abraq Alhabara, Sabah Natural Reserve, Kabd, Wafra oil field. Green is the farm ecosystem in Abdali farms, Ratqa, Sualibiyah, and Wafra farms. (image from Kuwait Institute for Scientific Research, GIS Department)

There are two main distinguishable climatic seasons in Kuwait, summer and winter, while spring is very short (March-April). Winter in Kuwait is mildly cool, with scarce fluctuated precipitation

averaging 110 mm. The rainy season usually starts in October and can last until May in some years. Although Kuwait is small with relatively severely hot and dry weather, it has a rich avifauna. This is due to its unique location on the crossing of three main migratory routes, with migration occurring during two seasons, spring and fall. This situation results in the hosting of a large number of migratory birds inside Kuwait territories (Jaman and Meakins, 1998). The three migratory routes through Kuwait are generally in either east-west or north-south directions. One of the migration routes that pass Kuwait is from Eastern Europe then Turkey, Syria and Iraq eastwards to Pakistan and India. The second route is from central and southern Russia, then Caspian Sea and Elburz Mountains, down the western side of the Zagros Mountains and central and exceptionally southern Africa (Clayton & Wells, 1987). On the third route, birds come from the Eurasian arctic and tundra to pass through Arabian Peninsula, to reach wintering grounds in the Indian Ocean (Figure 2).

Currently, the list of the birds observed in Kuwait contains more than 400 species, and most of them are migratory. The latest report from Birds of Kuwait Project Team shows that 46 species are resident, which means they breed and can be found along the year in Kuwait. For migratory birds, 293 are passage migrants, 234 are winter visitors, and 85 that are summer visitors - these categories being non-exclusive.

There are some migratory birds which come to Kuwait for breeding, and the number of these birds could reach 50 species, and 12 species are considered rare breeders in Kuwait (Pope & Zogaris (Eds), 2012).



Figure 2. The three main migratory routes that pass through Kuwait. The first route (1) is coming from eastern Europe, passes through Syria and Iraq to end in Pakistan and India. The second route (2) comes from eastern Eurasia through the Caspian Sea and Elburz Mountains, then passes to Eastern Africa. The third route (3) is coming from arctic Eurasia, through the Arabian Peninsula towards the Indian Ocean. (Google Maps).

Birds are a diverse and well-studied animal taxon with representatives in all types of habitats and ecosystems. When bird communities are well characterized in an ecosystem, rich information can be obtained concerning the relative health and productivity of the ecosystem (Venier and Pearce, 2004). Birds can be adequately monitored with standardized methods like point counts, where

every bird seen or heard is recorded by skilled observers or citizens (Venier and Pearce, 2004). Additionally, as the sound is increasingly utilized to identify birds with conventional methods, scientists now use bird sound as an additional tool for birds' surveys, in particular water birds. Automated acoustic recordings are widely used for detecting bird sound for surveys and identification of species (Brandes, 2008).

1.2 Wetland ecosystem in arid regions

Kuwait and most of the Arabian Peninsula suffer from an arid climate where water is the most demanding resource. The scarcity of water has resulted in wetlands being of great importance to people, flora and fauna. Although there are few wetlands in Kuwait, they include the coastline and a freshwater habitat in the Jahra Pool Reserve (Al-Saqer, 2003; Al-Abdulghani, 2013). Other scattered waterholes can be found during the rainy season, but this does not make them wetlands. Farms also have water resources, but are still considered desert habitats.

Wetlands are renowned for their highest levels of biodiversity and biological productivity (Whittaker and Likens, 1973). They provide various functions and processes, such as productivity, biodiversity support, nutrient cycling and water storage. Defining wetlands is yet a challenge due to the high diversity of habitats they include, ranging from inland to seashore ecosystems. In addition to the presence of shallow water or wet soil periodically, wetlands are mainly characterized by the presence of water-adapted plants (hydrophytes), which range from mosses to giant trees, and hydric soil, with biochemical features influenced by anaerobic conditions of flooding (Cowardin et al., 1979). Wetlands are dynamic in water regime and,

therefore, variable in vegetation patterns and birds use (Weller, 1999). They vary predictably and dramatically by season or year and are subject to long-term variation because of large-scale climate patterns and cycles.

1.3 Bird communities as indicators of ecosystem quality

Monitoring of bird distribution and abundance can detect changes in population size and range related to environmental pressures such as habitat and land use changes, climate change, and direct threats (Thuiller et al 2014, Stephens et al. 2016). Also, bird communities' assessment can identify the success or failure of conservation management programs, when species diversity is maintained or enhanced by development (Bibby et al., 1992). Bird species are used as an indicator to represent habitat improvement (Cui et al., 2009). Assessment of habitat quality for birds is done by scientists and specialists from different sectors for a variety of purposes. Some of these purposes are to measure the habitat quality to evaluate the effectiveness of some form of management or wetland mitigation (Weller, 1999). Vegetation structure and food resources are important for the attraction of birds and to enhance their diversity. Birds respond to many of the same environmental parameters as plants do, thus, birds are closely linked with the succession process, regardless of the time frame (Weller, 1999). Aquatic vegetation communities can colonize quickly, thereby providing good shelter conditions and food resources for birds (Cui et al., 2009). Birds are sensitive to environmental conditions (Cardoni et al., 2008). Population size and density are often used as an indicator of good or poor habitat. Also, it is essential to have a measurement of habitat features to correlate with population indices for providing some relative scale of quality (Weller, 1999).

1.4 Ecosystem Monitoring

Monitoring an ecosystem requires several measures that can be categorized into three major ecosystem attributes. These attributes are (1) species diversity; (2) vegetation structure; and (3) ecological processes. Diversity is usually measured by evaluating the richness and abundance of species within multiple trophic levels (Weiermans and van Aarde, 2003). Furthermore, calculating the diversity of species among several functional groups could be beneficial because it gives an indirect measure of ecosystem resilience (Peterson et al., 1998). Vegetation structure is usually determined by measuring vegetation cover (e.g., herbs, shrubs, trees), woody plant density, biomass, or vegetation profiles (Salinas and Guirado, 2002; Kruse and Groninger, 2003). Ecological processes such as nutrient cycling and biological interactions (e.g., mycorrhizae, herbivory) are essential because they provide information on the resilience of the restored ecosystem.

Still, ecosystem monitoring faces real challenges, and these are related to financial budget, time, and availability of trained and educated manpower. It is usually limited by cost, time, and lack of experienced investigators. Furthermore, long –term research is required for the estimation and evaluation of the ecosystem diversity and structure (Ruiz-Jaen and Aide, 2005). That results in the emergence of the need to promote and enhance the monitoring techniques to evaluate and measure species diversity and distribution (Simenstad et al., 2006), yet, with reasonable cost, effort and efficiency. Emerging as a science for the need to understand and investigate the natural sound in an environment and ecoacoustics can offer such monitoring techniques.

1.5 Ecoacoustics technology

Ecoacoustics is the ecological investigation and interpretation of environmental sound.

Ecoacoustics deals with the sound as a subject, and studies its properties, how it evolves, and aims at finding its function in an ecosystem. This discipline considers the sound as an element in the ecosystem, which can provide more understanding of an environment. That means investigating the sound can give knowledge on the dynamics of an ecosystem such as diversity, abundance, even behavior of species (Sueur and Farina, 2015). Recent development in the field of ecoacoustics is giving new prospects for the use of its technology. Ecoacoustics is a science where the soundscape is analyzed in both spatial and temporal scales to help in comprehending biodiversity along with other biological questions.

On the other hand, soundscape is the assemblage of sounds that emanates from a landscape. This assemblage is composed of the vocalization of animal groups (biophony), the sounds from the non-living elements such as wind, water streams and rain (geophony) and the sounds from anthropogenic sources (anthropophony) (Pijanowski et al, 2011).

Monitoring the soundscape using tools offered by acoustic techniques can support ecologists by providing signals that indicate the health of an ecosystem (Laiolo, 2010; Pijanowski et al, 2011). As a result, acoustic indices are developed to be used in identification of the diversity and other ecological aspects such as species assemblage measurement (Sueur et al, 2008; Depraetere et al., 2012). These indices can be correlated with the traditional biodiversity indices.

Acoustic monitoring can be more preferable for research than the conventional methods. First, the data can be collected and analyzed in faster ways. Some ecosystems are difficult to access and navigate through, which limit the ability for repeated visits, such as dense forests, desert, arctic. In addition, the equipment and manpower needed in acoustics technique are less expensive and need less maintenance. Furthermore, acoustic monitoring minimizes the human impact on the ecosystem which in result minimizes the errors. Because of these advantages, acoustic monitoring can cover a wider range of habitats with more efficiency, on a long term scale (Sueur et al., 2008; Barker and Lepper, 2012).

1.6 Bird monitoring efficiency

Bird surveys could be conducted in easy-to-follow protocols, but only by skilled observers, which will eventually offer valuable knowledge about the life of the birds of interest (Venier and Pearce, 2004). For water birds, as of interest in our study, there are several methods to monitor their abundance and diversity, for example, line transect, point counts, boat transects (Weller, 1999). Before the start of any survey, there must be a considerable assessment of a certain technique. First, a planner must evaluate the feasibility of the technique by conducting a preliminary survey. Secondly, an assessment of the habitat must be done to determine the different aspects of the ecosystem, and that will give information on how seasonality and variation of water levels will affect the use of a technique. Thirdly, techniques must be synchronized temporally and spatially so that it can measure the alteration of the phenology of birds' life cycle (breeding and migration). Finally, repeated surveys are essential to assess the accuracy and efficiency of the techniques. In a real research situation, these steps could not be all possible, financially and in time availability.

There are several factors to be considered when choosing a survey technique. These factors depend on the species characteristics and composition in an ecosystem, and how these species would respond to the technique used. Visual counts depend on the visibility of a species, which differ according to seasons and the physical surroundings. Also, the species becomes more secretive during incubation and brood rearing. On the other hand, birds tend to be more obvious during the breeding season when they are displaying and claiming their territories, as this is the period of the highest vocal activities in their life cycle (Weller, 1999).

The vocalization of birds is an important factor in studying birds. It plays a major role during their life cycle, like during breeding, nesting, and predation avoidance. The dawn and dusk chorus are two phenomenal acoustic activities of most birds. Specifically, the dawn chorus is a more prominent feature of birds singing. Dawn chorus is the singing of several bird species after the merging of the sunlight, before sunrise, and continues after sunrise (Staicer et al., 1996). Studies on why birds choose these times for their most energetic acoustic activities showed that this time is characterized by more free acoustic space and less background activities. Therefore, birds spend less energy and effort on singing at these times than other times of the day (Brenowitz, 1982; Brown and Handford, 2003).

These choruses are well studied because most ornithologists benefit from these acoustic events to identify bird diversity in a particular habitat. Research investigations have been done on the factors that stimulate these two features. These investigations showed that several inherent, social, and environmental elements control these chorus activities in birds. Sunrise time is the

most influential factor in the timing of the dawn chorus (Brown, 1963). Sunrise time also could be accompanied by several factors such as light intensity and solar radiation (Thomas et al., 2002). Other factors that could alter the sunlight intensity could also be considered factors that affect dawn chorus. These factors may include cloud cover, rain, and lunar light (Bruni et al, 2014). Anthropogenic activities may also affect the dawn chorus. Some bird species alter their dawn singing activities to be earlier than the start of human noise in the morning (Arroyo-Solís et al, 2013). In the case of insect noise, birds tend to avoid masking their singing by insects' acoustic activities. Birds achieve this avoidance by altering their acoustic signals temporally and spectrally. Birds also use this tactic among birds in their community to overcome acoustic space competition (Stanley et al, 2016).

Therefore, conventional surveys depend mainly on the acoustic signals for many species of birds (Dejong and Emlen, 1985; Brewster and Simons, 2009). So, acoustic recording devices are accompanying the observers to improve the detectability of their survey methods (Klingbeil and Willig, 2015). In a conventional bird survey, the observer uses the acoustic cues emitted by a bird to identify it passively (Rosenstock et al., 2002). But, with the new discoveries in the field of acoustic research, autonomous recording devices can be set in the field and programmed to record in a scheduled and specific regime (Shonfield and Bayne, 2017).

With the rise of acoustic technologies in the field of ecology and ornithology, these techniques are widely used in monitoring and sampling of bird communities. Acoustic techniques have been used in assessing diversity, abundance, distribution, and occupancy (Lambert and McDonald, 2014; Drake et al., 2016). The advantage of repeated surveys made acoustic technology a good

candidate for long-term monitoring research (Furnas and Callas, 2015). Also, this will enhance the use of statistical analysis and reduce the biases of detectability (Royle and Nichols, 2003). Automated acoustic technology gains advantages by eliminating some of the known biases that are associated with the conventional methods.

Where it is difficult for observers to survey nocturnal species, automated technology made it possible to detect these groups of birds (Rognan et al., 2012). Additionally, presence of the observer could alter the bird behavior, scare it away, or disturb it (Gutzwiller and Marcum, 1997; Carey, 2009). So, automated acoustic technology reduces the impact of observers on wildlife, thus reducing the biases caused by observers' presence. The effect of the presence of persons who set the automated recorders is very limited and is temporary. The birds are back to normal after a short period of time and during the recording periods (Shonfield and Bayne, 2017).

Moreover, the resulting data from the automated recording technology can be analyzed multiple times by several experts to ensure the quality of identification and assessment of the ecosystem variables (Haselmayer and Quinn, 2000; Hobson et al., 2002).

1.7 Challenges in survey methods and ecosystems assessment

In conclusion, surveys conducted in wetlands must be feasible in time and cost. Also, the methods need to be used for long periods of time. So, considering bio-acoustic techniques as a tool in these surveys can be very beneficial, as they can provide lots of information for a long time. Besides, they can decrease the time and efforts needed for the purposes of monitoring birds in wetlands.

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Assessment of Kuwait Avian Biodiversity Using eBird Data

1.1 Summary

1.1.1 Context

Kuwait's biodiversity is characterized by a rich avifauna distributed in four main ecosystems, coastal, freshwater, farm, and desert. The high level of bird species richness is due to the unique location of Kuwait joining three migratory routes. Kuwait ecosystems host indeed 350 migratory bird species during their migration journey as passage migrants, seasonal visitors, or breeders. Kuwait also has 46 resident breeding bird species.

1.1.2 Problematics

Comprehensive studies on the distribution of Kuwait avifauna along different ecosystems and the variation of species richness across habitats and seasons are still needed for defining efficient conservation policies

1.1.3 Methods

We used data from the eBird collective platform to conduct a comparative study on species richness over x years and along four habitats representing the ecosystems of Kuwait. We used mixed models and multivariate analyses to assess time and habitat variation.

1.1.4 Main Results

We illustrated the variation pattern of species richness among seasons in different habitats, with higher species richness in March-April, and in September-November. Our results showed a difference in species richness and species habitat preference, where we found that freshwater habitat has the highest species richness among others.

1.1.5 Perspective

These results could be used further to investigate species richness and phenology in different habitats. In addition, the results could be used to compare with results from other survey methods.

1.2 Introduction

The importance of investigating the status of avian biodiversity in any region or country can help understand the nature of the ecosystem and how it responds to various factors such as climate change, desertification, and pollution. This can offer a diagnostic tool for environmental health and give policymakers useful expert advice to make the right decision to overcome ecological problems (Howard et al 1998; Ricketts et al 1999; Franklin 1999; Mac Nally et al 2004). Also, documentation of avian biodiversity is vital for educational and research purposes and can help elaborate Kuwait's environmental image internationally.

There were several continuous surveys of birds in Kuwait. Most of them are done by volunteer groups and local expert birdwatchers. Several of these experts are actively participating in the eBird database by uploading their surveys and records. Most of these census activities occurred in the past six years, linked to the development of the eBird platform (Sullivan et al. 2009). Some historical data goes back to 1975, but these are limited in the number of species and locations. For the purpose of our investigation, we sought to get the Kuwait birds records from the eBird platform, which is an international platform that lends its tremendous records to interested researchers upon request. eBirds are considered a valuable tool in what is called citizen science (Sullivan et al., 2014).

Citizen science is a concept that is increasingly used in the environmental conservation field. It is getting more reputation and significance (Bonney et al. 2009, 2014, Bonter and Cooper 2012, Dickinson et al. 2012, Ellwood et al. 2017). It can be identified as the participation of a common

interested group of people who continuously record wildlife data. These records now can be uploaded in various platforms, where it is used internationally. It is known as being easily accessed with low cost and good quality (Callaghan, 2017; Tulloch et al. 2013, Bonney et al. 2014, Kobori et al., 2016). Most of the common platforms for this kind of data are used in bird monitoring, e.g., Christmas Bird Counts (National Audubon Society 2012), Breeding Bird Survey (Sauer et al. 2015), and eBird (Sullivan et al. 2009, 2014). One of the commonest ways of reporting bird records at a locality is to provide a checklist of observed species. A checklist is a list of bird species recorded during one period of birdwatching (Johnston et al., 2020). On eBird, a checklist is considered as "Complete" if the observer confirms that he/she reports all detected species (seen and/or heard), and not only a group of species (Callaghan et al., 2017). The observers also submit the associated metadata, such as time and date, location, GPS points, habitat, observation effort (time spent at a location), and distance traveled during the observation (Kelling et al., 2018). Also, information includes the survey protocol followed by the observer. Different protocols include "stationary," "traveling," or "exhaustive." Upon submitting all data are reviewed by professional or verified experts (Sullivan et al., 2014). The revision date is also included in the checklists data, which could help the researchers to use only revised and approved data.

Our main questions for this chapter is the estimation of avian species diversity in Kuwait and how they differ among seasons (annual phenology) and spatially among different habitats. The ways to answer these questions must go through estimating the avian diversity in various ecosystems. Then, we must compare several habitats to estimate the species similarity among

them. Finally, we shall find the temporal variation of avian diversity linked to climatic and migratory seasons.

We planned to approach our goals by conducting a comparative study between different habitats during six years by utilizing metadata from the platform eBird. We used the complete validated checklists obtained from various locations in Kuwait after proper processing to achieve the desired amount of data records. These checklists will be used to estimate the species richness and abundance in several ecosystems in Kuwait, namely Coastal, Desert, Freshwater and Farmland ecosystems.

We hypothesize that higher species richness will occur during temperate weather periods in spring and fall, when numerous migratory species cross the country. Higher availability of food, water resources, and breeding shelter resources will attract more migratory birds, increasing species richness.

1.3 Materials and Methods

1.3.1 Data processing and filtering

For this study, we downloaded the Checklist data for Kuwait birds (eBird Basic Dataset version ebd_KW_relDec-2020) from eBird (<http://ebird.org/ebird/data/download>). To further filter the data to the desired level, we used R software, package "auk." The desired level of filtering is to get only complete lists, during the six years period, no repeated lists. We only included the complete checklists using the function "complete." We used the function "unique" to exclude the repeated checklists done by multiple observers (with the same group identifier). Then, we filtered

the data and grouped it into several years and months using the function "date". As we have retained four different habitats in Kuwait (Coast, Desert, Freshwater, and Farms), we divided the checklists according to the locations of these habitats. For each habitat, we chose some locations that represent them. For the Desert we chose Sabah Al-Ahmad Nature reserve, Kabd Station, Lyah, and Abraq. For Farms we chose Abdaly, Jahra, Wafra, Sulaybiah. For the Coast we chose Sulaibikhat Bay, Zour Bay, Kubbar Island, and Boubyan Island. The only Freshwater habitat was Jahra Pool Reserve. Then, we used the filter "date" to divide according to Year and months for each habitat. Finally, we calculated the species richness SR, species Diversity SD, and Evenness. In table 1, we stated the resulted checklists, the number of observers who submitted the checklists, number of observations that been recorded, and the number of species recorded in all checklists for each habitat/year

We noticed that each part of the data (Habitat/Year/Month) has a different number of checklists. So, to standardize the analysis, we set a filter to calculate a minimum number of checklists that were recorded at a location at a certain date.

Table 1. General statistics obtained from analyzing the Kuwait checklists from eBird in four habitats Freshwater, Desert, Coast and Farms, for six years (2015 – 2020). Number of checklists that have been used, number of observers submitting the checklists, and species richness in each habitat/year.

Location	Year	Checklists	Observations	Observers	Species Richness
Freshwater	2015	397	12099	69	256
Freshwater	2016	226	6651	35	242
Freshwater	2017	192	8185	30	233
Freshwater	2018	188	7097	33	239
Freshwater	2019	109	3355	25	214
Freshwater	2020	60	1999	19	184
Desert	2015	341	4782	55	195
Desert	2016	239	2798	33	189
Desert	2017	154	2627	30	189
Desert	2018	135	2888	22	190
Desert	2019	91	1513	35	180

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Desert	2020	91	1688	47	155
Coast	2015	316	5036	51	237
Coast	2016	105	1307	34	196
Coast	2017	118	1818	33	206
Coast	2018	98	1466	34	185
Coast	2019	150	2385	48	182
Coast	2020	67	1168	30	158
Farms	2015	145	2156	40	158
Farms	2016	109	1252	21	161
Farms	2017	204	3318	29	190
Farms	2018	204	3984	37	216
Farms	2019	185	4674	53	218
Farms	2020	168	5604	50	209

1.3.2 Statistical Analysis

We used Linear Mixed Models (LMM) to assess the seasonality of bird diversity in Kuwait, and to study habitat effect on species richness. Our variables were species richness, the number of all species recorded (count), for each habitat (categorical), in each month and year (date) in a complete checklist. For our purpose, we used two R packages: *nlme* (function *lme*) and *lme4* (function *lmer*). First, we filtered the data to delete missing entries, for the months of no data recorded. We made a model with Location and Month as fixed effects, and Year as random effect for all habitats.

We also chose the Non-Metric Multidimensional Scaling (NMDS) as a second analysis tool because our goal was to study whether the different habitat types have different species compositions or not. The variables were the number of individuals of each species (count) of each species (categorical), in each habitat (categorical). A complete list of all species found in all habitats were prepared. In this list, an absence/presence of each species was established in all four habitats in six years. We again performed statistical analyses using the R software, version 3.5.1. First, we created the Sørensen's dissimilarity matrix, using the function *vegdist* from the *vegan* package. Then, we used the *metaMDS* function in the *vegan* package, and tested the stress value. After the stress value and the fit (R^2) showed it had a good fit (stress = 0.06, $R^2 = 0.98$), we plotted out the results to see if there is a difference between the different habitats. Then, to test if the differences were significant or not, we used two testing methods. First, the Analysis of Group Similarities (ANOSIM), using the *anosim* function in the *vegan* package. Second, the

Non-parametric MANOVA (PerMANOVA), using the *adonis* function in the *vegan* package to run the PerMANOVA.

1.4 Results

1.4.1 Seasonality

Using LMM, we found a trend revealing the seasonality of species richness, with a sharp peak for the spring season during March and April, and a steeper peak of species richness in the Fall season starting from late August to November (Figure 1). Also, when we looked at each habitat separately, we found the same trend, but most obvious in freshwater habitat (Figure 2). For all habitats, the output of our model showed that months with significantly different species richness (p -value < 0.001) were March-April (highest values), then September, October, November (high values), then June and July for the lowest species richness (Table 2).

Table 2. The output of the model we made using the Linear Mixed Models LMM.

<i>Predictors</i>	SR_All		
	<i>Estimates</i>	<i>CI</i>	<i>p</i>
(Intercept)	70.79	59.20 – 82.39	<0.001
Location [Desert]	-8.57	-17.53 – 0.40	0.061
Location [Farm]	1.12	-7.69 – 9.93	0.803
Location [Freshwater]	39.61	30.82 – 48.40	<0.001
Month [Feb]	-4.06	-17.17 – 9.05	0.544
Month [Mar]	23.71	10.75 – 36.67	<0.001
Month [Apr]	40.85	27.55 – 54.16	<0.001
Month [May]	1.72	-13.73 – 17.16	0.827
Month [Jun]	-31.85	-51.12 – -12.58	0.001
Month [Jul]	-21.11	-40.42 – -1.81	0.032
Month [Aug]	-3.12	-17.77 – 11.53	0.677
Month [Sep]	21.77	8.64 – 34.89	0.001
Month [Oct]	17.50	4.03 – 30.98	0.011
Month [Nov]	14.56	1.07 – 28.04	0.034
Month [Dec]	-10.87	-24.75 – 3.01	0.125
Random Effects			
σ^2	513.07		
τ_{00} Year	34.57		
ICC	0.06		
N Year	6		
Observations	212		
Marginal R ² / Conditional R ²	0.520 / 0.550		

The resulting graph in figure 3 shows the pattern of species richness and annual phenology of birds in Kuwait. The winter months of December, January, and February have an average species richness of less than 100. During this period, temperatures drop and the rainy season begins. This is followed by the spring months when the desert blooms and temperatures are moderate. As a result, species richness begins to increase to more than 100 species, reaching its highest value in April. This is also concomitant to the large passage of long-distance migrants commuting between Africa, south-east Asia and northern Europe. Then, as temperatures rise, the rainy season ends and the summer season begins. During the summer months from May to August, species richness is at its lowest until it reaches its lowest point in June. Finally, with the improvement of weather conditions, the temperature begins to decrease and the autumn season records a further increase in species richness from September to November.

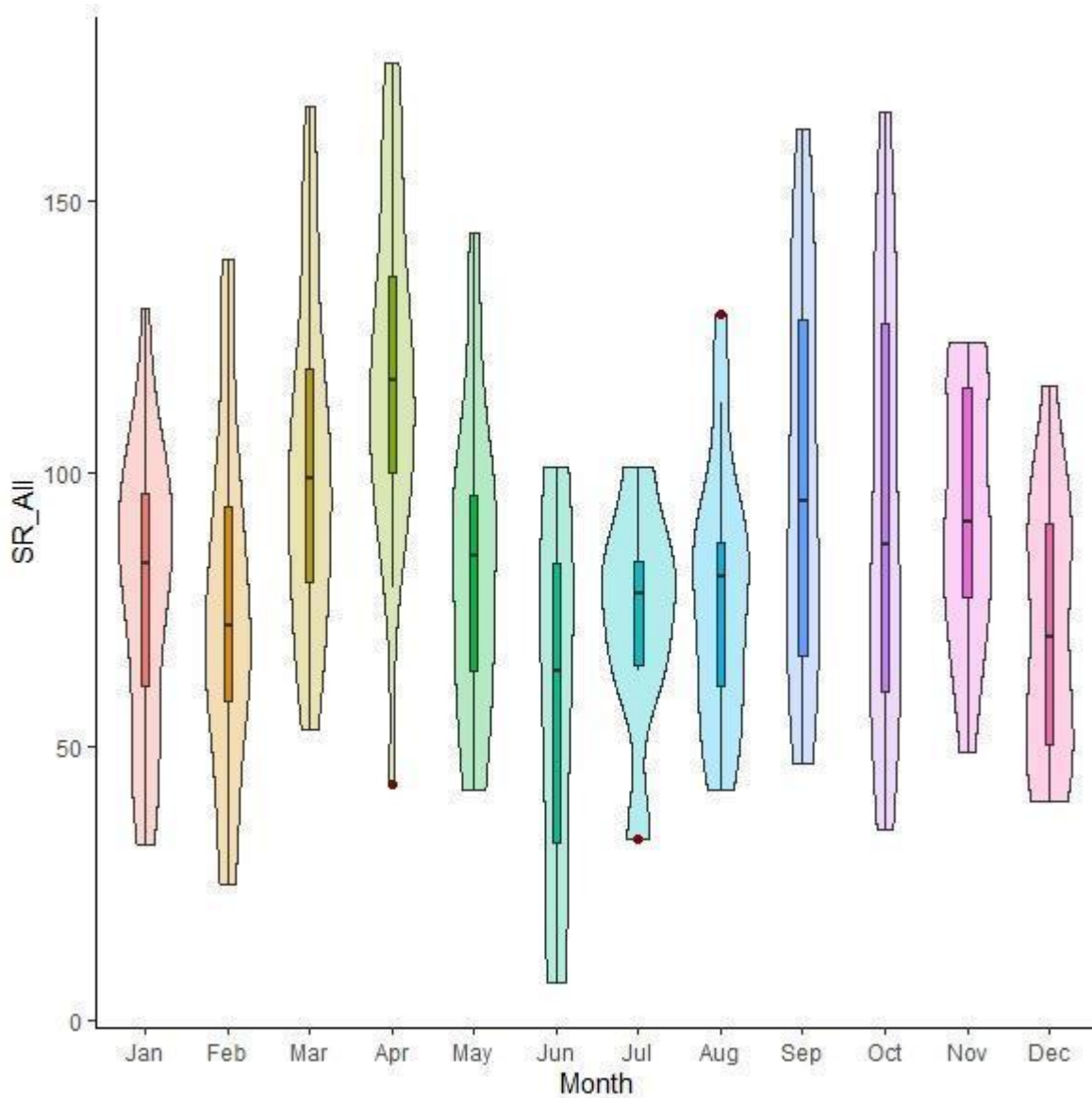


Figure 3. The monthly average Species Richness of Kuwait's birds. Two peaks of species richness SR_{All} , first in March-April, the second in September, October, November.

Figure 4 shows in detail the annual phenology in the different habitats. Although the same pattern of low and high peaks in species richness is found in all habitats, there are marked differences among them. Freshwater habitat had the highest species richness, followed by coastal, farms, and

desert. In the freshwater, species are found in all months and birds are recorded regardless of the season due to the suitable conditions around the water basins. Species are also found in farms in all months. Likewise, Farms have species present in all months. Farms, similar to freshwater habitats, provide good conditions such as water, food, and shelter in all seasons. Thirdly, Coastal habitat possesses more species richness than farms in the spring, unlike the fall months. Coastal birds are more abundant in spring than farm or desert species.

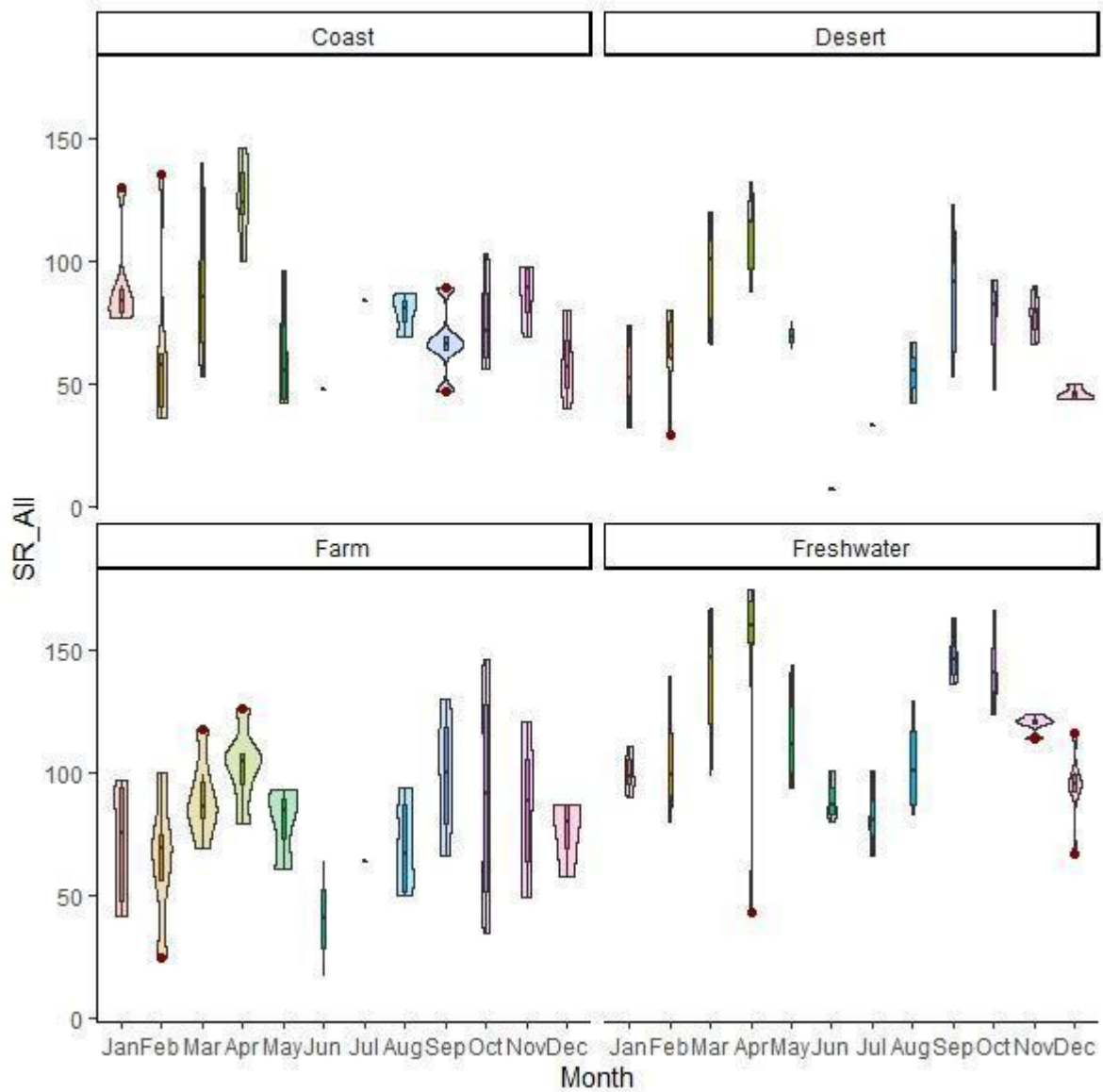


Figure 4. Species richness showed a variation along the year in all habitats. Freshwater habitat displays the most obvious seasonality.

On the other hand, desert species that seek farms and the desert are more numerous than coastal habitat species during the fall season. In the desert, species richness is lowest due to the scarcity of food and water and the harsh climate. In summer, June and July, species richness is lowest

compared to the other habitats. Desert bird species are difficult to see during this time. The high temperatures and sunlight reduce the quality of visibility in the desert. In addition, most desert birds are pale in color, camouflaged with their surroundings, and hide in shelters during the day.

1.4.2 Habitats and Species composition

For habitat effect on the species richness and habitat preferences, our LMM analysis showed that Freshwater is the habitat with the largest species richness. Farm and coast were closer in species richness, but further analysis showed that they differ in species composition. Desert has the lowest species richness (Figure 5). Table 1, showed that freshwater habitat has the most significant species richness with p-value < 0.001.

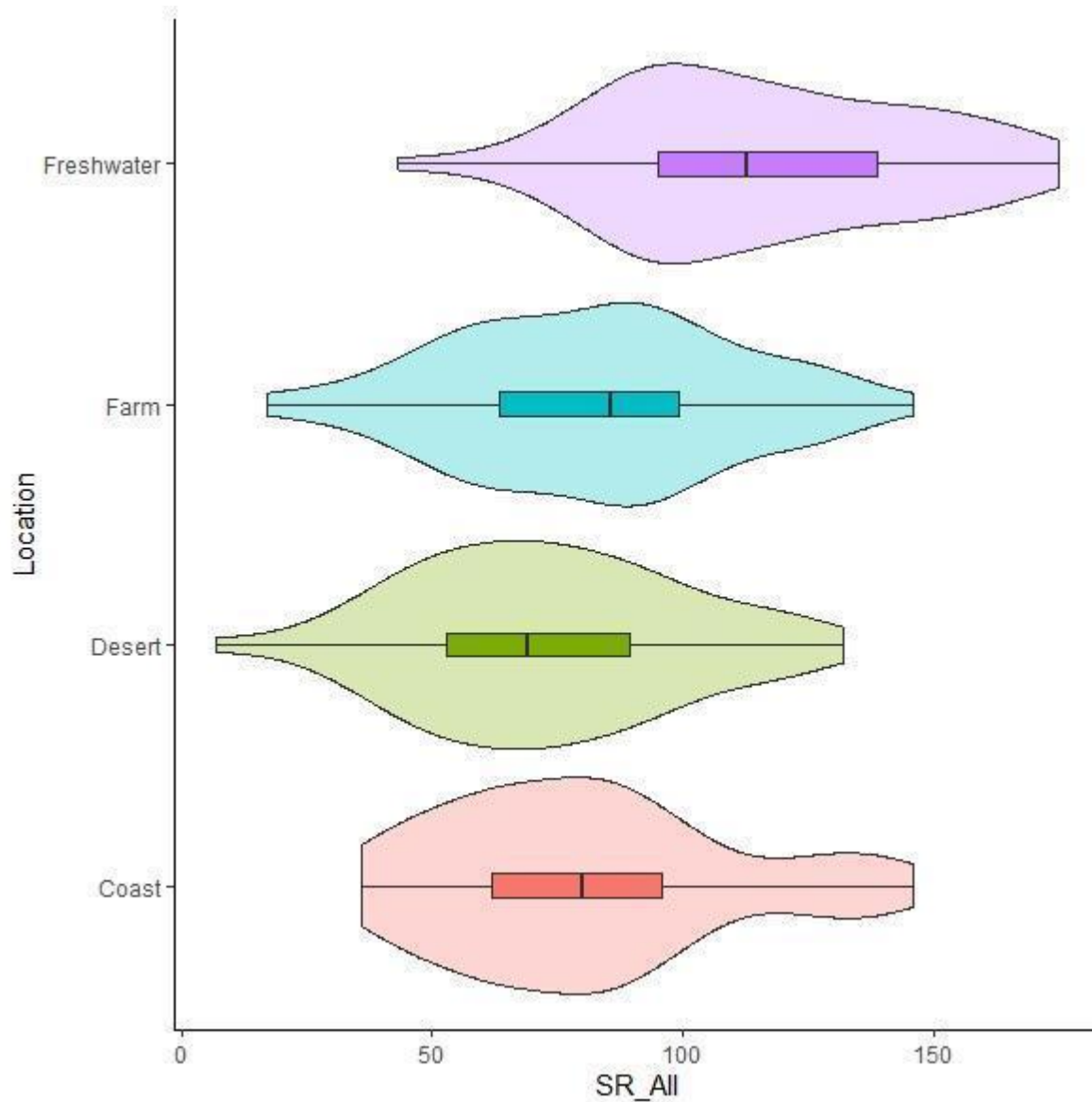


Figure 5. LMM model showed that Freshwater habitat has more species richness, followed by Farm and Coast, and last was desert.

The Non-Metric Multidimensional Scaling (NMDS) was done to investigate the difference in species composition between the four habitats. While testing the significance of differences

between these habitats, ANOSIM test reported in a significant difference with a p-value equal to 0.001, on the other hand, Non-parametric MANOVA (PerMANOVA) test revealed also a significant difference with f-value equals to 0.003. Statistics from the two tests are listed in (Table 3).

The analysis showed that Freshwater and Coastal habitats are close in species composition with more shared species. Farm and Desert habitats are far from these two types of habitats with less shared species. On the other hand, Desert and Farm habitats are closer in their species composition, but also have unshared species (Figure 6). As the results of LMM showed almost equal species richness between Coast and Farms, the NMDS results that they are different in their species composition, with dissimilar species.

For the year's effect, NMDS showed less variation in species composition in Freshwater and Desert. Coast and farms have unified efforts on recording birds and/or submitting checklists.

Table 3. Statistics summary from the Non-Metric Multidimensional Scaling (NMDS) and Non-parametric MANOVA (PerMANOVA) tests.

Test	Statistic R	Significance
ANOSIM	0.83	0.001
PerMANOVA	0.61	0.001

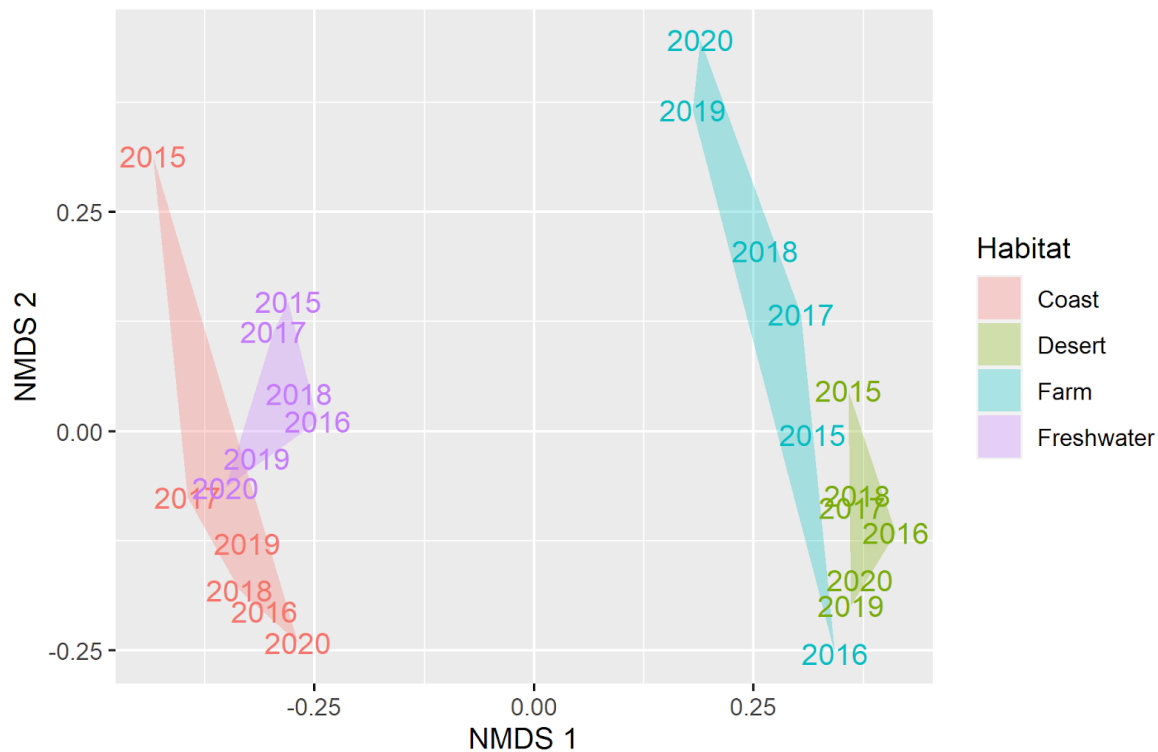


Figure 6. Non-Metric Multidimensional Analysis (NMDS) shows the degree of similarity between habitats, and the change among years. Coast and freshwater habitats are closer in species composition and differ from the desert and farm habitats. While desert and farm habitats are closer in species composition similarity, but not sharing most of their species. Freshwater and desert shows less variation in species composition across the years, while coast and farm species composition varies among years, the year 2015 for coast, and year 2016, 2019 and 2020 in farms.

1.4.3 Seasonal species abundances in different habitats

The Statistical analysis of species recorded in the complete checklists using R packages provides several lists of each habitat in the two migration seasons. The two migration seasons had different characteristics in terms of species composition and abundance. Some species occur only in one season and not in the other. Some species occur in both seasons but in different abundance. These lists are presented in Tables 4 and 5.

Table 4. Kuwait migratory birds During Spring season.

Coast Spring	Cou nts	Desert Spring	Cou nts	Farm Spring	Cou nts	Freshwat er Spring	Cou nts
Black-h eaded Gull	18430	House Sparro w	7240	House Sparrow	19703	Slender-bi lled Gull	10604
Slender -billed Gull	16652	Greater Short-t oed Lark	5360	Barn Swallow	6734	Black-hea ded Gull	10170
Little Stint	11830	Comm on Chiffch aff	3727	Western Yellow Wagtail	3777	Greater Flamingo	9231
Greater Flamin go	6625	Pied Wheate ar	3219	Eurasian Collared -Dove	2544	Barn Swallow	7973
Commo n Redsha nk	4125	Barn Swallo w	2624	Commo n Chiffcha ff	1692	Eurasian Coot	6131
Curlew Sandpi per	3313	Ortolan Buntin g	2559	Red-thro ated Pipit	1589	Bank Swallow	4923
Dunlin	3292	Comm on Redstar t	2399	White-e ared Bulbul	1463	Great Cormoran t	4587

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Broad-billed Sandpiper	3206	Crested Lark	2391	Laughing Dove	1428	Little Stint	4422
Barn Swallow	2543	Isabelline Wheatear	1906	European Bee-eater	1351	White Wagtail	3204
House Sparrow	2540	Western Yellow Wagtail	1878	Collared Pratincole	1141	Black-bellied Plover	3024
Common Ringed Plover	2351	European Bee-eater	1357	Willow Warbler	1073	Bar-tailed Godwit	2623
Lesser Sand-Plover	2250	Willow Warbler	1135	Cattle Egret	1058	Black-winged Stilt	2389
Red-necked Phalarope	2065	Northern Wheatear	1123	Common Redstart	1024	Eurasian Moorhen	2232
Bar-tailed Godwit	2003	Eurasian Skylark	1000	Black Kite	1015	Dunlin	2129
Gray Heron	1832	Pale Rockfinch	957	White Wagtail	899	Ruff	2102

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Black-bellied Plover	1754	Eurasian Hoopoe	922	Bank Swallow	865	Red-necked Phalarope	2007
Pied Wheatear	1735	Black-crowned Sparrow-Lark	911	Ortolan Bunting	828	Eurasian Curlew	1976
Terek Sandpiper	1599	Tawny Pipit	885	Eurasian Blackcap	788	Curlew Sandpiper	1815
Lesser Crested Tern	1416	Eurasian Collared-Dove	860	Pallid Swift	712	Broad-billed Sandpiper	1783
Eurasian Curlew	1330	Eurasian Blackcap	817	Spanish Sparrow	695	Common Ringed Plover	1651
Great Cormorant	1305	Lesser Kestrel	761	Rock Pigeon	628	Garganey	1578
Ruddy Turnstone	1281	Spanish Sparrow	685	Tree Pipit	564	Gray Heron	1566
Isabelline Wheatear	1272	Laughing Dove	685	Black-winged Stilt	499	Squacco Heron	1550

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Kentish Plover	1250	Great Gray Shrike	663	Lesser Whitethroat	463	Eurasian Oystercatcher	1457
White-eared Bulbul	1197	White-throated Robin	612	Crested Lark	458	Terek Sandpiper	1354
European Bee-eater	1084	Black-eared Wheatear	599	European Starling	428	Ferruginous Duck	1322
Western Reef-Heron	1030	Red-throated Pipit	599	Common Snipe	409	Common Greenshank	1247

Table 5. Kuwait migratory birds During Fall season.

Coast Fall	Cou nts	Desert Fall	Cou nts	Farm Fall	Cou nts	Fresh Fall	Cou nts
Dunlin	34137	Greater Short-toed Lark	6578	House Sparro w	33097	Spanish Sparro w	18829
Greater Flamin go	24537	House Sparrow	4768	Eurasi an Collar ed-Do ve	27479	Great Cormor ant	13207
Black-h eaded Gull	18364	Steppe Eagle	3671	Cattle Egret	9097	Black-h eaded Gull	11992
Slender -billed Gull	12882	Crested Lark	3528	White Wagtai l	5673	Eurasia n Coot	10306
Commo n Buzzar d	10133	Common Buzzard	2411	Barn Swallo w	5472	Slender- billed Gull	7430
Little Stint	9922	Eurasian Skylark	2369	Europe an Starlin g	5166	Dunlin	6705
Great Cormor ant	8252	Western Yellow Wagtail	1982	Northe rn Lapwi ng	4257	Blue-ch eeked Bee-eat er	6230

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Gray Heron	7322	Barn Swallow	1324	Blue-c heeked Bee-ea ter	4167	Greater Flaming o	5942
Kentish Plover	4889	Eurasian Collared-Dove	1005	Laughi ng Dove	3515	Eurasia n Moorhe n	5810
Commo n Redsha nk	3256	Spanish Sparrow	996	Black Kite	3210	Bank Swallo w	5503
House Sparrow	3167	Isabelline Wheatear	964	White- eared Bulbul	2826	Gray Heron	4773
Lesser Sand-Pl over	2971	Eurasian Hoopoe	885	Greate r Short-t oed Lark	2402	Eurasia n Collare d-Dove	4425
Lesser Black-b acked Gull	2560	Common Chiffchaff	857	Wester n Yellow Wagtai l	2075	Little Egret	4100
Crab-Pl over	2476	Desert Wheatear	730	Creste d Lark	1855	Little Stint	3796
Eurasia n Curlew	2182	White Wagtail	588	Bank Swallo w	1843	Gargane y	3461

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White-eared Bulbul	1779	Blue-cheeked Bee-eater	577	Rock Pigeon	1809	Barn Swallow	3111
Barn Swallow	1380	Bank Swallow	570	Water Pipit	1326	Kentish Plover	2862
Western Reef-Heron	1372	Water Pipit	557	Pallid Swift	1302	Caspian Tern	2517
Common Ringed Plover	1356	Laughing Dove	552	Namaqua Dove	903	Common Buzzard	2486
Little Egret	1256	Lesser Short-toed Lark	542	Black-winged Stilt	822	Steppe Eagle	2333
Bank Swallow	1245	Rock Pigeon	451	Common Myna	781	White Wagtail	2224
Black-bellied Plover	1196	Spotted Flycatcher	415	White-tailed Lapwing	731	Eurasian Curlew	2114
White-cheeked Tern	1180	Greater Hoopoe-Lark	397	European Bee-eater	658	Little Grebe	2105
Blue-cheeked Bee-eater	1147	European Bee-eater	372	Common Snipe	641	House Sparrow	2053

Eurasian Collared-Dove	1128	Greater Whitethroat	327	Common Wood-Pigeon	616	Black-bellied Plover	1930
Caspian Tern	1047	Eurasian Sparrowhawk	309	Spanish Sparrow	602	Northern Shoveler	1840

1.5 Discussion

The rich avifauna in Kuwait is regularly observed and recorded. There are several means to document birds in Kuwait. Interested birders who continuously record bird occurrence and abundance in Kuwait usually use the platform offered by eBird. This resulted in an enormous amount of useful data that can reveal the distribution and phenology of birds in Kuwait. Analysis of these datasets led to a clearer view of the status of Kuwaiti avifauna, their locations and seasonality.

We found by using the citizen data platform eBird that there are two major peaks of high values of species richness, a first one in Spring, and a second in Fall. These peaks correspond to the migratory activities that are taking place in Kuwait territories. Due to Kuwait locations, many birds visit it en route or for refueling during their migration journey. The main components of Kuwait's avian richness are owing to migratory species. In Kuwait, spring migratory birds seek the opportunity of temporary water patches and the surrounding annual vegetation in the desert for foraging sites and breeding shelters. As the rainy season starts in November, the annual plants

start to grow, bloom, and produce seeds later, approximately in March (Omar et al, 2000). That makes available food for many migratory and resident birds, and makes a good chance for reproduction. This is explained by the fact that spatial and temporal dynamics in migratory behavior is well connected to resource availability (Gauthreaux, 1982).

In our results, we noticed that the Spring season is shorter than the Fall season. This could be due to the fact that water and food are temporary and disappear faster in Spring. It is noticeable that birds migrate between their migratory habitats more rapidly in spring than in fall in several habitats around the world (Curry-Lindahl, 1981; Terrill and Ohmart, 1984). The explanation of a faster and shorter spring migration period could be due to different seasonal nature. For Spring migration, pre-breeding birds tend to follow a time minimizing strategy with maximum speed. This will give a bird species the favorability of getting to the breeding territory faster than the competing species, with more access to the other resources like food and nest building materials (Kokko, 1999). Also, the first arrivals get the opportunity of early mating, and thus, increase their reproductive performance (Moore et al., 2005; van Noordwijk et al., 1995). In addition, early arrival and early breeding will allow sufficient time to raise the hatched and fledging young so they can be strong enough to migrate with the parents (McNamara et al. 1998).

For Fall migration, birds seek the coastal and permanent water bodies. Most of the species are raptors and water birds. Adult birds arrive sooner than followed by adults and juveniles. The increased numbers of migration flocks with juveniles learning to migrate would result in longer stopovers. Therefore, the birds take a little longer to arrive and depart. In the Fall, this period is

characterized by moderate temperatures that could provide good stop-overs from the migratory birds arriving from the cooler upper locations.

Furthermore, habitats differed in their species richness. Freshwater habitats showed the highest species richness among the others. Freshwater wetlands are rare in Kuwait, and the Jahra Pools appear to be Kuwait's first and only official freshwater site (Ashour et al., 2020; Al-Saqr, 2003).

It is characterized by its abundance of food resources and its suitability for birds and other organisms to roost and breed, and therefore has higher biodiversity than the other desert areas in the vicinity. Farms and Coast came after Freshwater in species richness. Coast habitat is rich in bird species because it includes Kuwait Bay, where most of the coastline of the bay is considered a nature reserve, including Jahra Pool Reserve, Sulaibikhat Bay, Jal Az-Zor National Reserve, Al-Doha Nature Reserve, and other private and public coasts with restricted access, such as those of the Kuwait Institute for Scientific Research and Kuwait University (Al-Abdulghani et al, 2013). Regarding wetlands, Bobyan, where access is restricted, is a nature reserve for breeding shorebirds such as Crab plovers, herons, and spoonbills (Bom & Al-Nasrallah, 2014).

Also, Coastal ecosystems in the Arabian Gulf, where Kuwait is located, have six times the species diversity of other offshore ecosystems (Burt, 2014). The area is characterized by extensive tidal mud flats, and the tranquility of the water also makes this a particularly attractive place for birds. Unfortunately, Kuwait Bay has recently been heavily impacted by human encroachment related to the urban development of Kuwait City. As a result, large areas of mudflats used by birds and related species have been lost.

This change in habitat necessitates close monitoring of bird communities. When we look at bird richness in Farms, we could relate this richness to the abundance in food and water resources.

Lower species richness in the Desert is due to the scarcity of food and water and the harsh climate. In summer, June and July, species richness is at lowest compared to the other habitats. Desert bird species are difficult to see during this time. The high temperatures and sunlight reduce the quality of visibility in the desert. In addition, most desert birds are pale in color, camouflaged with their surroundings, and hide in shelters during the day.

For desert birds, reservation and controlled access at several sites in Kuwait had a beneficial effect on diversity. These sites serve as shelter, feeding and breeding sites (Alsdirawi & Faraj, 2004). For example, Sabah Al-Ahmad Nature Reserve provides a home for several wildlife species, including mammals, reptiles, and birds, as it is a well-protected area that denies access to hunters and over-grazers (Nassep et al., 2017). In addition, the Wafra Joint Operation area, also known as a controlled access area, has served the natural habitat well. It became a reserve for different bird species, migratory birds and resident birds (Al-Khalifa et al., 2012). KISR Research Station in Kabd has been a favorable site for desert migratory birds since 1976. The vegetation cover provides good breeding materials, hiding shelters and food resources. There are many watering holes on the site that are used for irrigation of agricultural research projects and also serve as drinking and bathing sources for the birds. (Brown, 2009).

For species composition variation among habitats, we found that Freshwater and Coast were closer in species composition similarity. As mentioned, Freshwater habitat is in Jahra Pool

Reserve (JPR) which is located in Kuwait Bay, a part of the Kuwait coastal area. Many coastal bird species are recorded in JPR. Freshwater-Coast habitats are different in species composition than Desert-Farms. Coastal and Desert-Farm habitats are different and attract different types of birds. Table 2 shows Coast habitats attract more waders, terns, and other water birds that are restricted to coast and shore ecosystems, while farms attract desert birds that seek water and shelter, with few freshwater birds. Farms and Desert are closer in species composition because farms are located near desert areas, and attract desert bird species that seek food, water, and shelter. That resulted in the similarity of species composition between Farm and Desert.

Variations in species composition between years were not the same in the four habitats. The Freshwater habitat had less variation in species composition. Freshwater habitat is found only at Jahra Pool Reserve and is continuously monitored by local managers, who also actively submit their checklists to eBird (personal contacts), along with other interested birders who found JPR to be a very important place for birding. For Desert, the observation effort could be consistent even for interested birders, and the harsh climate and difficult access limit the regularity of visits. Species composition at Coast and Farms varied more from year to year because access to these habitats was limited in 2019 and 2020 due to the lockdown due to COVID -19.

In chapter two, we will use an automatic acoustic monitoring to further study habitat related daily change in species richness in two contrasted habitats, freshwater and desert. The acoustic methods we used provide a full year of data which could overcome the observational bias made

by human observers who conduct surveys only in the preferred seasons and locations, or only in absence of sanitary lockdowns.

In chapter three of this thesis, we will look at the arrival and departure timing of two species. The delicate detection of the first arrival that can be determined by the acoustic techniques can provide the information about the effect of climate change on birds migration in Kuwait and wetlands in dry regions, which will give a better perspective to the nature of bird communities in this complex ecosystem.

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Estimating the acoustic diversity of bird community in freshwater and desert reserves in Kuwait using alpha acoustic indices

2.1 Summary

2.1.1 Context

The study of Kuwait's biodiversity is in continuous assessment. This assessment needs more than the traditional surveying methods to provide a repeatable and objective estimation. Acoustic methods are a vastly growing field in biodiversity studies and can be used in Kuwait's long-term biodiversity assessment. In particular, acoustic indices appear as a promising tool for determining local bird diversity.

2.1.2 Problematics

Bird diversity in two habitats in Kuwait needs to be evaluated more to determine their importance for conservation and biodiversity.

2.1.3 Methods

We deployed automated recording units in six locations, covering six microhabitats in two main habitats in Kuwait, freshwater, and desert. We collected audio files for one year. The audio files were processed and analyzed to find the proper acoustic index that best represents the biodiversity of birds in the studied habitats.

2.1.4 Main Results

We found that the nROI index was the best correlating index with species richness and abundance in freshwater and desert habitats in Kuwait. This index showed six different microhabitats' annual and diurnal phenology of acoustic activities.

2.1.5 Perspective

Our results determined the proper usage of acoustic indices in evaluating bird richness in Kuwait. It could set a protocol to investigate species diversity in other locations and habitats in Kuwait.

2.2 Introduction

There has been a tremendous growth in the need to conduct environmental assessments of various ecosystems worldwide. This growing need requires diversification of research and monitoring methods to overcome the increasing budget and effort required for many conventional research and survey methods (Sueur et al., 2014; Sueur and Farina, 2015). Ecoacoustics is an emerging discipline that can participate in long-term monitoring plans and ecological surveys. Ecoacoustic methods have demonstrated their capabilities in various aspects of ecological and conservation research (Sugai et al., 2020; Schoeman et al., 2022). These methods have been successfully used in assessing species richness, habitat use, mapping habitats, and niches, and studying animal behavior (Kirschel et al., 2011; Celis-Murillo et al., 2009; Sedláček et al., 2015). Birds, whose territorial songs can be identified and detected aurally or automatically (Gasc et al., 2015), are one of the main targets of ecoacoustics.

One of the facilitating elements of the development of ecoacoustics is the availability of autonomous recording units (ARU). These affordable devices enabled researchers to collect acoustic data from a large range of habitats and ecosystems, at different temporal scales, from a few days to several years, according to accurate predefined schedules (Brandes, 2008). These technologies allow researchers to monitor even remote or hard to access places such as desert, dense tropical forests, or deep seas.

Sound plays an important role in the success and survival of various species at different periods of their life cycle. Sound is essential in species recognition being critical in mating choice and reproductive success (Gerhardt, 1994; Höbel and Gerhardt, 2003). Therefore, species identity,

together with social, behavioral and ecological traits, can be detected and analyzed using passive acoustic monitoring (Laiolo, 2010). The ensemble of the sounds produced by an assemblage of species in a certain habitat and at a peculiar time can also be specific and considered as an ‘acoustic signature’ (Farina, Eldridge & Li, 2021).

If recording at a large scale is now ready, there are still challenges to retrieve the ecological information from large audio datasets. To bypass the difficult identification of species singing in complex acoustic environments, ecoacoustics has proposed new metrics consisting in assessing the acoustic diversity of a recording (Sueur et al., 2014; Buxton et al. 2014; Alcocer et al., 2022). These acoustic indices, easy to compute, can help interpreting the acoustic data into ecological meaningful data (Farina, 2019). Because acoustic indices are mathematical functions that reveal the complexity or heterogeneity of a sound sample, any difference in animal diversity or community composition should lead to a change in acoustic signature and, hence, in acoustic indices (Alcocer et al., 2022).

Ecoacoustics relies on converting sounds in audio files from time x amplitude dimensions to time x frequency x amplitude dimensions using the Fourier transform. Acoustic indices can be categorized into intensity indices, complexity indices, and soundscape indices. For intensity indices, the measurement is based on the sound amplitude. Complexity indices evaluate how much a recording is heterogeneous in one or more dimensions. Acoustic complexity indices were developed to indicate species richness and/or abundance. Soundscape indices intend to evaluate

the relative importance of geophony, biophony and anthrophony, the three main components of soundscapes (Farina, 2019).

In the Arabian Peninsula, Kuwait occupies a key position for bird migration, being at the crossroad of three migratory routes over an extremely arid area (Pope & Zogaris (Eds), 2012). In 1987, Kuwait artificially created wetlands as major resting sites for both resident and migratory birds (Ashour et al., 2020; Al-Saqer, 2003). However, the spatial and temporal dynamics of these bird populations in relation with climate and migration are still unknown. Fundamental ecological information is then crucially missing for appropriate national conservation decisions.

Here, we deployed ecoacoustic methods by freshwater and desert soundscapes to assess bird acoustic diversity changes over a complete year in Kuwait. Using a recently developed acoustic index, we could estimate, compare and visualize the acoustic seasonality of six bird acoustic communities.

2.3 Material and Methods

2.3.1 Study Sites

An artificial freshwater site with four sampling points (Jahra Pool Natural Reserve) and a desert site with two sampling points (Kabd KISR Research Station) were both monitored. Each recording point corresponded to a specific microhabitat.

2.3.1.1 Jahra Pool Natural Reserve

Jahra Pool Natural Reserve (29.3659, 47.6927) is considered as the first freshwater wetland reserve in Kuwait. It was declared as a natural reserve in 1987, under the management of the Environment Public authority in Kuwait. The total area of the main reserve was initially 2.5 km², expanded to 18 km² in 2016. The reserve, which was created by the effluent of the tertiary treated water coming from the treatment plant in Jahra City, is composed of several freshwater ponds surrounded by reed beds. Consequently, the place became a major attraction for resident and migratory birds, where they could find shelter, foraging and breeding sites. The reserve management now maintains the ponds with regular water income to keep it in a sustainable status. The size of the ponds fluctuates according to season and precipitation, with a reduced size during the dry season, that is between June and August. The vegetation cover includes perennial and annual desert plants, some halophytes, and plantations of trees such as acacias and willows. The community of birds consists of sea birds, freshwater birds, waders, desert birds, and raptors, for a total of 320 species. The reserve is also inhabited by mammals, reptiles, insects, and amphibians (EPA report 2020, Ashour et al., 2020).

2.3.1.2 Kabd KISR Research Station

Kabd Kuwait Institute for Scientific Research is a research station that was established in 1978 as the start of a field study project on management plan for the usage of natural vegetation at the site for animal production (Omar, 1991). The station, which is dedicated to agricultural and environmental studies, is located south-west to Kuwait City (29.1753, 47.7360) and occupies 40

km² of land. Access to the station is restricted only to research purposes giving a good opportunity for wildlife rehabilitation being now transformed into a nature reserve. The reserve consists of a desert ecosystem. The dominant vegetation consists of *Rhanterium epapposum* and *Cyperus conglomeratus*. Vegetation cover also includes several perennials and annuals. These plants provide a suitable shelter for migratory and resident birds. The station is inhabited by many reptiles and insects, and few mammals like the desert fox and desert gerbils (Omar et al, 2000; Brown, 2009).

2.3.2 Sampling design

2.3.2.1 Recordings

Soundscapes were recorded with digital audio field recorders (Song Meter SM4, Wildlife Acoustics, Inc., Concord, Massachusetts, USA). The recorders were set to record stereo .wav files at a sampling rate of 44,100 Hz. The gain of the left and right microphones was set to +16 dB and +24 dB respectively so that different dynamics could be obtained. The pre-amplifier gains were set at +26 dB.

The spatial design was specific to each site due to different landscapes. In Jahra, four recorders were installed, one in each main microhabitat, that is (i) coastal (J1), (ii) transition between coastal and freshwater (J2), (iii) freshwater (J3), and (iv) desert (J4) (Figure 7). In Kabd, as the environment was more homogenous, only two recorders were installed in the middle of the protected area, but in two distinct microhabitats, an *Eucalyptus* sp. tree (K3) and open vegetation (K5) (Figure 8).

In both sites, the distance between the recorders was at least 500 meters so that pseudo-replication was avoided (Hauptert et al., 2022). The recorders were positioned to avoid

road noise as much as possible, oriented in the same direction, the left microphone pointing towards North-West (90°), and installed at the same height (1.5 m). The recorders were programmed to record during dawn and dusk choruses and during the night when migrating birds fly over the sites and produce night calls. During this period, the recorders recorded two minutes every ten minutes (2' on, 8' off). All recorders started on the 26 of July 2020 and worked for a complete year. This sampling led to a total of 6,600 h, 4,400 hours for Jahra site, and 2,200 hours for Kabd site. Due to some equipment failure, 13% of the recordings were missing so that a total of 6,739 hours were obtained, 4,393 hours for Jahra site, and 2,346 hours for Kabd.

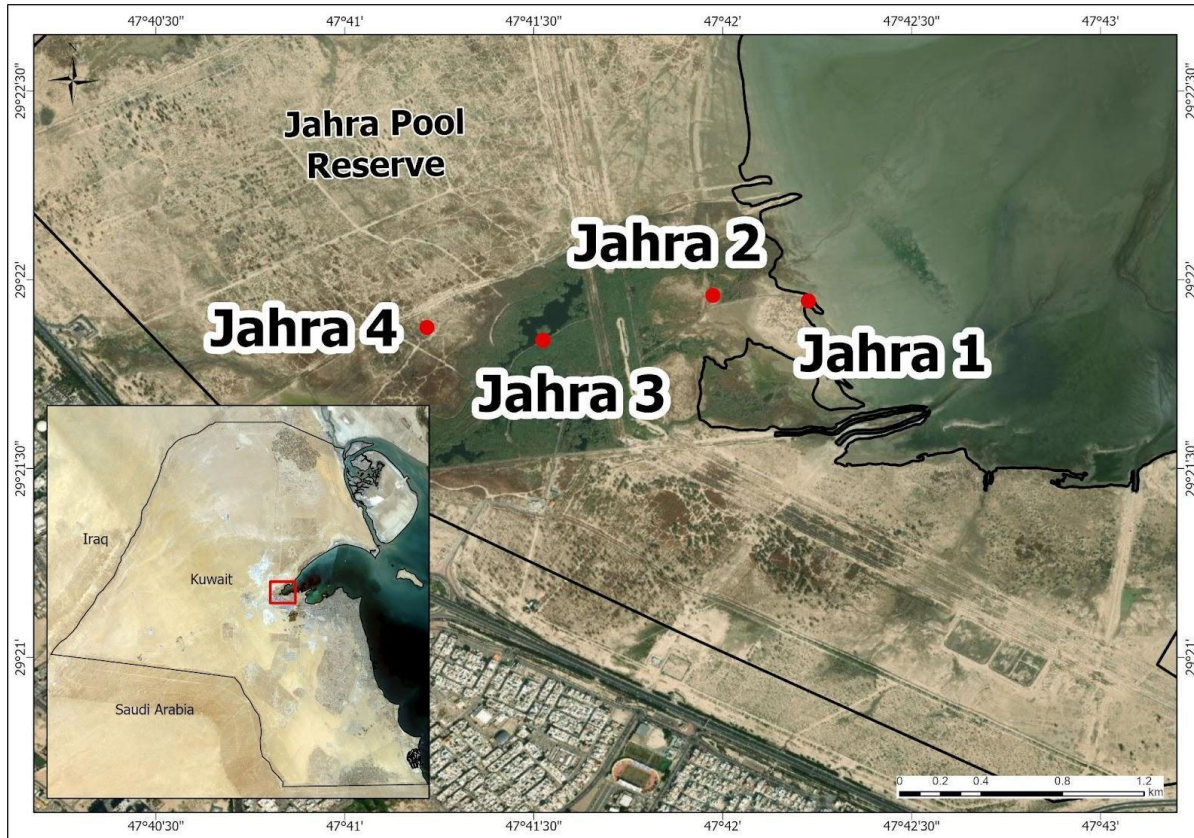


Figure 7. Freshwater site: Jahra Pools (1km x 2km), transect of four recording sites equipped with autonomous recorders (Wildlife SM4) separated by at least 500 m, (1) seashore (J1), (2) transition between coastal and freshwater (J2), (3) freshwater (J3), and (4) desert (J4). (image from Kuwait Institute for Scientific Research, GIS Department)

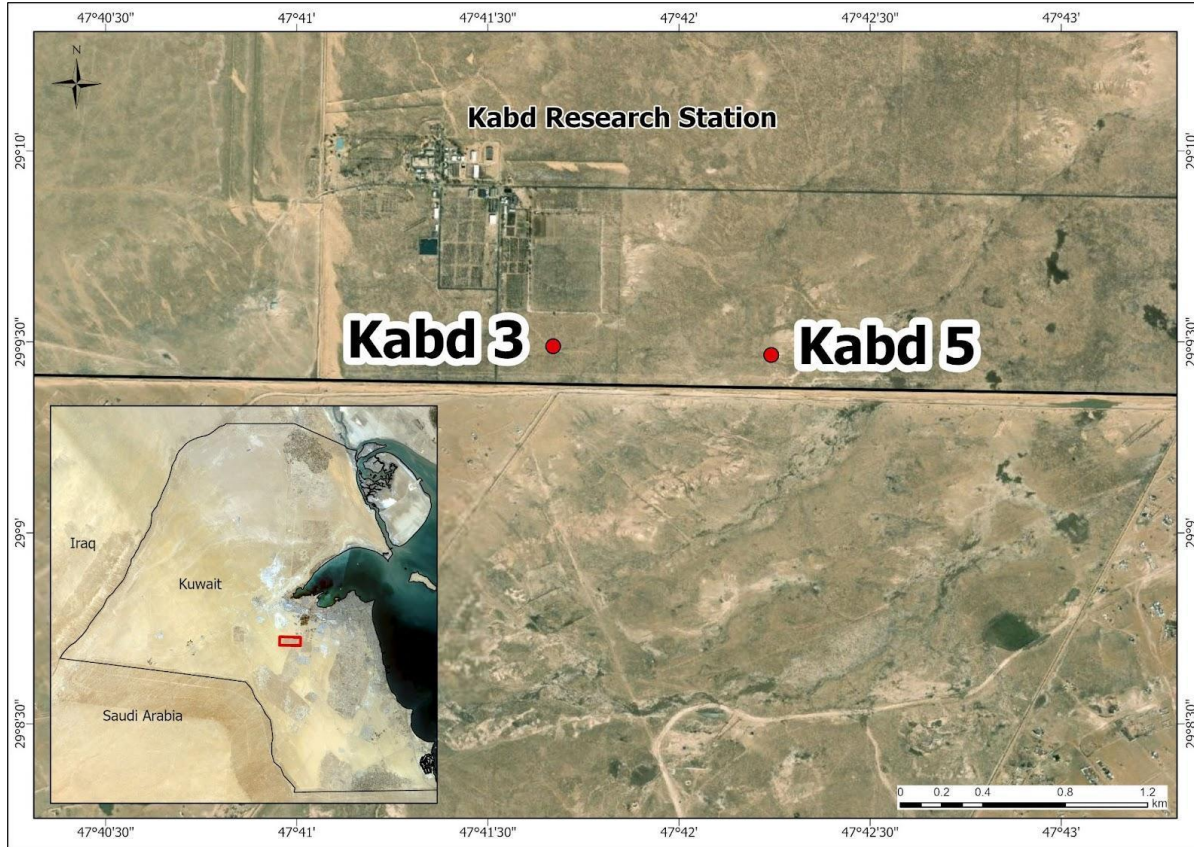


Figure 8. Desert site: KISR Research station at Kabd, two recording sites (SM4 autonomous recorders) separated by 500 m inside the protected part of the station, on a tree (K3) and in the open desert (K5). (image from Kuwait Institute for Scientific Research, GIS Department)

2.3.3 Data processing

2.3.3.1 Subsampling

To test the validity of the acoustic indices, we selected a representative subsample of the audio files dataset for manual annotations. We selected files from two hours before sunset, and two hours after sunrise. Then, we randomly selected two 15-second audio files from each hour so that we obtained 8 files per day.

2.3.3.2 *Manual annotations*

Each 15 second audio file was screened out by one of us (SO) with the software Audacity v2.3.2 (Audacity Team, 2019) with the following settings: 0-10 kHz linear frequency scale, 1024 sample window size, Hann tapering window, 10 dB gain, 69 dB range, dark theme. All bird sounds (calls and songs) were framed in time and frequency using the annotation tool. Labeling was made by selecting a bounding box in the time-frequency domain (i.e., spectrogram) for each bird song signature. This annotation was either identified with a species name (strong labelization) or with an alphabetical letter (weak labelization) when identification was not possible. All other non-birds' sounds were also annotated such as dog barking, human voice, insects, plane, or running water. A latin letter (i.e., label) was given to similar acoustic signatures.

From the label text files associated with all audio files, we selected the labels corresponding to bird songs and ignored all others. We then obtained the acoustic abundance as the total number of labels, and the acoustic richness as the number of unique labels.

2.3.3.3 *Automatic indices calculation*

Sixty-two indices were computed on the subsampled audio files using the Python package scikit-maad (Ulloa et al., 2021) (Table 6). Among these indices, two recent indices, nROI and aROI, were used (Targowla et al., in prep). These indices are based on the delimitation of regions of interest (ROI) in the spectrogram after removing stationary background noise. The index nROI counts the number of ROI found in a recording when the index aROI calculates the percentage of the total area of the spectrogram covered by the ROIs. The delimitation of the ROIs was operated

by (1) subtracting the stationary background noise with a median equalizer function, (2) rejecting ROIs with an area smaller than 0.1s x 100Hz or larger than 0.1s within the frequency band 1289 Hz-5068 Hz which corresponded to the inter-quartile range of the frequencies used by birds as estimated with manual annotations, and (3) rejecting the ROIs with a ratio frequency / duration superior to 10. These selections allowed to exclude short and wide or long and thin bounding-boxes that were mostly due to noise (wind, rain). Both nROI and aROI indices were calculated for three specific frequency bands corresponding to three different soundscape sections: (1) a low frequency band (0–1256Hz) that was a mix of anthropogeny (human voice, vehicle noise), geophony (wind), and a part of biophony (amphibians, insects and a few birds as the Eurasian Collared Dove), (2) a middle frequency band (1256 — 5224 Hz) that corresponded to biophony dominated by birds and with a few insects, and (3) a high frequency band (5224 — 15000 Hz) that included insect biophony.

Table 6. List of 62 indices computed for correlation with species richness and abundance derived from manual annotations (Ulloa et al., 2021).

Index	Name	Main reference
ACI	Acoustic complexity index	Pieretti et al. (2011)
ACTspCount	Spectral activity count	Towsey et al. (2017)
ACTspFract	Spectral activity fraction	Towsey et al. (2017)
ACTspMean	Spectral activity mean	Towsey et al. (2017)
ACTtCount	Temporal activity count	Towsey et al. (2014)
ACTtFraction	Temporal activity fraction	Towsey et al. (2014)
ACTtMean	Temporal activity mean	Towsey et al. (2014)
ADI, AEI	Acoustic diversity index	Villanueva-Rivera et al. (2011)

AEI	Acoustic evenness index	Villanueva-Rivera et al. (2011)
AnthroEnergy	Energy of the anthropophony	Kasten, et al. (2012)
aROI	area covered by spectrogram regions of interest	Targowla et al., in prep.
BGNf	frequency background noise	no reference
BGNt	temporal background noise	no reference
BI	Bioacoustic index	Boelman et al. (2007)
BioEnergy	Energy of the biophony	Kasten, et al. (2012)
EAS	Entropy of average spectrum	Towsey et al. (2017)
ECU	Entropy of spectral variance	Towsey et al. (2014)
ECV	Entropy of the spectrum of coefficients of variation	Towsey et al. (2017)
EPS_KURT	Kurtosis of spectral maxima	Towsey et al. (2014)
EPS_SKEW	Skewness of spectral maxima	Towsey et al. (2014)
EVNspCount	Spectral event count	Towsey et al. (2017)
EVNspFract	Spectral event fraction	Towsey et al. (2017)
EVNspMean	Spectral event mean	Towsey et al. (2017)
EVNtCount	Temporal event count	Towsey et al. (2020)
EVNtFraction	Temporal event fraction	Towsey et al. (2020)
EVNtMean	Temporal event mean	Towsey et al. (2020)
H_gamma	Gamma frequency entropy	Zhao (2010)
H_GiniSimpson	Gini-Simpson frequency entropy	Zhao (2010)
H_Havrda	Havrda-Charvat frequency entropy	Zhao (2010)
H_pairedShannon	paired Shannon spectral entropy	Zhao (2010)
H_Renyi	Renyi frequency entropy	Zhao (2010)
Hf	Frequency entropy	Sueur et al. (2008)
HFC	High frequency cover	Towsey et al. (2017)
Ht	Temporal entropy	Sueur et al. (2008)
KURTF	frequency kurtosis	no reference

KURTt	temporal kurtosis	no reference
LEQf	frequency continuous equivalent sound level	no reference
LEQt	temporal continuous equivalent sound level	no reference
LFC	Low frequency cover	Towsey et al. (2017)
MEANf	frequency mean	no reference
MEANt	temporal mean	no reference
MED	temporal median value of the envelope	no reference
MFC	Mid frequency cover	Towsey et al. (2017)
NDSI	Normalised Difference Soundscape Index	Kasten, et al. (2012)
NP	Number of frequency peaks	Gasc et al. (2013)
nROI	number of regions of interest (ROIs) in the spectrogram	Targowla et al., in prep.
RAOQ	Rao's quadratic entropy	Botta-Dukat (2005)
rBA	biophony/anthropophony ratio	no reference
ROU	roughness of the spectrogram	Ramsay & Silverman (2005)
SKEWf	frequency skewness	no reference
SKEWt	temporal skewness	no reference
SNRf	frequency signal-to-noise ratio	no reference
SNRt	temporal signal-to-noise ratio	no reference
TFSD	normalized time and frequency second derivative	Aumond et al. (2017)
VARf	frequency variance	no reference
zVARt	temporal variance	no reference
ZCR	zero-crossing rate	no reference

2.3.3.4 Correlation between manual annotations and automatic acoustic indices

We estimated the reliability of the indices for the estimation of acoustic diversity by computing the non-parametric Spearman correlation between acoustic abundance/richness found with manual annotations and acoustic indices.

2.3.3.5 Comparison between nROI and ACI index

We compared the results of nROI with the Acoustic Complexity Index (ACI) which is one of the most popular ecoacoustic index (Alcocer et al., 2022). ACI is a derivative of the energy of the spectrogram along the time axis, frequency by frequency band (Pieretti et al, 2011). It is sensitive to the amount of frequency variation along the time axis. ACI is then normalized to the average sound energy. Bird songs produce large energy variations that should yield a high ACI value, while a stationary sound, such as continuous insect stridulation, should yield a low ACI value.

2.4 Results

2.4.1 Manual annotations

The results of the manual annotations on the subsample are provided in Table 7. The distribution of the resulting species abundance and richness is indicated in figure 9 and 10. Acoustic abundance was higher in Jahra, the median ranging from 7 to 11, while in Kabd the median ranged from 0 to 1. Acoustic richness was also higher in Jahra with a median ranging from 3 to 5 different sounds than Kabd with only 0 to 1 different sounds.

The soundscape of Jahra was dominated by birds with 85% of the audio files including birdsongs and covering the frequency bandwidth from 703 Hz to 5341 Hz. The soundscape of Kabd was

mainly occupied by noise, with from 92% to 96% of the annotated audio files containing noise. Insect sound accounts for 18 to 29% of the audio files in J2, J3, and J4, but only 2.6%, for J1, a value close to those observed in Kabd where they reached 2.7% and 2.2% respectively. Insect sound covers a bandwidth from 1,420 to 9,886 Hz in Jahra and a bandwidth from 186 to 9,677 Hz in Kabd.

In Jahra, with the exception of J4, the frequency centroid had a bimodal pattern, with the first mode around 2,500 Hz corresponding to bird sounds and the second mode 3,800 Hz corresponding to insect sounds (Figure 11). In the desert sites (J4, K3 and K5), the distribution of the frequency centroid was unimodal with a peak at around 3,900Hz due to birds

The distribution of minimum and maximum frequencies was bimodal for birds, with two peaks for the minimum frequency (around 800 Hz and 2000 Hz) and two peaks for maximum frequency (around 3500 Hz and 5000 Hz) (Figure 12). The two peaks of the minimum and maximum frequencies of the birds in Jahra were outside the range of the two frequencies of the insects. More specifically, there was a large low frequency peak for birds around 800 Hz in case of J2 and J3. The same bi-modal repartition of minimum and maximum frequency was observed for insects, with two minimum frequency peaks around 500 Hz and around 4000 Hz and two maximum frequency peaks around 3500 and 6500 Hz. However, the frequency range of insect sounds in J2 and J3 was wider than in J1. In J4, the desert section of Jahra, the peaks of the maximum frequencies of the bird sounds overlap with the peaks of the insect sounds. In Kabd, the minimum and maximum frequency peaks almost coincide with the peaks of the bird sounds.

There was a group of bird’s call/song in K3 at very low frequency below 500 Hz, very distinct to the other group which is slightly higher than for Jahra.

All together, these results indicate that each recording site had a specific soundscape composition and there was a similarity between the desert site of Jahra with both Kabd sites.

Table 7. Manual annotations. Descriptive statistics of the manual annotations achieved on the sub-sample dataset. For each variable the sample size (n), and specific percentiles are given. J and K refer to Jahra and Kabd sites respectively.

	J1	J2	J3	J4	K3	K5	all
Number of total files (2 minutes length)	33491	34169	32048	32096	33129	37261	202194
Number of annotated files (15 seconds length)	576	544	512	504	441	495	3072
Acoustic abundance							
Maximum (90% percentile)	22	23	20	19	10	9	19
Median (50% percentile)	11	9	11	7	1	0	6
Minimum (10% percentile)	1	0	2	00	0	0	0
Acoustic richness							
Maximum (90% percentile)	8	8	9	7	3	2	7
Median (50% percentile)	4	4	5	3	1	0	3
Minimum (10% percentile)	1	0	1	0	0	0	0
Bounding-box birds							
Number of annotated files with birds	535	471	495	422	249	205	2377

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75th percentile of maximum frequency	5312	5107	4990	5341	5888	5078	5224
25th percentile of minimum frequency	1582	1139	703	1884	2041	2314	1256
Bounding-box insects							
Number of annotated files with insects	15	101	142	146	12	11	427
75th percentile of maximum frequency	8012	6964	9886	7685	6247	9677	8095
25th percentile of minimum frequency	1420	3461	4960	3050	490	186	3330
Bounding-box noise (annotations)							
Number of annotated files with noise	238	468	420	387	407	480	2400
75th percentile of maximum frequency	3532	8200	9592	6657	9494	3681	8828
25th percentile of minimum frequency	114	145	127	166	302	144	162

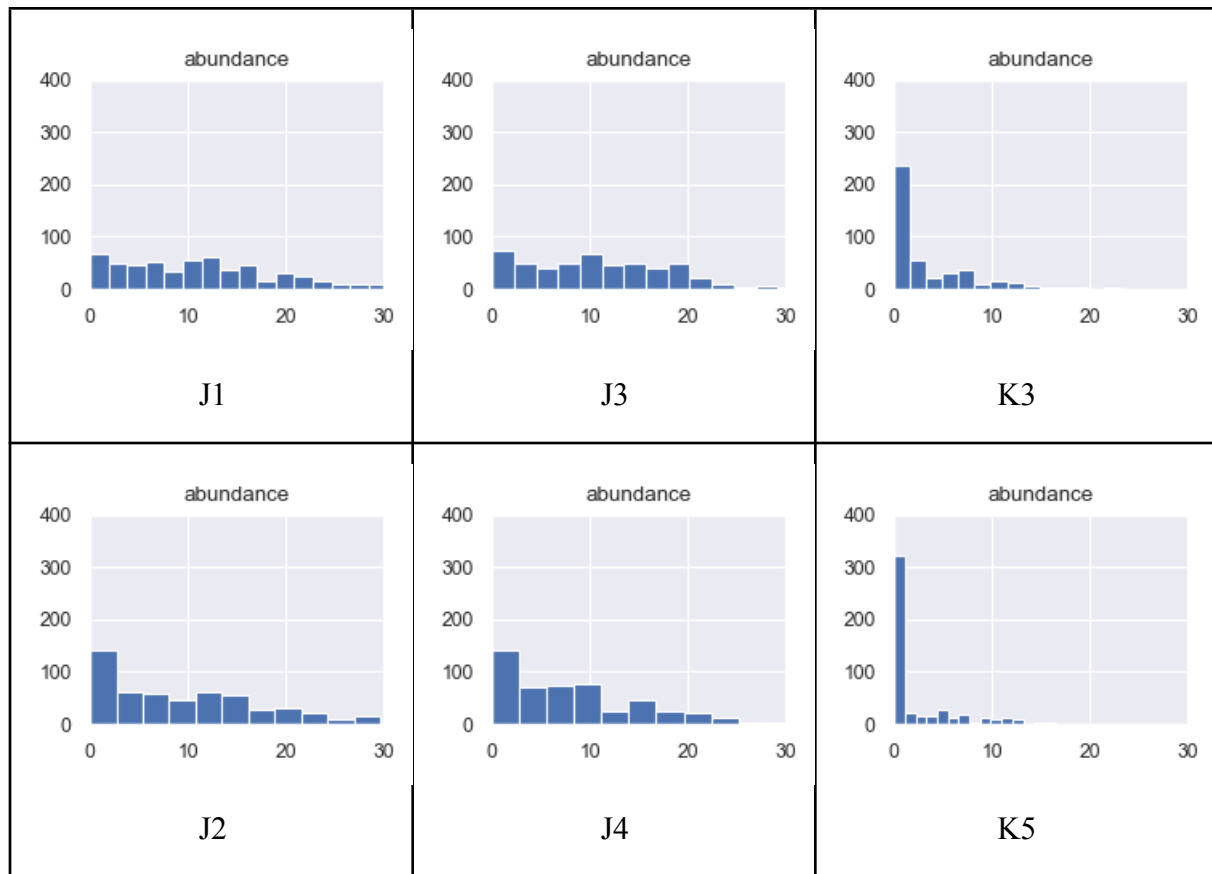


Figure 9. Distribution of acoustic abundance per audio file and per site estimated from manual annotations. J refers to Jahra sites, and K refers to Kabd sites.

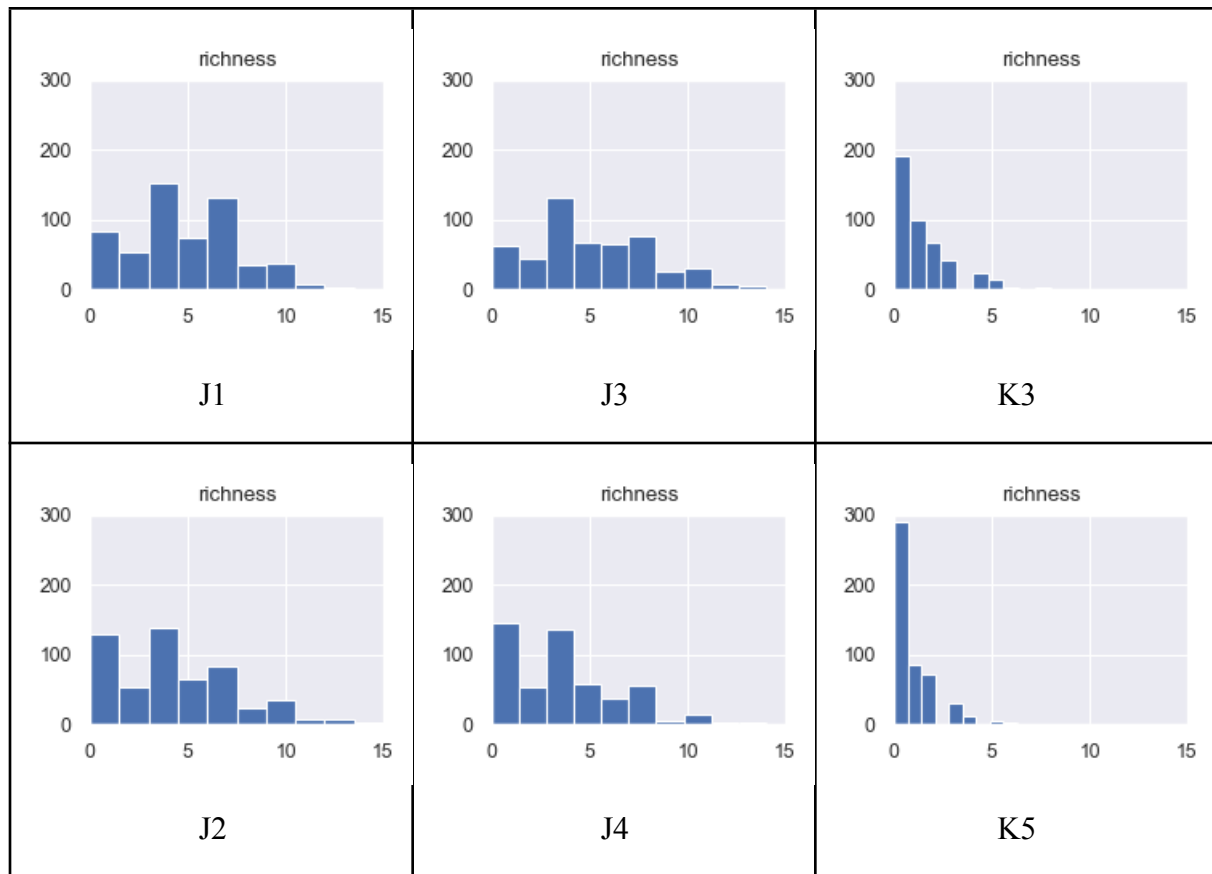


Figure 10. Distribution of acoustic richness estimated from manual annotations for each site. J refers to Jahra sites, and K refers to Kabd sites.

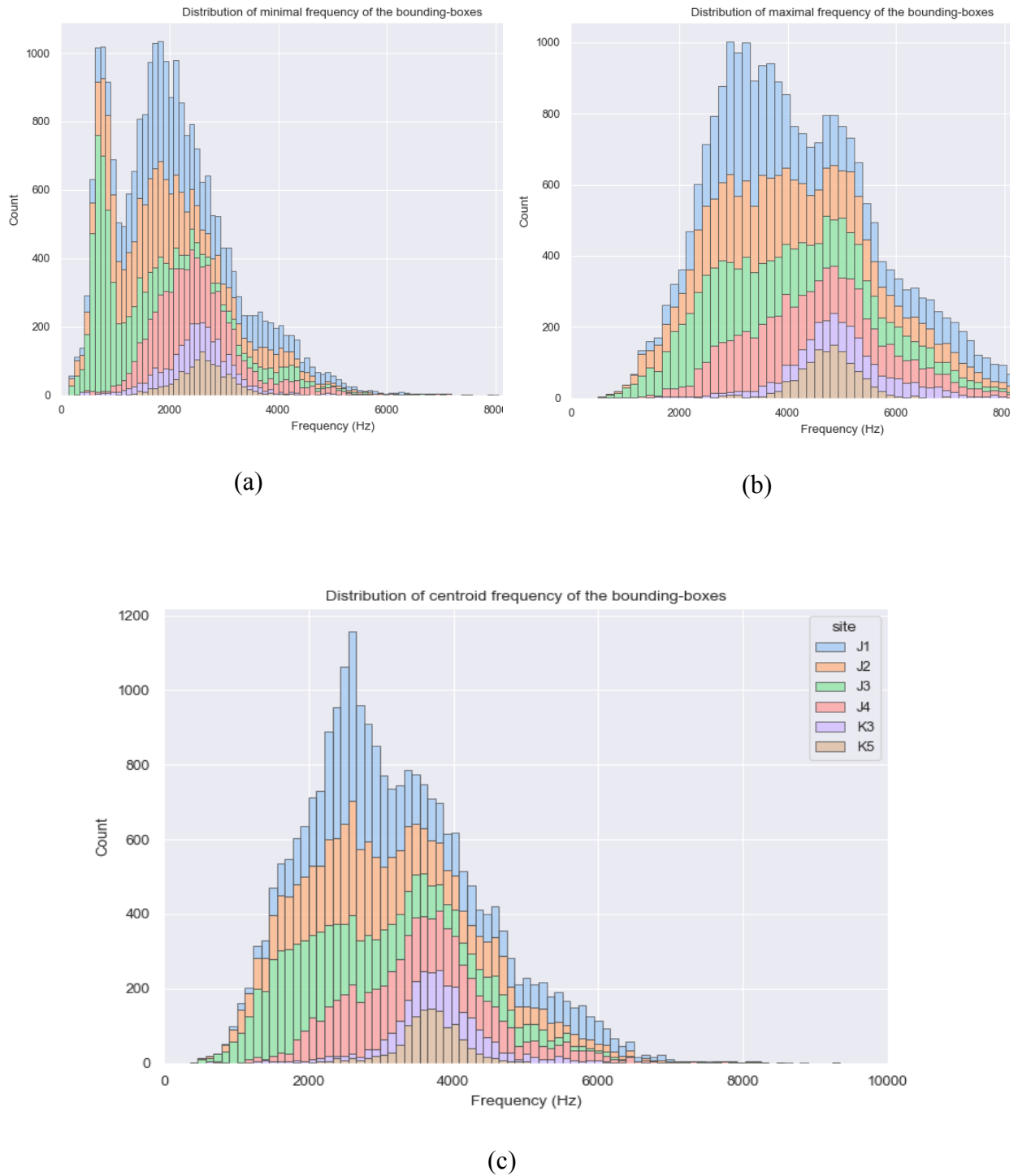


Figure 11. Distribution of the (a) minimal, (b) maximal and (c) centroid frequency of the bounding-boxes for each site. J refers to Jahra sites, and K refers to Kabd sites.

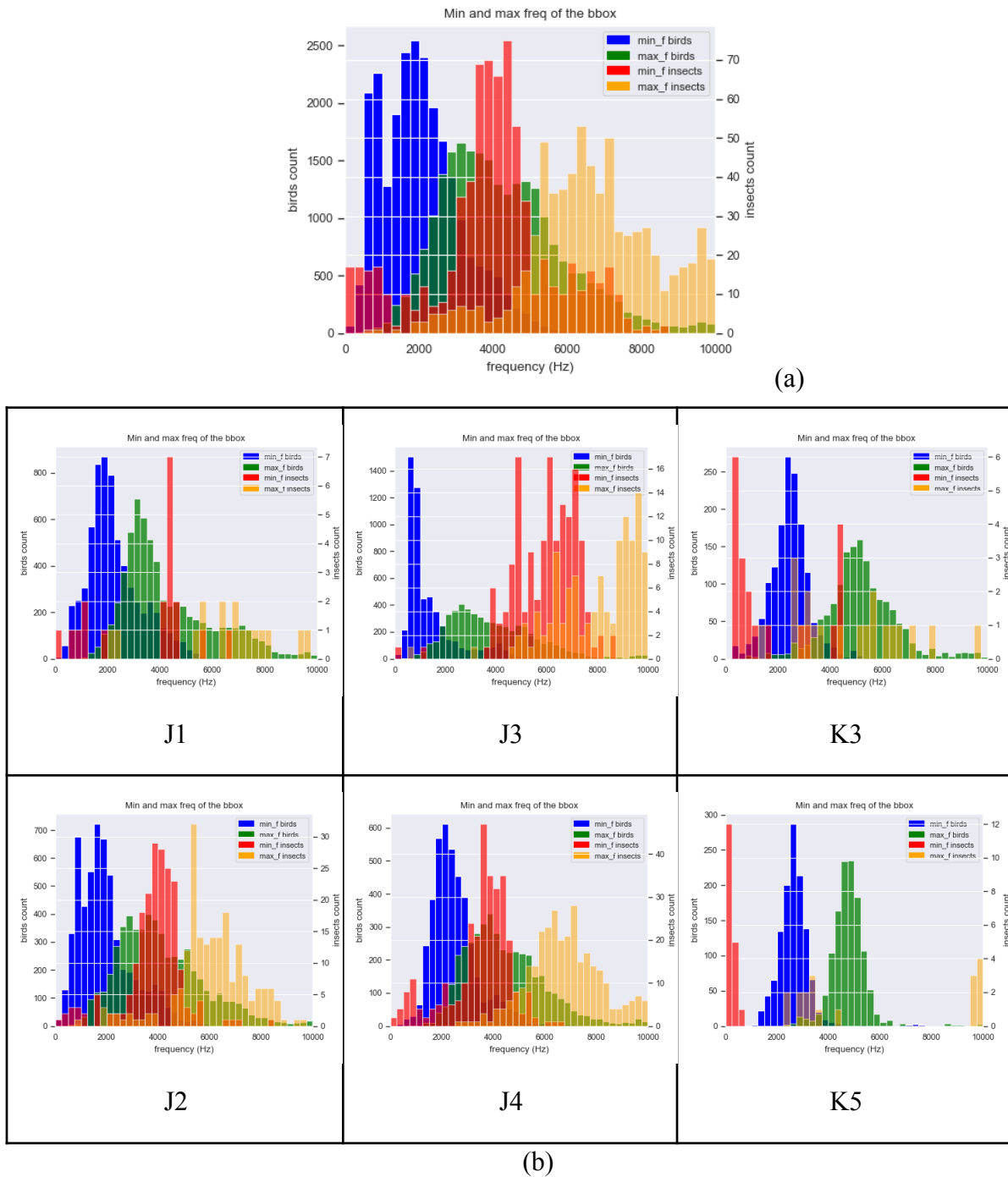


Figure 12. Distribution of the minimum and maximum frequencies of the bounding boxes for birds or insects at all sites (a) and for each site (b). J refers to Jahra sites, and K refers to Kabd sites.

2.4.2 Correlation between manual annotations and automatic acoustic indices

The correlation between all 62 indices and the richness and abundance found by manual annotations indicated that the index nROI correlated the best with richness and abundance ($0.65 < R < 0.87$ for Jahra sites, $0.62 < R < 0.78$ for K3 and K5 sites respectively). When combining all sites together, nROI had the highest correlation coefficient with abundance ($R = 0.83$) and richness ($R=0.76$) (Table 8, Figures 13-14).

Table 8. Correlation between the best acoustic indices to bird species richness and abundance with $R > 0.6$. The correlations are listed for each site, then for all sites. J refers to Jahra sites, and K refers to Kabd sites.

	J1	J2	J3	J4	K3	K5	all sites
Correlation coefficient R between Abundance and Index	LFC -0.62 VART -0.62 LEQt -0.62 aROI 0.75 nROI 0.75	EAS 0.69 NBPEAKS 0.72 aROI 0.85 nROI 0.87	NBPEAKS 0.64 BI 0.65 EAS 0.66 ROItotal 0.76 aROI 0.80 nROI 0.81	aROI 0.73 nROI 0.81	nROI 0.62	ECU 0.60 ECV 0.63 aROI 0.72 nROI 0.78	LFC -0.60 aROI 0.74 nROI 0.79
Correlation coefficient R between Richness and Index	aROI 0.64 nROI 0.66	LFC -0.64 SNRf -0.61 EAS 0.60 NBPEAKS 0.70 aROI 0.76 nROI 0.77	ADI -0.67 NBPEAKS 0.60 BI 0.62 ROI total 0.64 AEI 0.67 aROI 0.71 nROI 0.72	aROI 0.61 nROI 0.73	none with R > 0.6	ECV 0.61 aROI 0.69 nROI 0.74	LFC -0.62 aROI 0.72 nROI 0.76

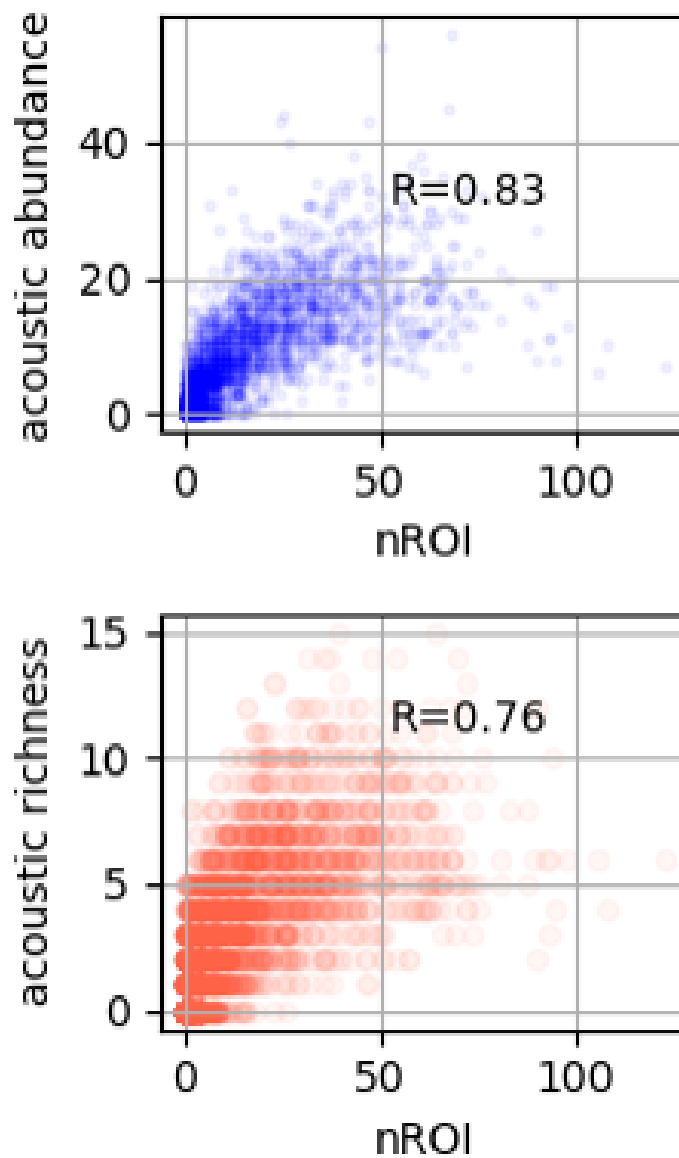


Figure 13. Correlation between the acoustic index nROI and the richness and abundance estimated from manual annotations for all sites together.

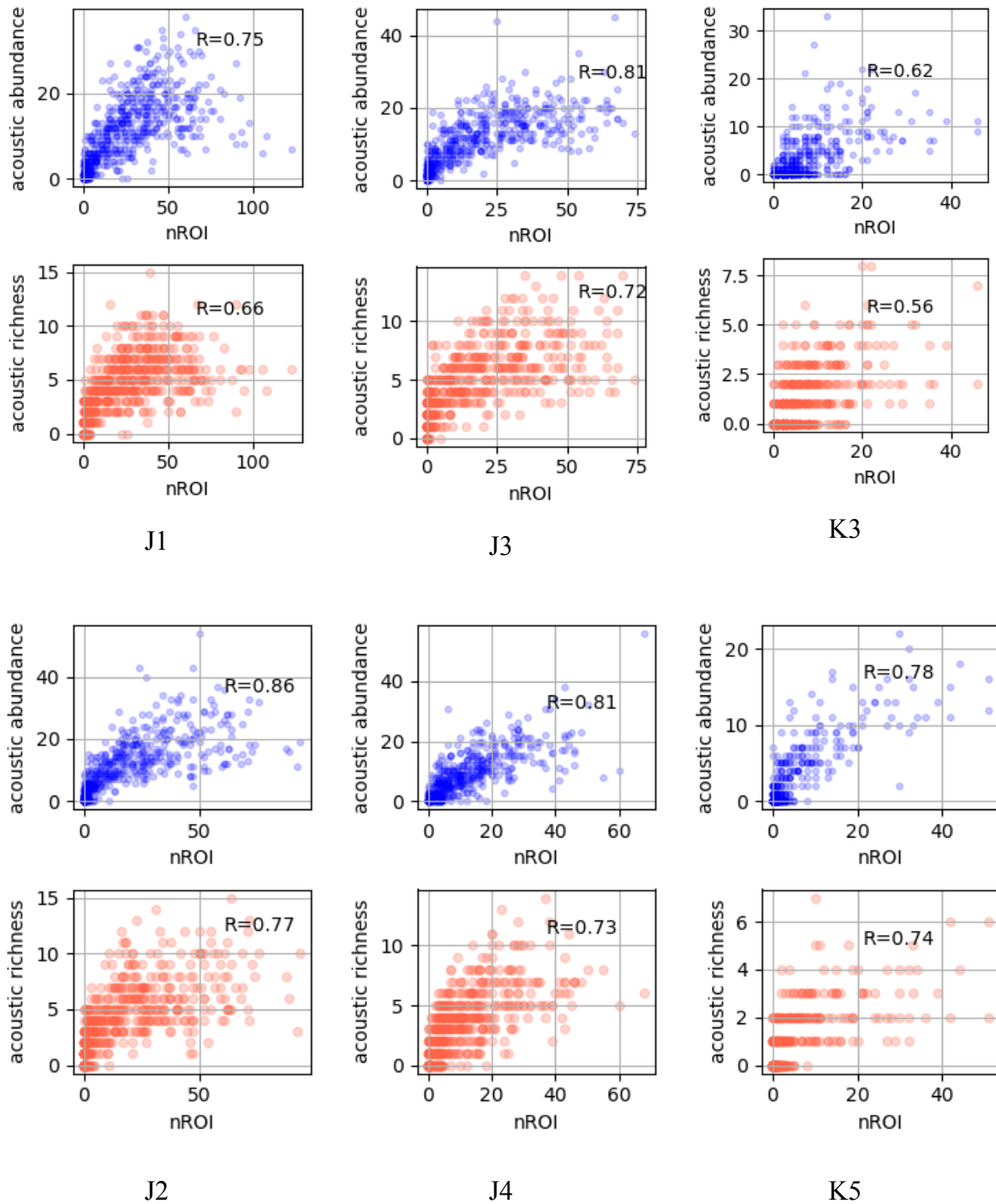


Figure 14. Correlation between nROI with species abundance and species richness for each site.

2.4.3 nROI

The minimum, median, and maximum values of nROI showed a clear decrease along the Jahra transect, with the highest value close to the seashore and the lowest value in the desert (Table 9).

This agreed with the acoustic abundance and richness obtained with the manual annotations.

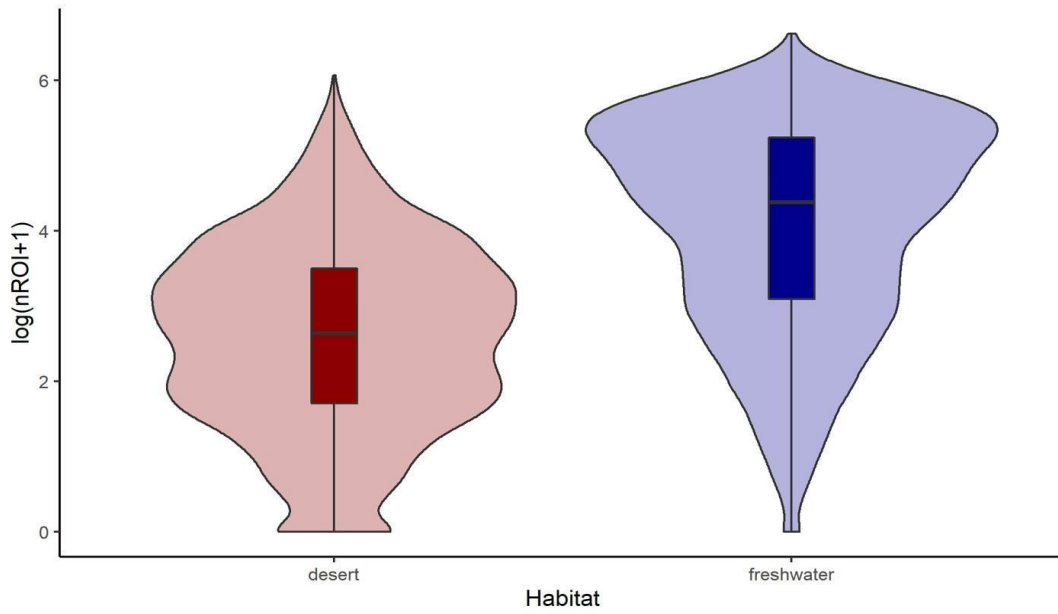
Table 9. Maximum (90th percentile), median (50th percentile) and minimum (10th percentile) of nROI for each site.

	J1	J2	J3	J4	K3	K5
nROI maximum (90th percentile)	59	52	48	29	17	20
nROI median (50th percentile)	24	17	18	10	5	3
nROI minimum (10th percentile)	2	1	2	2	2	1

2.4.3.1 Seasonal variation of nROI among habitats

In general, nROI was higher in the freshwater habitat than the desert habitat. To further investigate this variation, the microhabitats in Jahra showed a variant in nROI. The highest nROI values were found in the coastal microhabitat (J1), while nROI values were lower and almost similar in the transitional (J2) and freshwater (J3) habitats. Low values of nROI were observed in the desert part of Jahra (J4), with values close to those observed in the tree desert habitat (K3). The minimum values obtained in the open desert microhabitat (K5) were the lowest among all other sites (Figure 15).

a)



b)

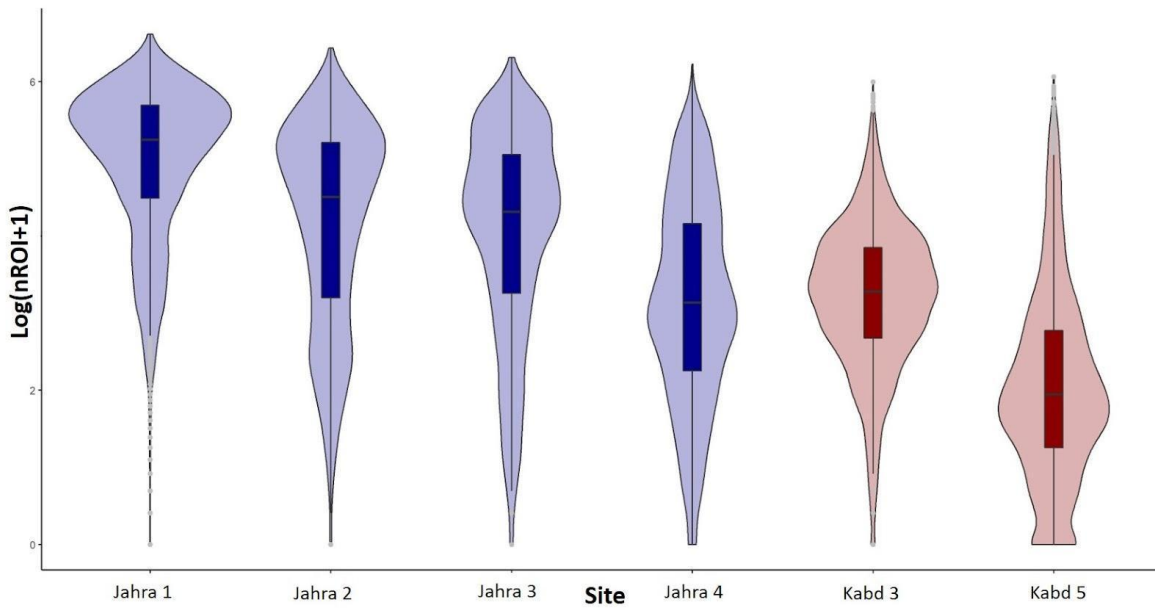


Figure 15. Variation of $nROI$ among habitats and microhabitats. (a) Jahra freshwater habitat and Kabd Desert habitat. (b) Variation of $nROI$ between microhabitats. Due to non normal distributions, $nROI$ values were log-transformed. Violin plots depicting the interquartile range (box), range (whiskers), kernel probability density (side curves).

The monthly variation of nROI showed higher values of acoustic activities at all months at Jahra freshwater habitat than the Kabd desert habitat. At Jahra sites, high nROI were recorded during winter, spring and fall seasons. There was no clear seasonal pattern except that the lowest nROI values occurred in June, in both sites (Figure 16).

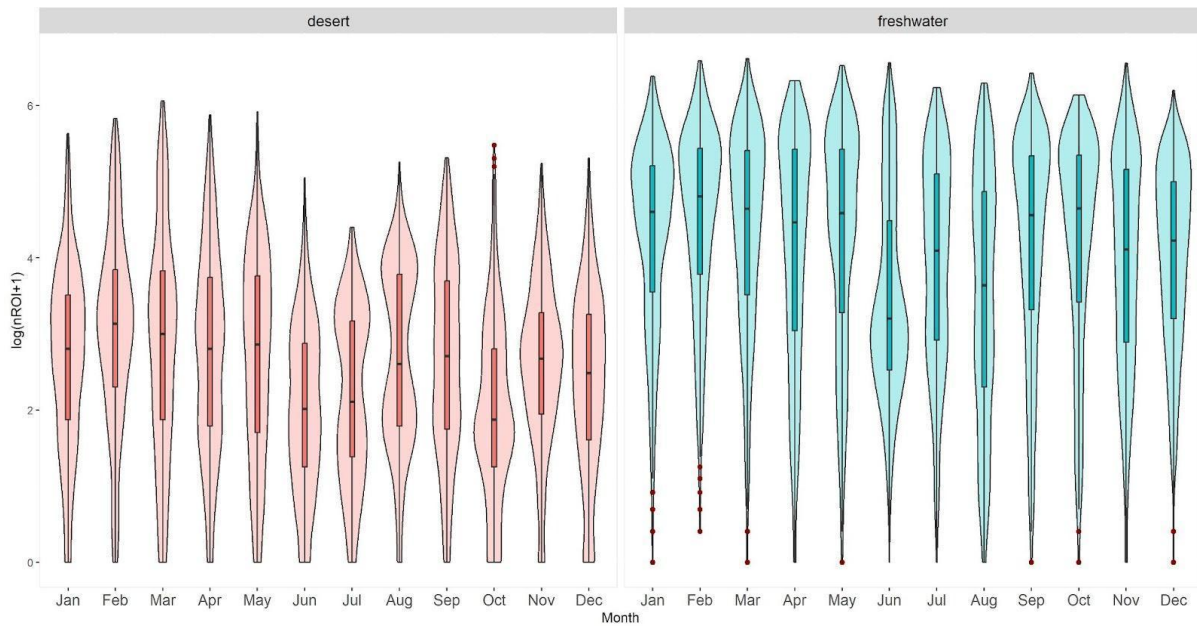


Figure 16. Monthly variation of nROI between Desert Kabd habitat and Freshwater Jahra habitat. Due to non normal distributions, nROI values were log-transformed. Violin plots depicting the median (black point) the interquartile range (box), range (whiskers), outliers (red points), and kernel probability density (side curves).

2.4.3.2 Diurnal variation of nROI, among habitats

The nROI log results indicated that the highest nROI were recorded at the hours of sunrise and sunset, in both habitats. (Figure 17).

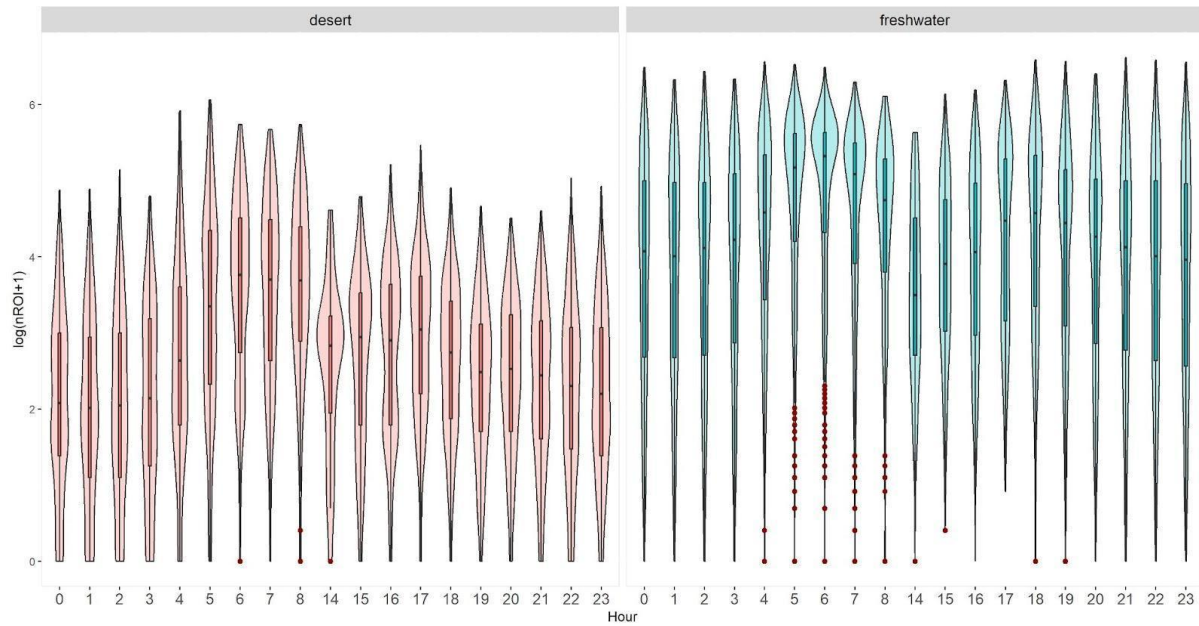


Figure 17. The hourly variation of nROI at both habitats, Desert and Freshwater. The highest values of nROI were found during the hours of sunrise (4 to 7 am) and sunset (17 to 18 pm). Due to non normal distributions, nROI values were log-transformed. Violin plots depicting the interquartile range (box), range (whiskers), kernel probability density (side curves).

Temporal heatmaps of the nROI index for each site showed areas of low and high activity as a function of time of day and year (Figures 18 - 23). Activities were almost always higher in the coastal microhabitat. Inland microhabitats in J2 and J3 had less acoustic activity but with a visible pattern of acoustic activity at dawn and dusk. In the desert habitat in J4, K3, and K5, the nROI showed less acoustic activity than the other three sites, even if dawn and dusk choruses were still highlighted, although to a lesser extent. Higher nocturnal activity was also noted, but the timing of this activity differed among habitats, with Jahra 1 had more nocturnal activities most of the year, followed by Jahra 2, Jahra 3, and Jahra 4. While in Kabd sites there were no nocturnal activities. The times of high acoustic activity are summarized in Table 10.

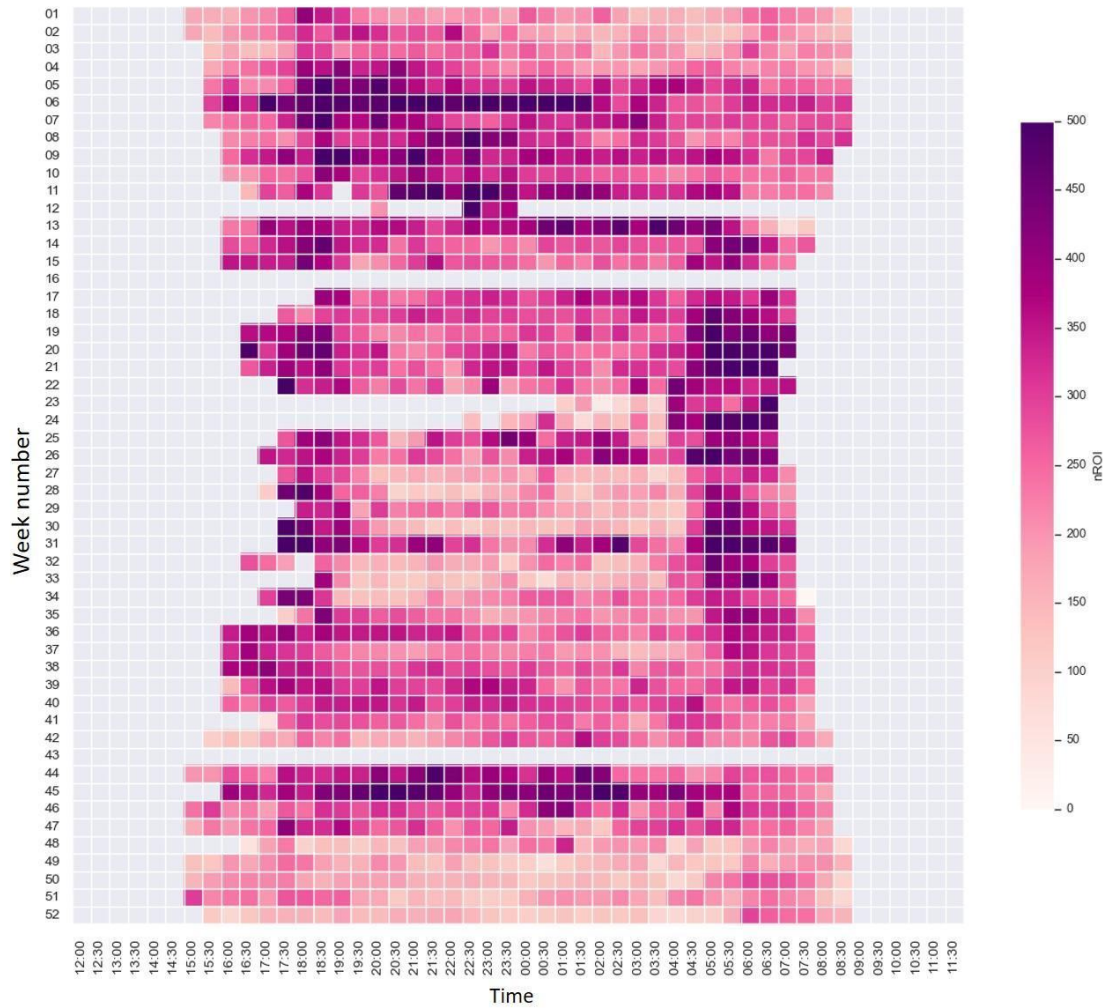


Figure 18. Jahra 1 coastal, Number of regions of interest (nROIs) corresponding to the number of acoustic events (between 1256Hz and 5224Hz). The values of nROI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). nROI values were scaled by the duration of the audio file to allow comparison across sites. Gray squares indicate missing data out of recording schedule or due to recorder failures.

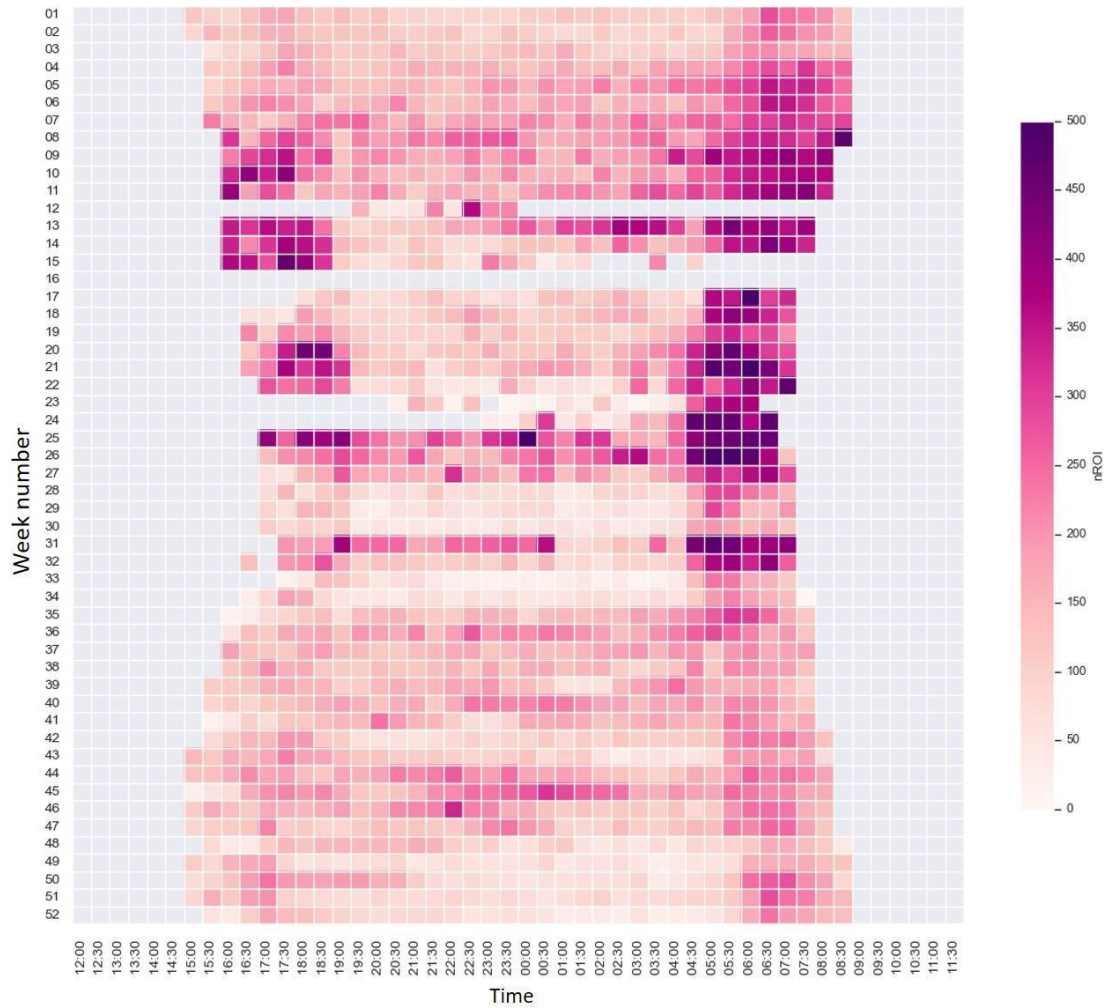


Figure 19. Jahra 2 transition between coastal and freshwater, Number of regions of interest (nROIs) corresponding to the number of acoustic events (between 1256Hz and 5224Hz). The values of nROI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). nROI values were scaled by the duration of the audio file to allow comparison across sites. Gray squares indicate missing data out of recording schedule or due to recorder failures.

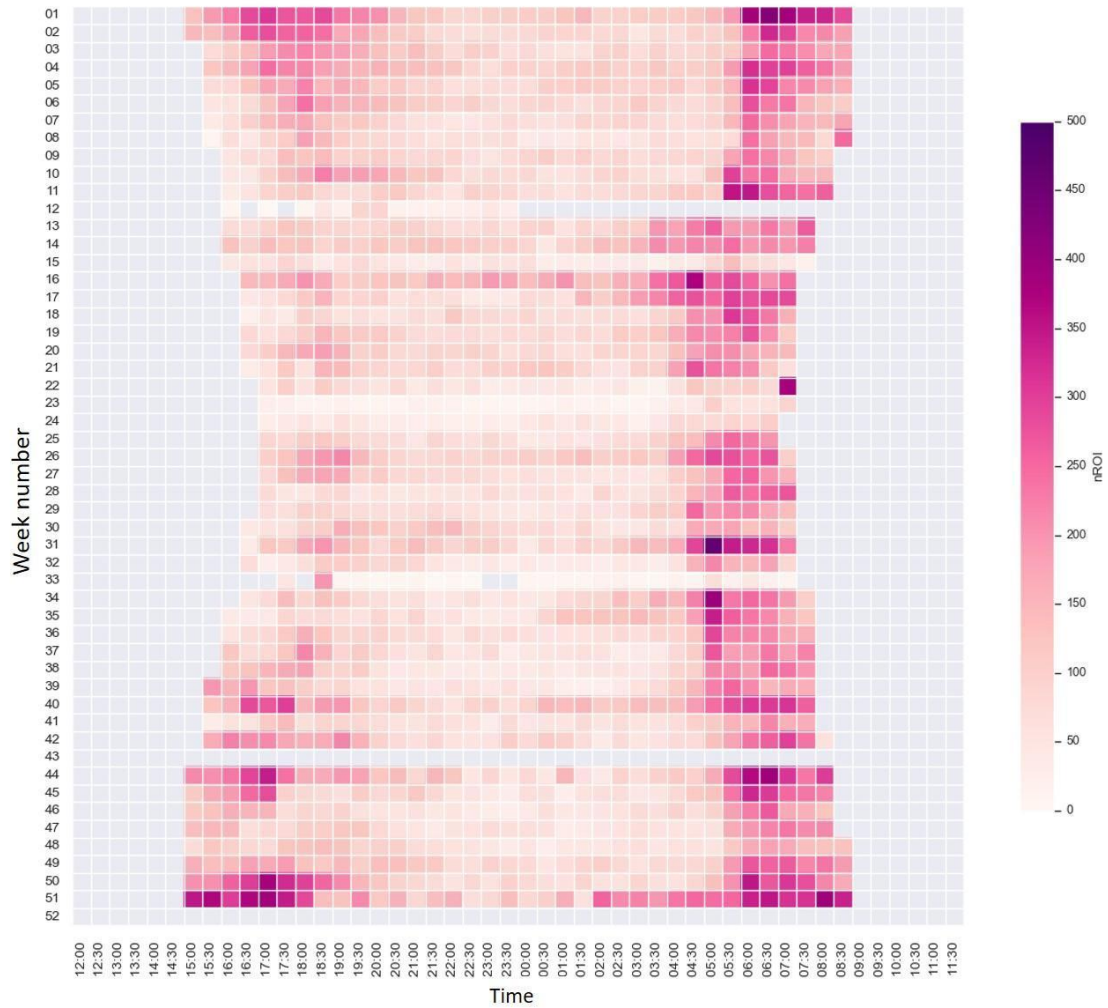


Figure 20. Jahra 3 freshwater, Number of regions of interest (nROIs) corresponding to the number of acoustic events (between 1256Hz and 5224Hz). The values of nROI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). nROI values were scaled by the duration of the audio file to allow comparison across sites. Gray squares indicate missing data out of recording schedule or due to recorder failures.

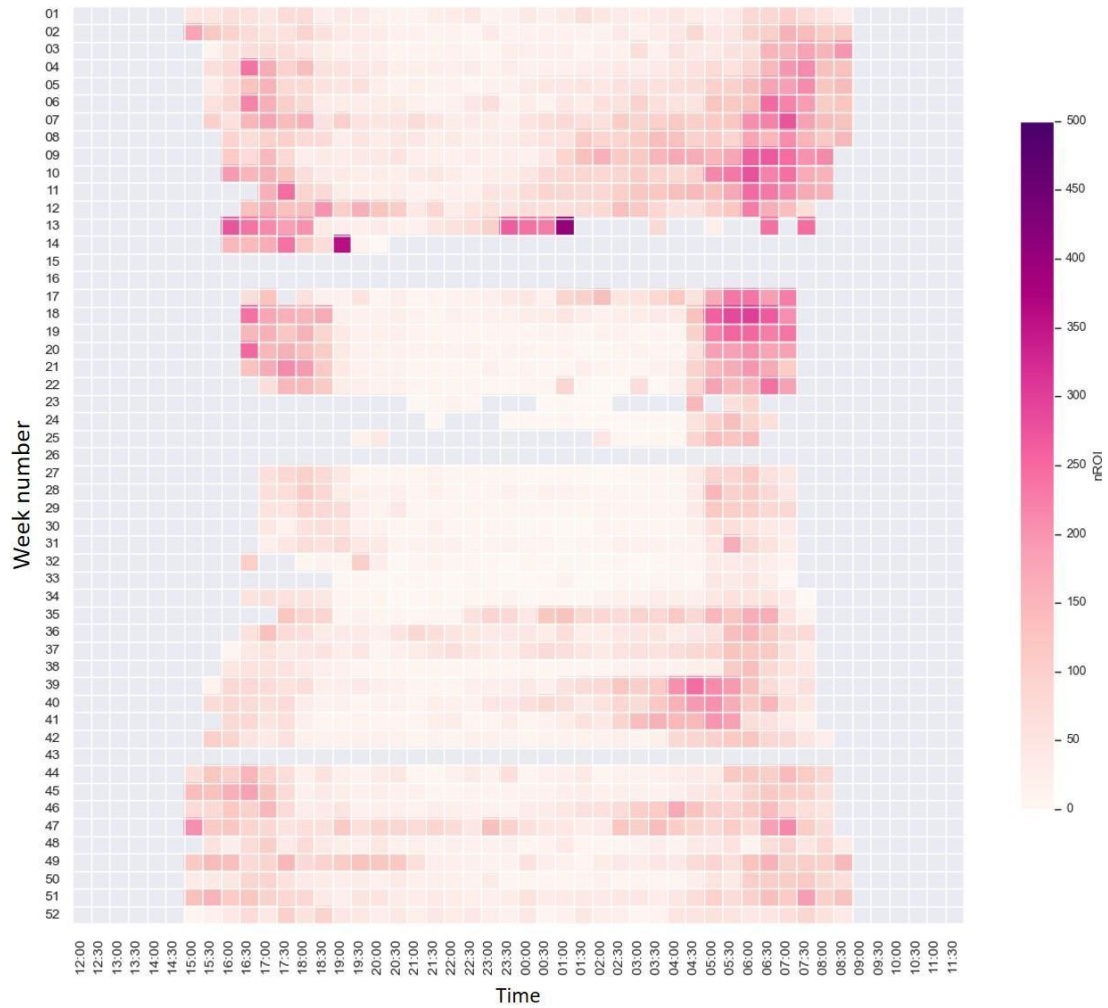


Figure 21. Jahra 4 desert, Number of regions of interest (nROIs) corresponding to the number of acoustic events (between 1256Hz and 5224Hz). The values of nROI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). nROI values were scaled by the duration of the audio file to allow comparison across sites. Gray squares indicate missing data out of recording schedule or due to recorder failures.

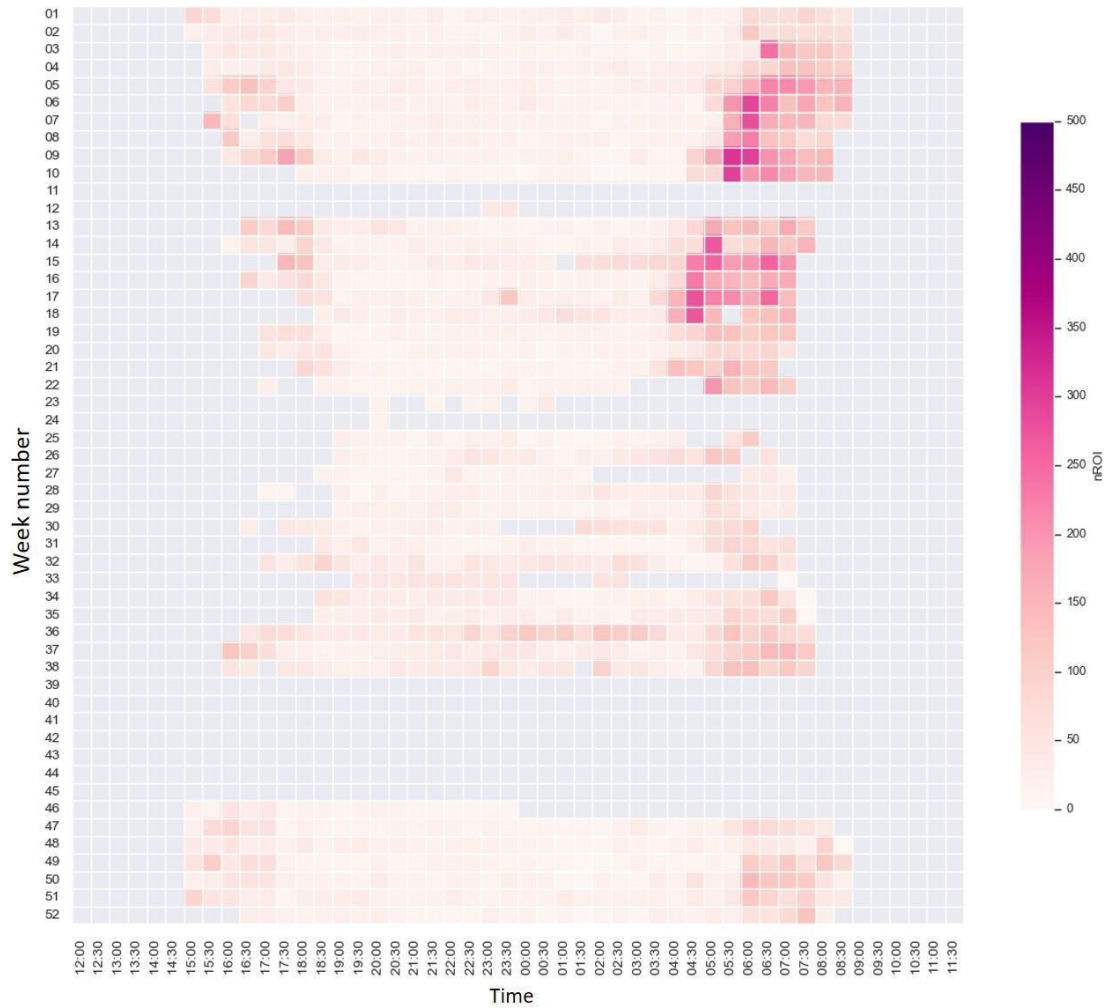


Figure 22. Kabd 3 desert tree, Number of regions of interest (nROIs) corresponding to the number of acoustic events (between 1256Hz and 5224Hz). The values of nROI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). nROI values were scaled by the duration of the audio file to allow comparison across sites. Gray squares indicate missing data out of recording schedule or due to recorder failures.

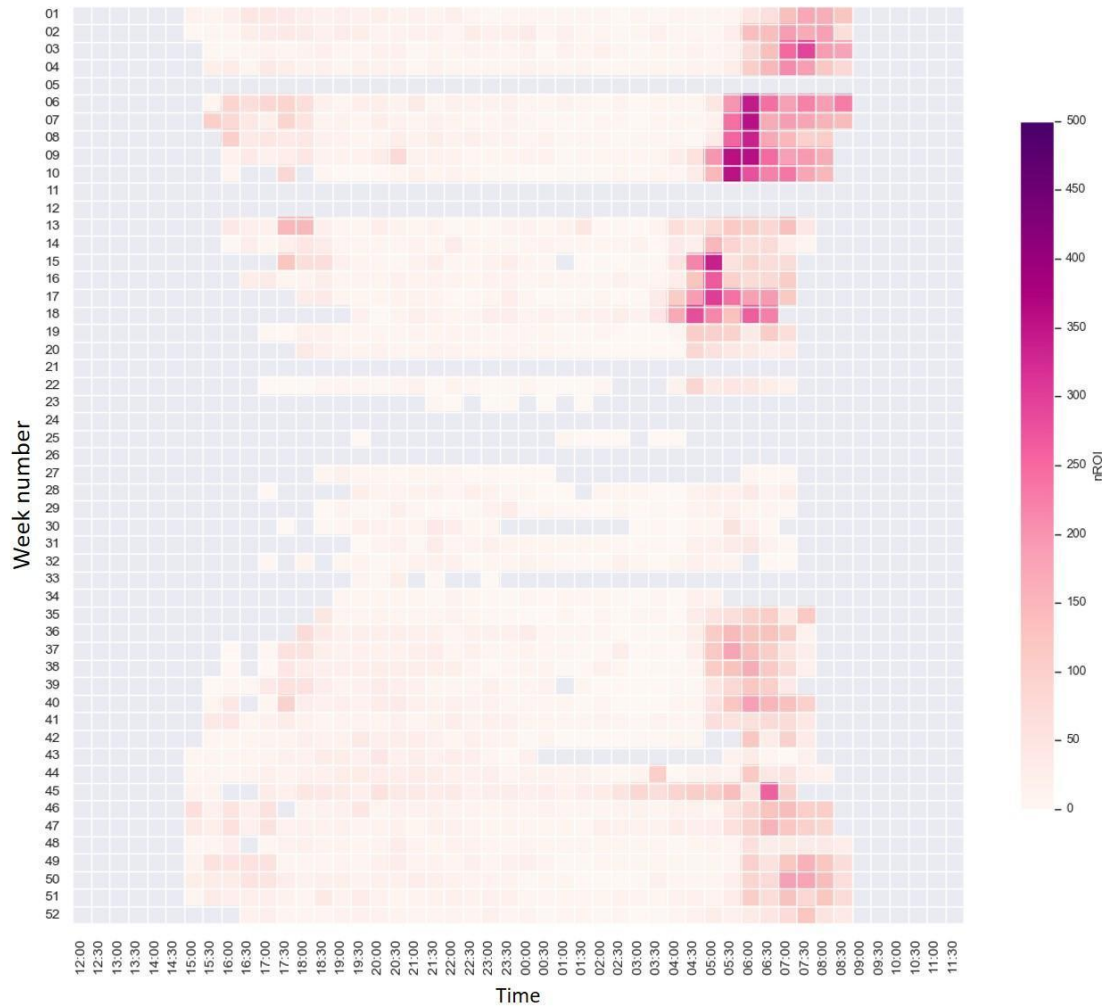


Figure 23. Kabd 5 open desert, Number of regions of interest (nROIs) corresponding to the number of acoustic events (between 1256Hz and 5224Hz). The values of nROI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). nROI values were scaled by the duration of the audio file to allow comparison across sites. Gray squares indicate missing data out of recording schedule or due to recorder failures.

Table 10. Summary of high acoustic activities indicated by nROI index at dawn/dusk, and nocturnal time of each site

Site	Microhabitat	Higher nROI	Nocturnal activities
Jahra 1	Coastal	Weeks 18-26 (late April to late June)	Week 6 (early February) Week 8 (late February) Week 11 (mid-March) Weeks 25 and 26 (late June and early July) Week 31 (early August) Weeks 44-46 (from November 1 to 21)
Jahra 2	Transition between coastal and freshwater	Weeks 13, 14 (late March-early April) Weeks 18-26 (early May-early July)	Week 12 (late March) Week 25 (late June) Week 31 (early August) Weeks 44-46 (from November 1-21)
Jahra 3	Freshwater	Weeks 11-22 (mid-March - early June)	Week 16 (late April) Week 51 (late December)
Jahra 4	Desert	Weeks 9-22 (first of March - early June)	Week 13 (late March - early April)
Kabd 3	Desert Tree	Weeks 5-17 (first of February - first of May)	
Kabd 5	Open desert	Weeks 5-17 (first of February - first of May)	

2.4.4 ACI

The heatmap of ACI clearly showed chorus activity at dawn and dusk, and nocturnal activity during spring, early summer, and fall seasons. At the other three Jahra sites, the patterns were rather similar except that ACI estimated more acoustic activities in open desert areas K3, K5. We found nocturnal activities at Jahra 1 in the week 31-32, and a distinguished night activity at Jahra 2 during the weeks 23 and 29 and at hours from 18 to 23. ACI detected more nocturnal activities at Kabd sites than nROI (Figures 24 -29).

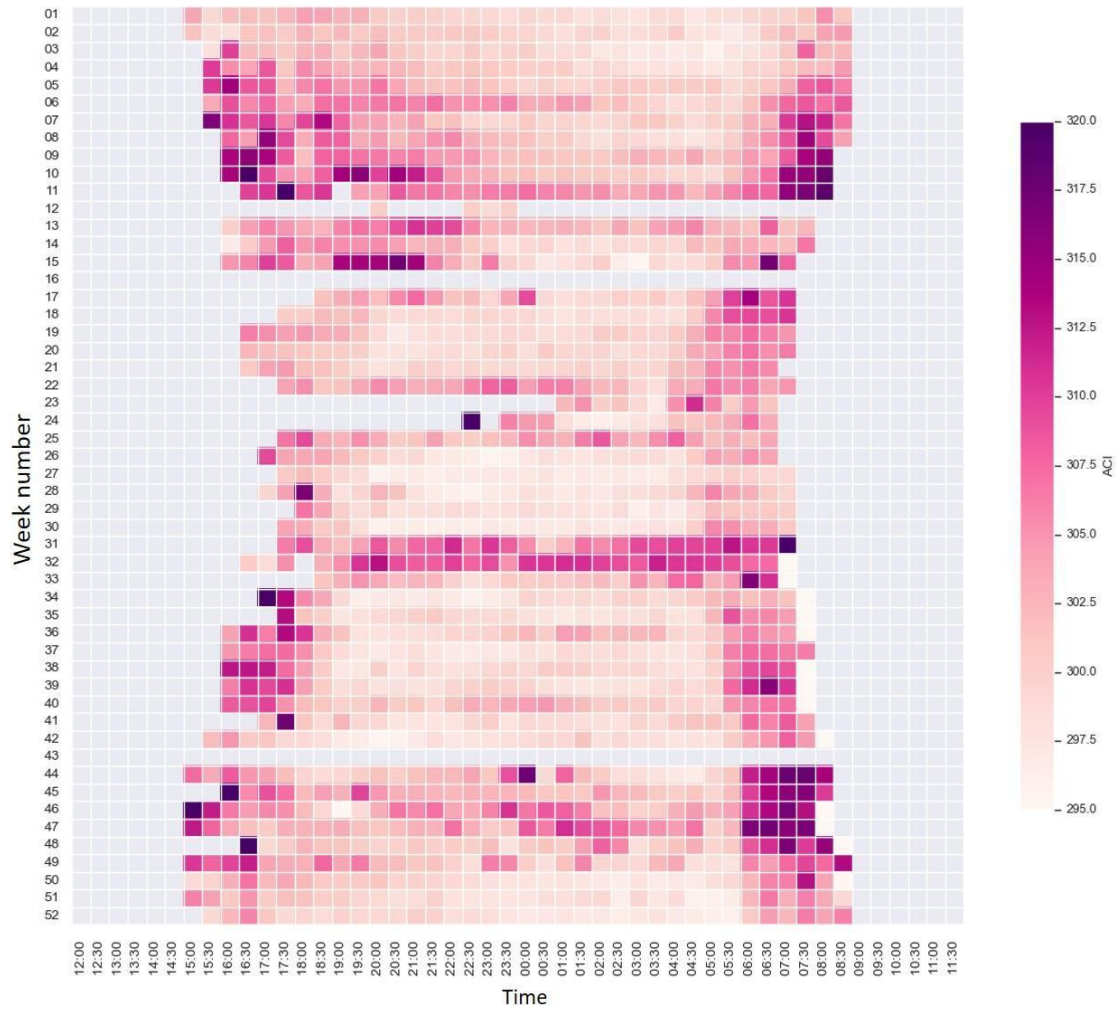


Figure 24. Jahra 1 coastal, Heat map of Acoustic Complexity Index (ACI) depending on the week and the time with the filtered dataset (with selection of the ACIs between [1256 - 5224] Hz). The values of ACI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). The values of ACI could not be scaled to allow comparison across sites.

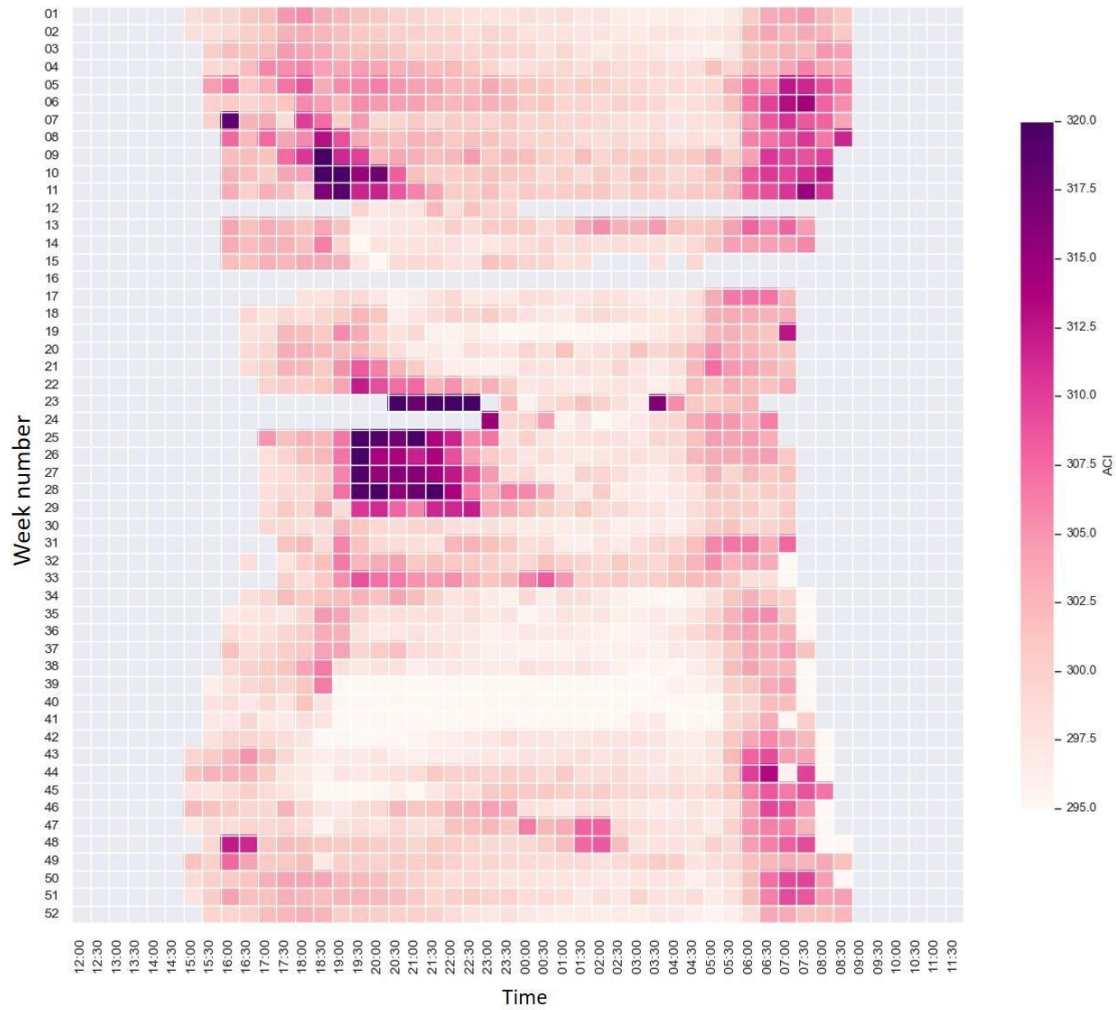


Figure 25. Jahra 2 transition between coastal and freshwater, Heat map of Acoustic Complexity Index (ACI) depending on the week and the time with the filtered dataset (with selection of the ACIs between [1256 - 5224] Hz). The values of ACI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). The values of ACI could not be scaled to allow comparison across sites.

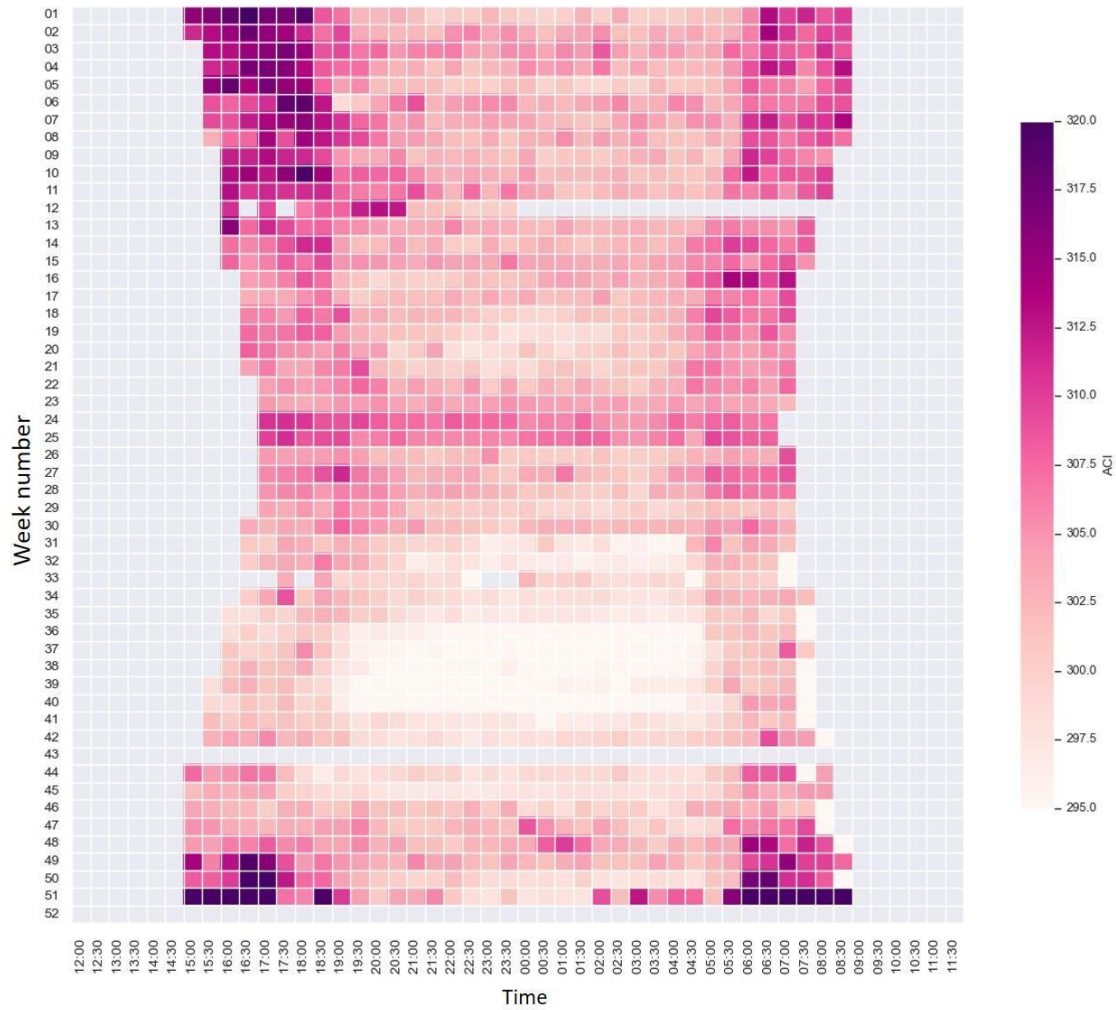


Figure 26. Jahra 3 freshwater, Heat map of Acoustic Complexity Index (ACI) depending on the week and the time with the filtered dataset (with selection of the ACIs between [1256 - 5224] Hz). The values of ACI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). The values of ACI could not be scaled to allow comparison across sites.

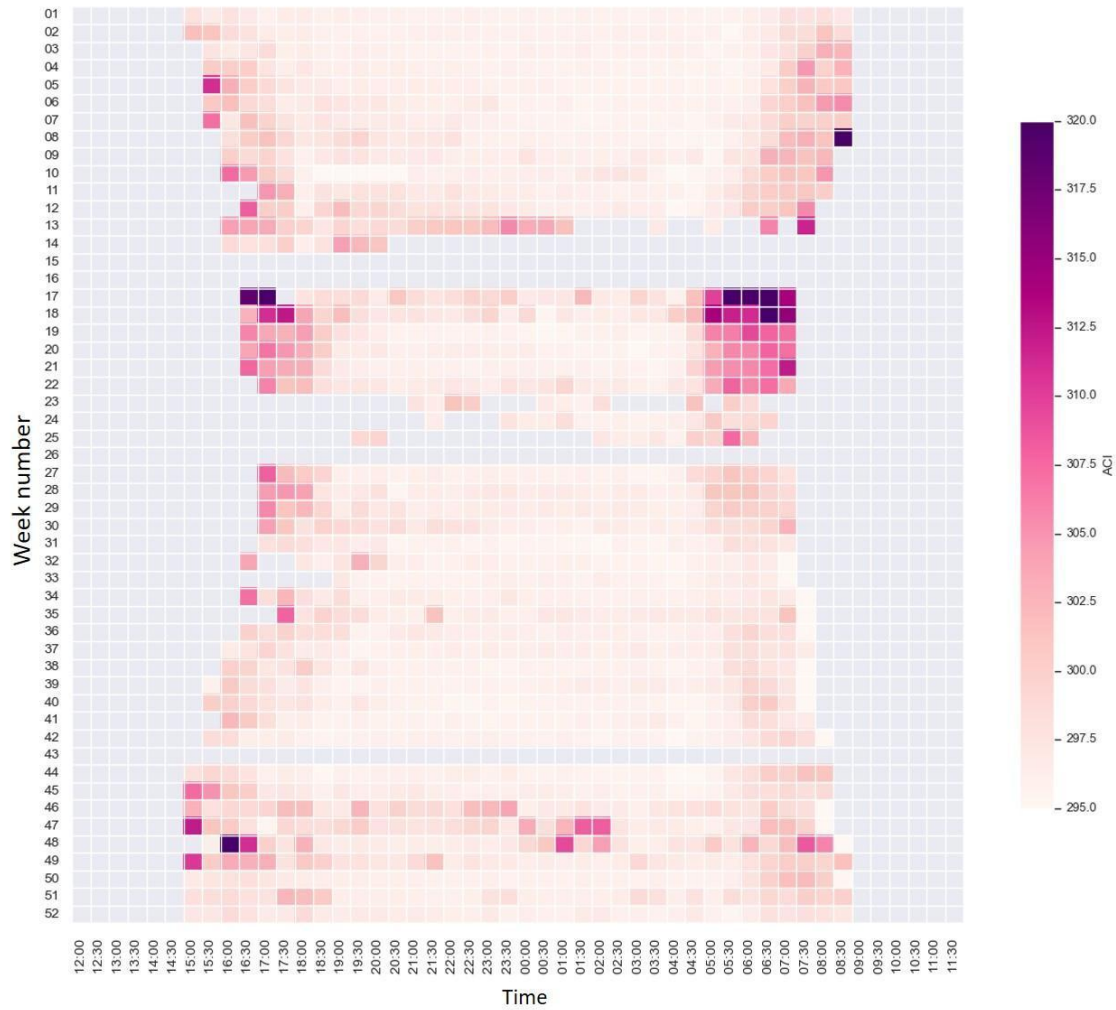


Figure 27. Jahra 4 desert, Heat map of Acoustic Complexity Index (ACI) depending on the week and the time with the filtered dataset (with selection of the ACIs between [1256 - 5224] Hz). The values of ACI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). The values of ACI could not be scaled to allow comparison across sites.

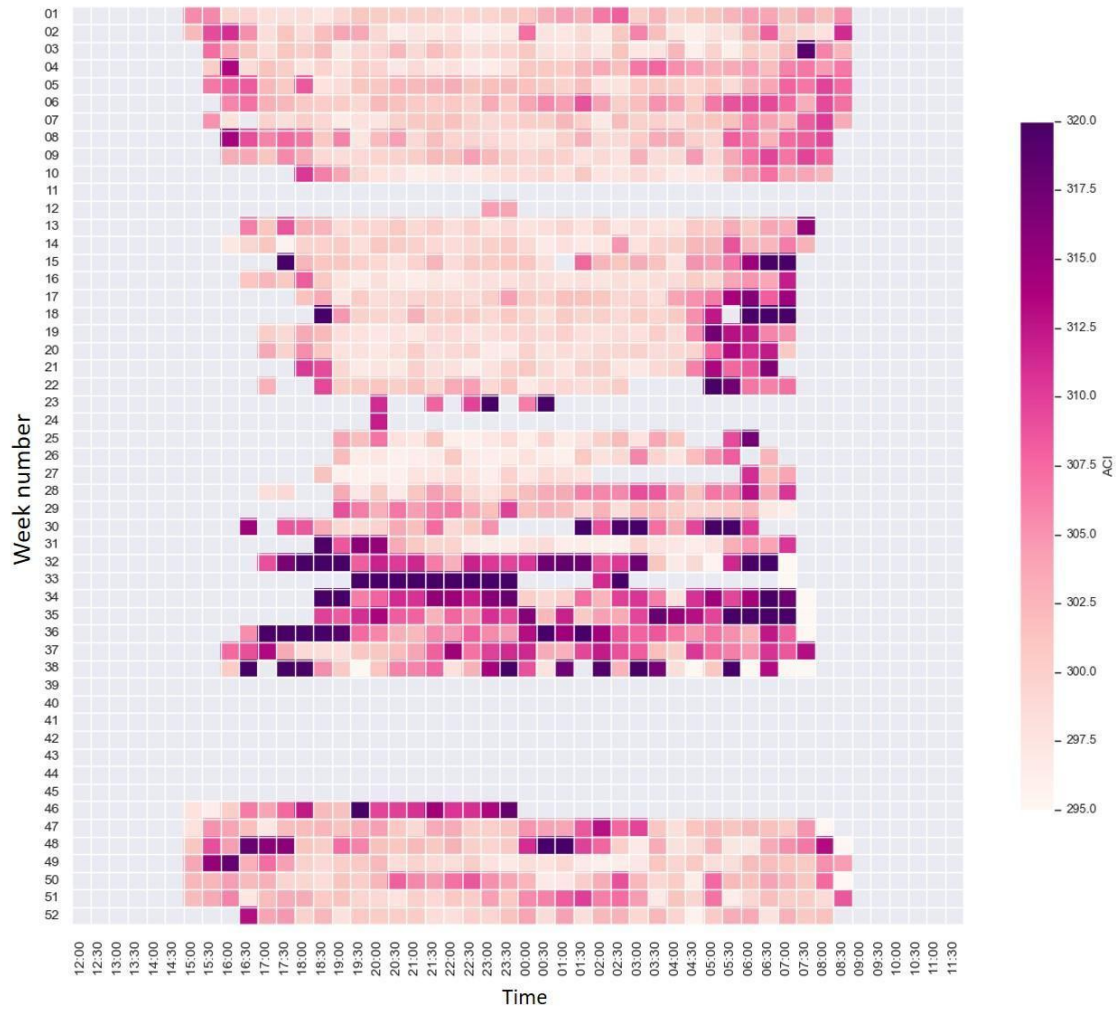


Figure 28. Kabd 3 desert tree, Heat map of Acoustic Complexity Index (ACI) depending on the week and the time with the filtered dataset (with selection of the ACIs between [1256 - 5224] Hz). The values of ACI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). The values of ACI could not be scaled to allow comparison across sites.

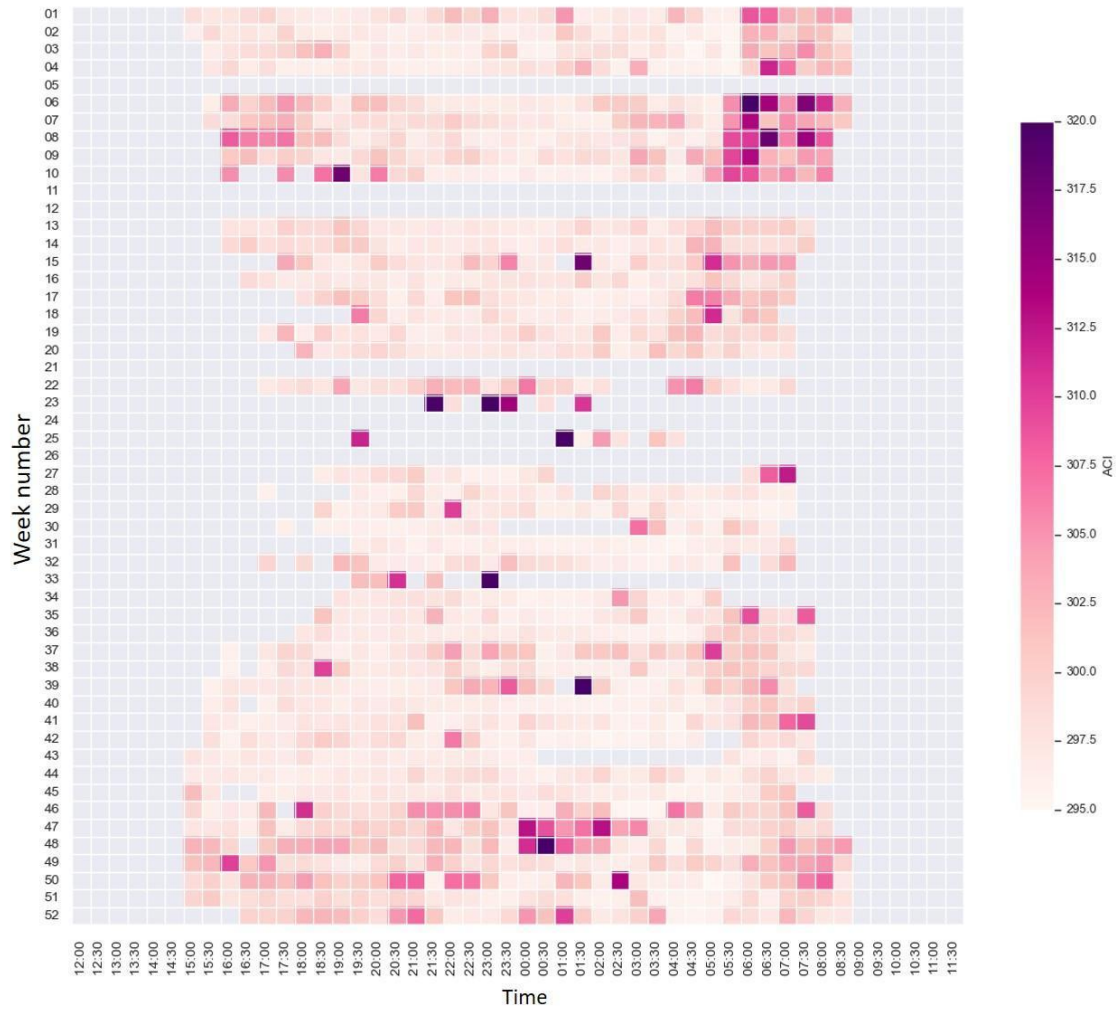


Figure 29. Kabd 5 open desert, Heat map of Acoustic Complexity Index (ACI) depending on the week and the time with the filtered dataset (with selection of the ACIs between [1256 - 5224] Hz). The values of ACI are depicted according to a color scale for each week (from week 1 to week 52) and each time of the day (from noon to noon). The values of ACI could not be scaled to allow comparison across sites.

2.5 Discussion

Here, we monitored for the first time the soundscapes of freshwater and desert habitats in the Arabian Peninsula. We mainly aimed at estimating the diversity of bird communities inside these soundscapes in order to document their dynamics along a complete year. If recording devices (ARUs) can be deployed in the field over long time periods and in relatively high numbers, the main challenge of ecoacoustics still concerns the extraction of meaningful ecological information in the large amount of data acquired. Automatic species identification is progressing thanks to the development of AI solutions such as the use of Hidden Markov models (see Chapter 3) or convolutional neural networks (Kahl et al, 2021) but their reliability is still challenged when the songs of several species overlap at the time of dawn and dusk choruses. This was particularly the case here in freshwater habitats where up to 23 species could be found to sing together.

To get around that problem, several acoustic indices have been proposed to measure acoustic diversity within audio recordings without species identification (Napoletano, 2004; Sueur et al. 2014; Buxton et al. 2018; Alcocer et al. 2022). These acoustic indices are based on the idea that acoustic diversity is positively correlated with species richness (Sueur et al., 2008; Pieretti et al. 2011). The number of acoustic indices increased quickly so that more than 70 are now available.

Choosing the proper acoustic index or indices is not trivial as the reliability of an index can be related to the habitat type, the spatial and temporal scale of the study, and the similarity and dissimilarity between the surveyed sites (Mammides et al, 2017). Acoustic indices are often used with no precaution, in a blindly way. However, it is of prime importance to check their reliability for the dataset to be explored. Here, we then first applied a set of 62 indices on a labeled

subsample of recordings so that we could assess the correlation between the indices and the acoustic diversity estimated by an expert. This pre-test clearly revealed that the nROI and aROI indices were the best acoustic diversity estimators so that they could be calculated with confidence on all recordings.

The temporal heatmaps obtained with nROI index first clearly indicate more acoustic activities around sunrise and sunset, and higher activities during night at several times of the year. This temporal pattern can be explained by the dusk and dawn choruses and the nighttime activity of migrant birds (Mathevon and Aubin, 2020). The nROI index revealed higher activity in June and July, a seasonality that does not match with the pattern drawn from eBird data (see Chapter 1). By using the results of nROI, we could notice higher activities in some sites, like J2, starting from January to February. This may be a result of the observer bias effect, but higher acoustic activities may suggest a presence of bird species that were recorded by visual counts.

The comparison between habitats by the resulting nROI, also showed a variation between habitats, microhabitats, time of the year, and time of the day. The results from Chapter one, indicated that freshwater habitats recorded higher species richness than desert locations in Kuwait. This was supported by our nROI index results, where nROI was higher at freshwater sites as a result of higher species richness which led to higher acoustic activities. Also, microhabitats at Jahra showed a variation in nROI, the coastal and freshwater microhabitats resulted in higher nROI than the dry desert part of Jahra. The latter showed close nROI with Kabd tree site, while Kabd open desert microhabitat showed the lowest nROI.

The monthly variation of nROI in the two habitats showed a different pattern from the visual methods shown in chapter one. Although the nROI were higher in all months in freshwater habitats, almost the same pattern of low and high values is still obvious. However, the lowest nROI recorded in June, was similar to the lowest value of species richness recorded by visual methods in both habitats. Acoustic methods were able to detect species vocalization more than the conventional methods. The nROI log results were able to show the dawn/dusk acoustic activities at both sites, and clearly detected the higher richness in freshwater habitats at similar time of the day. This validated the accuracy of our nROI index in estimating the species richness and abundance at our deployment sites.

When we compared heatmaps of acoustic activities representing nROI and ACI, we found similarity between the two in indicating the dawn/dusk activities. However, ACI detected some nocturnal activities in Jahra 1 and 2. Also, ACI detected nocturnal activities at Kabd sites. For Jahra 1, the nocturnal activities were July-August, which might correspond to nocturnal migrational activities of some coastal birds, as we will investigate in chapter 3. Jahra 2 nocturnal activities at weeks 23-29 June-July, just after sunset till nearly midnight, could correlate to some birds activities, or other groups such as amphibians at this coastal-freshwater habitat. ACI index depends on the variation of intensity in the spectral and temporal scales, while ignoring sounds with the constant intensity (Pieretti et al., 2011).

In conclusion, acoustic indices can provide an estimation of bird community dynamics across several sites, the temporal heatmaps offering a view of these dynamics at a glance. However, this is still an estimation that is not enough to describe the other components of the acoustic soundscape, which include other biophony sounds of amphibians, insects and mammals. Also, other sound sources like geophony and anthrophony should be more carefully considered in the estimation as it could have an effect on birds behavior or land use. In addition, identifying other sound sources could lead to more clear identification of bird sound activities, thus better estimation of birds acoustic richness. The acoustic method could be more evaluated by enhancing the study design to include other ecosystems like coastal line, farms, and other desert areas. Expanding the scale spatially to cover more areas in Kuwait would provide more bird areas, species, and information on habitat preferences. Future study could be done to compare different microhabitats at a given site, or evaluate the variation of acoustic diversity in a gradient scale. It would be also interesting to expand the recording time schedule to cover more day time after sunrise till sunset, and estimate the acoustic activities of different components of the soundscape that could be different outside the current time scale in our study. Furthermore, covering more years could explore the effect of climate change, habitat loss, and species turnover. These promising tools given by acoustic indices could escalate the biodiversity monitoring plans and could be a key to guide further analysis of a certain habitat if it is also combined by other estimation tools like automated acoustic recognition to get information on species level, and visual surveys.

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Estimation of annual phenology of a migratory and a breeding species using automated acoustic detection

3.1 Summary

3.1.1 Context

Traditional and acoustic monitoring methods revealed the annual phenology of bird diversity in Kuwait. However, studying species-specific phenology requires the development of proper methods to recognize species vocalizations. Developing such an approach to identify species' acoustic activities could provide a useful tool to determine the annual phenology of their vocal behavior.

3.1.2 Problematics

The migration phenology of target species has yet to be studied in Kuwait. Also, the life cycle phenology of resident species has also to be studied. Automatic acoustic recognition methods can be used to model the phenological trends in vocalizations of migratory and resident species, by studying their acoustic activities during a year of audio recording.

3.1.3 Methods

However, extensive data from audio recording cannot be analyzed manually, so we need to develop software training to identify our target species in our audio files. We used Kaleidoscope software to identify vocal signals emitted by two target species, to determine the phenology of their acoustic activities during one year of audio recordings.

3.1.4 Main Results

Automated recognition of species calls was used to assess the phenology of acoustic activities of a shorebird species, the Eurasian Curlew. In addition, the acoustic activities of a resident species, the Eurasian Collared Dove, helped to understand its behavior during the breeding and non-breeding phases.

3.1.5 Perspective

Our results advocate the further use of automatic audio-recording and the development of automated recognition to study the phenology of breeding and migration in Kuwait.

3.2 Introduction

Automated passive acoustic monitoring is largely adopted for ecological research and surveys, especially for birds. However, these techniques need a proper way of analysis that is feasible in terms of budget and time.

In the previous chapter, the acoustic indices technique appeared as a suitable method for extracting meaningful ecological information from the massive amount of audio data (Sueur et al., 2014; Doser et al., 2020). However, although acoustic indices are helpful in assessing various ecological aspects, there is still a need to offer information at the species level (Gibb et al., 2019). As a response, automated machine learning algorithms were developed to analyze audio files at the species-specific level. The need for automated signal recognition programs arises from the challenge faced by the amount of time necessary to process and extract target species detection from massive recording datasets (Shonfield and Bayne 2017; Knight et al, 2017).

Species identification through signal recognition is another approach of acoustic methods. In this approach, a pattern recognition algorithm, or a dataset for training a predictive model, is created from a compilation of identified bird calls of a particular species, which is later used to recognize the species in a series of audio files. The disadvantage of this approach is that it cannot be used for large bird communities where the sounds of multiple species have a high probability to overlap in time and frequency, like during dawn chorus.

The process of acoustic species recognition using a predictive model, or machine learning, involves training a computer program to positively detect an acoustic signature of a species vocalization, then to recognize it among other signal detections, and finally evaluate the detection

(Knight et al, 2017). Machine learning approaches are developed and continuously evaluated for their performance in acoustic recognition (Towsey et al., 2012; Ganchev, 2017), such as Hidden Markov models (HMM; Skowronski and Harris 2006, Potamitis et al. 2014, de Oliveira et al. 2015), random forests (Aide et al. 2013), or artificial neural networks (Jennings et al. 2008, Tachibana et al. 2018).

The software Kaleidoscope was developed to analyze the recordings obtained with an automated recorder unit (Wildlife Acoustic 2020). Following a k-means clustering algorithm, Kaleidoscope uses Hidden Markov models (HMMs) to identify clusters annotated by the user. Kaleidoscope's recognizer builds classifier algorithms that run the vocalization in audio files through the HMMs to raise the probability of detecting each call in the entire dataset. Kaleidoscope had relative success in call identification. Previous tests showed that the software performed well in the identification of simple and consistent calls such as those of the Common Nighthawk (Knight et al, 2017), Eastern Wood-Pewee (Doser et al, 2021), and Roroa Great Spotted Kiwi (Jahn et al, 2022). Another study compared the performance of Kaleidoscope with other similar softwares, and showed that it has the ability to give data review, high speed processing, classification, and data export (Xueyan and Jia 2020).

In the previous chapters, we revealed that there is a clear seasonal phenology of bird species richness in Kuwait. We found that freshwater was the habitat with the highest species richness, and attracted most migratory species, while desert was the habitat with the lowest species richness. We reported previously the general annual phenology of species richness in Kuwait, as determined by traditional and acoustic methods. Here, we aimed at determining some

phenology at the species level. We focused on two candidate species with simple and highly characteristic vocalizations: a migratory species, the Eurasian Curlew (*Numenius arquata*), and a resident species, the Eurasian Collared Dove (*Streptopelia decaocto*).

The Eurasian Curlew is a coastal shorebird breeding in northern Russia and wintering along the coasts of the Arabian Peninsula, East Africa and south-east Asia. In Kuwait, it is found in protected coastal areas, like Jahra Pool freshwater reserve. It is a very distinguishable species by sight and call. The Eurasian Collared Dove has a large distribution across Kuwait, and is potentially present from vegetated sites in the desert to freshwater sites, so in almost all types of habitats, including human settlements. The exact phenology of these species have not yet been studied, and it could help in understanding the migration phenology of birds in Kuwait.

More specifically, on one hand, we aimed at defining the migratory phenology and seasonal acoustic activity pattern for the long-distance migratory Eurasian Curlew. On the other hand, we wish to assess the annual phenology, the potential change of its acoustic behavior according to the life cycle phase for the resident Eurasian Collared Dove. To attain these objectives, we used automatic detections returned by Kaleidoscope for each week, so that a one year acoustic activity pattern could be assessed from six deployed automated recorders, disposed in different microhabitats.

3.3 Materials and Methods

3.3.1 Target species

3.3.1.1 The Eurasian Curlew

Scientific name: *Numenius arquata* (Charadriiformes, Scolopacidae)

The Eurasian Curlew is a common, non-breeding, winter visitor in Kuwait. It is a coastal bird usually seen in the protected and remote coastal areas of Kuwait. The Eurasian Curlew is a large wader with long down-curved bill that feeds by probing soft mud for small invertebrates (Figure 30). The species population is threatened by land use changes in the breeding range, including the intensification of agricultural practices, but also by the degradation of mudflats on stopover and wintering sites, and by human disturbance, including hunting.

The Eurasian Curlew is a highly vocal species with a unique and distinguishable call, that can be translated with the onomatopoeia "coor-lee", which gives the species its common name. The Curlew call is a sequence of A-B syllables. The first syllable (A) lasts around 0.5 s and shows a slow ascending frequency modulation. This introductory note can be repeated once or twice. The following second syllable (B) has an approximate length of 0.3s and shows sinusoidal frequency modulation about 500 Hz. This syllable can be repeated up to 11 times separated by gaps of less than 0.2 seconds, to reach a length of 7s (Figure 30). Both syllables fall in the same frequency range (1000-5500 Hz).

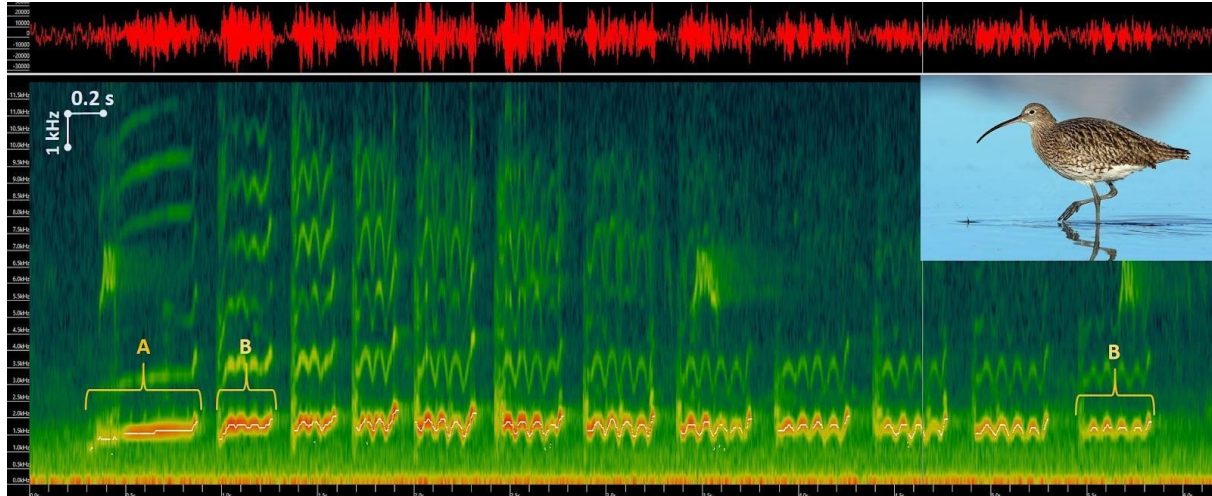


Figure 30. Eurasian Curlew call. The call sequence starts with a syllable A followed by a longer section of repeated different syllables (B). Frequency range between 1000 – 5500 Hz. Top right corner: adult of Eurasian Curlew *Numenius arquata* (credit to Aurélien Audevard).

3.3.1.2 Eurasian Collared Dove

Scientific name: *Streptopelia decaocto* (Columbiformes, Columbidae)

The Eurasian Collared Dove is a common breeding resident bird in Kuwait. Its distribution ranges across Eurasia, Arabia, and North Africa, while the species is also colonizing North America following introduction. This dove benefits from food and shelter availability in urban areas, farms, and deserts, where it roosts and breeds, mostly on trees. The major threat for these birds could be overhunting, as it is a game bird, though the species has mostly been increasing in range and population size in recent decades (Figure 31).

The call of the Eurasian Collared Dove consists of two alternating syllables, following the syntax A-B-A, that can be translated with the following onomatopoeia “woop-WOOO-woop”. There is

no frequency modulation, the fundamental frequency, which is also the dominant frequency, stays constant throughout the call, with a value between 250 and 400 Hz. (Figure 31).

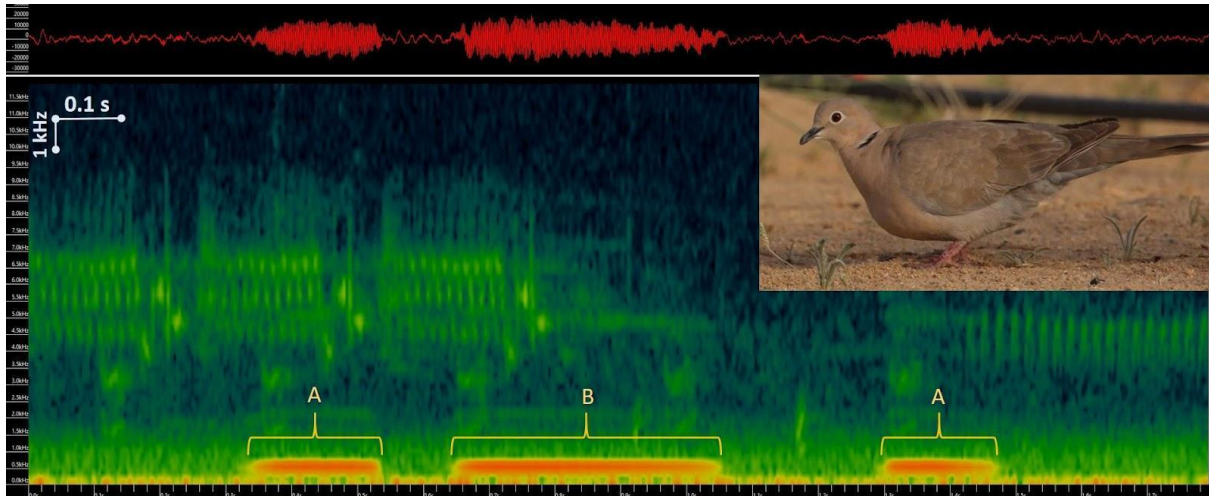


Figure 31. Eurasian Collared Dove call. The call consists of two parts, A and B, with the following syntax A-B-A. The frequency is constant ranging from 250-550 Hz. Top right corner: adult of the Eurasian Collared Dove *Streptopelia decaocto* (credit to Rashed Al-Hajji).

3.3.2 Recording sites

The audio recorders were deployed at two sites located in two main different habitats: Jahra Pool Reserve (JPR), a freshwater nature reserve, and Kabd Research Station (KRS), a desert habitat. In JPR, recorders were deployed in four microhabitats, namely sea coast, transitional coast with freshwater (TCF), freshwater pool, and desert. In KRS, one autonomous recording unit (ARU) was settled in each of two microhabitats: one in a tree (*Eucalyptus sp.*), and one in the open desert. One recording unit consisted in a Song Meter SM4 (Wildlife Acoustics) programmed to record 16 bit wav files starting two hours before sunset, till two hours after sunrise. Only two minutes were recorded in each ten minutes of an hour. There was a deficiency in the recorders

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during the following periods: Jahra coastal (18 – 29 October, 21 -27 March, 21 -28 April), Jahra Transition between Coast and Freshwater TCF (21 -27 March, 21 -28 April), Jahra Freshwater (16-30 December, 21-27 March), Jahra desert (18 – 29 October, 21 -28 April, 25 June – 4 July), Kabd Tree (October, 1-15 November, 11-27 March, 1-8 July), and Kabd Oben Desert (1-7 February, 11-27 March, 1-8 July) (Table 11).

Table 11. Number of audio files obtained by each autonomous recording unit (ARU) in each microhabitat.

ARU	Number of Audio Files
Jahra Coast	33,491
Jahra Transition Coast-Freshwater	34,169
Jahra Freshwater	32,048
Jahra Dry	32,096
Kabd Tree	33,129
Kabd Open Desert	37,261
Total	202,194

3.3.3 Automatic sound detection

We used Kaleidoscope (WildlifeAcoustic, 2020) which automated process is based on an unsupervised clustering process followed by Hidden Markov models (HMMs) applied on a spectrographic representation. A detection determines the start and end of a vocalization in the waveform in the spectrogram (Xueyan and Jia 2020).

The selection settings were 10.76 ms for the width of the Fourier window, 250 Hz for the minimum frequency, 5 500 Hz for the maximum frequency, and 0.35 s for the inter-syllable gap. The first step of the detection process consisted in building an unsupervised way sound clusters. These clusters worked as candidates of the calls produced by the Eurasian Curlew and the Eurasian Collared Dove, separately. We then checked all clusters and identified those that were related to both species of interest. This process was repeated several times, so that the definition of the clusters could be improved. The first run was on the main data set, then four runs were enough to finally find a good representative cluster. For each run, we calculated the total number of clusters, the number of clusters containing true species detections, and number of detections from the training dataset. The targeted detections in the new input files were then reinforced by the files in the training dataset. At the end point, the more detections from the target subfolder in a cluster, the better statistical power for the cluster. Then, we examined these clusters, and chose the best representative cluster for each target species. The representative cluster would have more true positive detections of the species call. True positive detections are the detections of the species call, and false positives are calls of other species found in the cluster. We validated the results by scanning the clusters of the target species. For our analysis, we included only the true

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positive detections. Tables 12 show the performance of the software in successfully finding true positive detections of the two species in each deployment recorder.

Table 12. Performance of Kaleidoscope software in extracting the true positive detections of Eurasian Curlew and Eurasian Collared Dove from audio files from six deployment recorders in different microhabitats.

	Total detections in cluster	Validated detections	Percentage
Eurasian Curlew			
Jahra Coast	6268	5957	95
Jahra Transition Coast and Freshwater	3641	331	9.1
Jahra Freshwater Pool	0	0	0
Jahra Dry	0	0	0
Kabd Tree	0	0	0
Kabd Open Desert	0	0	0
Eurasian Collared Dove			
Jahra Coast	10276	388	3.7
Jahra Transition Coast and Freshwater	2489	755	30
Jahra Freshwater Pool	2464	570	23
Jahra Dry	1379	209	15.15
Kabd Tree	22562	8624	38.2
Kabd Open Desert	3911	142	3.6

3.3.4 Comparison with traditional counting

Traditional observation data extracted from eBird (see Chapter 1) were compared with the acoustic detections. We considered eBird data for both target species in Jahra and only the Eurasian Collared Dove in Kabd.

The correlation between traditional counting and acoustic detection was achieved by merging the data per month, scaling the year time series between 0 and 1 and applying non-parametric Spearman correlation tests.

3.4 Results

3.4.1 Call detections

Only recordings from Jahra Coast and Jahra Transition Coast-Freshwater (TCF) included detections of curlews. For the other recorders, we obtained no true positive detections of that species. For the Eurasain Collared Dove, all recorders had true positive detections.

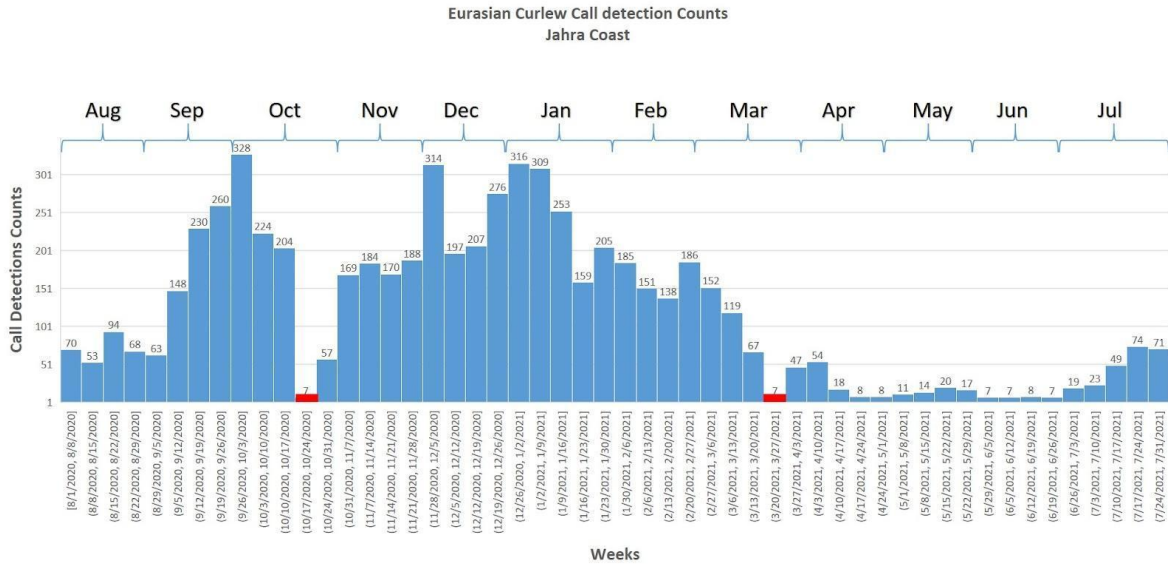
3.4.1.1 Eurasian Curlew

The Eurasian Curlew was detected 6,179 times in Jahra sites only. Jahra Coast was the site with the highest number of detections (5,957), with the remaining 222 detections at Jahra Coast-Freshwater transition site. We had no detections in other Jahra sites (Freshwater and Dry). At Jahra Coast, there were more detections from the week of June 26 and then increasing through the end of October, with higher peaks during the week of September 26 through October 3. This pattern was followed by another higher activity through March and a third lower peak from late June through late August. There were fewer detections from mid-April to late June (Figure 32 a).

In Jahra Transition, the same temporal pattern was observed as in Jahra Coast, but with less detection events (Figure 32 b).

Chapter 3: Estimation of annual phenology o using automated acoustic detection

a)



b)

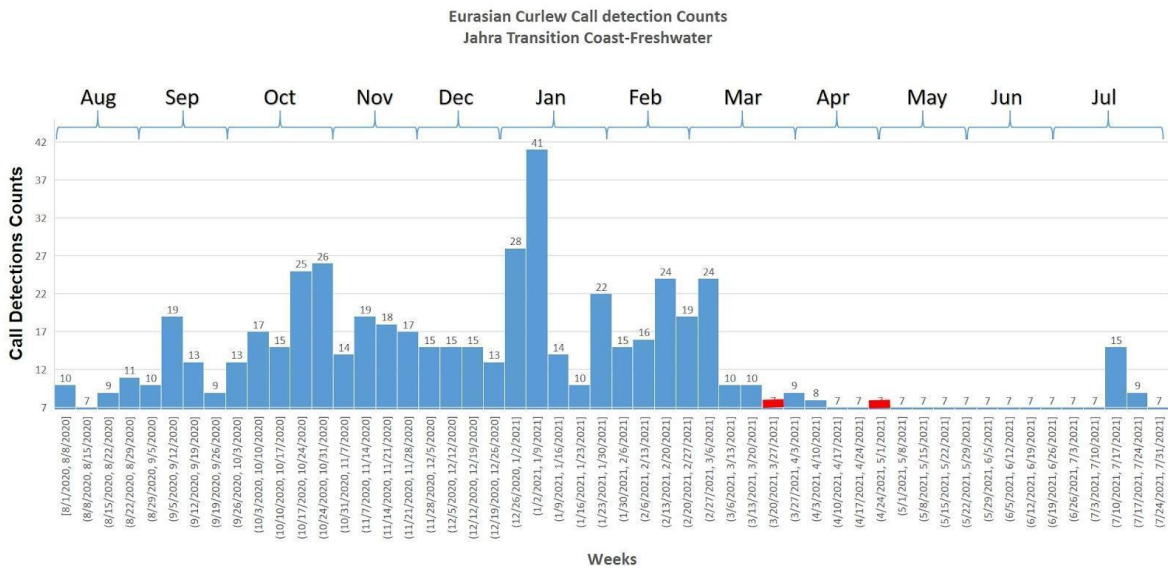


Figure 32. Eurasian Curlew acoustic detections in Jahra Coast site during the period from 1st of August 2020 till end of July 2021. a) Jahra coast, two peaks appear in September-October, and December-January. b) Jahra Transition Coast Freshwater TCF, the highest peak, appears in January. Red bars indicate the periods of recorder deficiency.

3.4.1.2 Eurasian Collared Dove

The Eurasian Collared Dove was detected 2,130 times in Jahra sites and 4,507 times in Kabd sites.

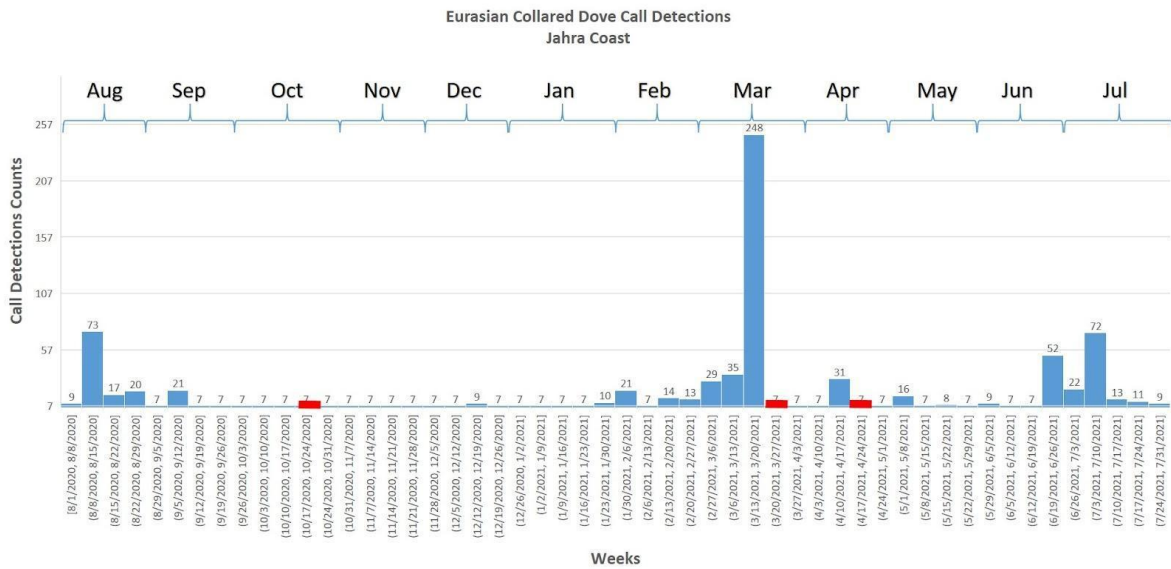
In Jahra the detection of dove calls was higher in Jahra TCF, followed by Jahra Freshwater, then Jahra Coast and Jahra Dry. Although there were more detections at Jahra coast, the percentage of true positive detections was higher in Jahra Dry. However, Jahra Coast and Jahra Dry microhabitats showed similarity in weekly detection peaks, the highest peak in February – March, and two lower peaks in June, July, and August. The other two adjacent microhabitats, Jahra TCF and Jahra Freshwater, showed the same February – March peak, but with additional high peaks in May. This May peak was higher in Jahra Freshwater (Figure 33).

Kabd Tree was the site with the highest number of detections while less detections were found in Kabd Open Desert and Jahra sites. Kabd Tree microhabitat acoustic detections analysis showed a higher amount of dove call detections than Kabd Open Desert. Although there was a noticeable difference between the two microhabitats in the detection quality, the peaks of detection corresponded to each other. Detection peaks occurred in January – February, March – April, July –August (Figure 34). Jahra TCF, Jahra Freshwater shared high peak in June, which is shifted from July peak in Kabd Tree

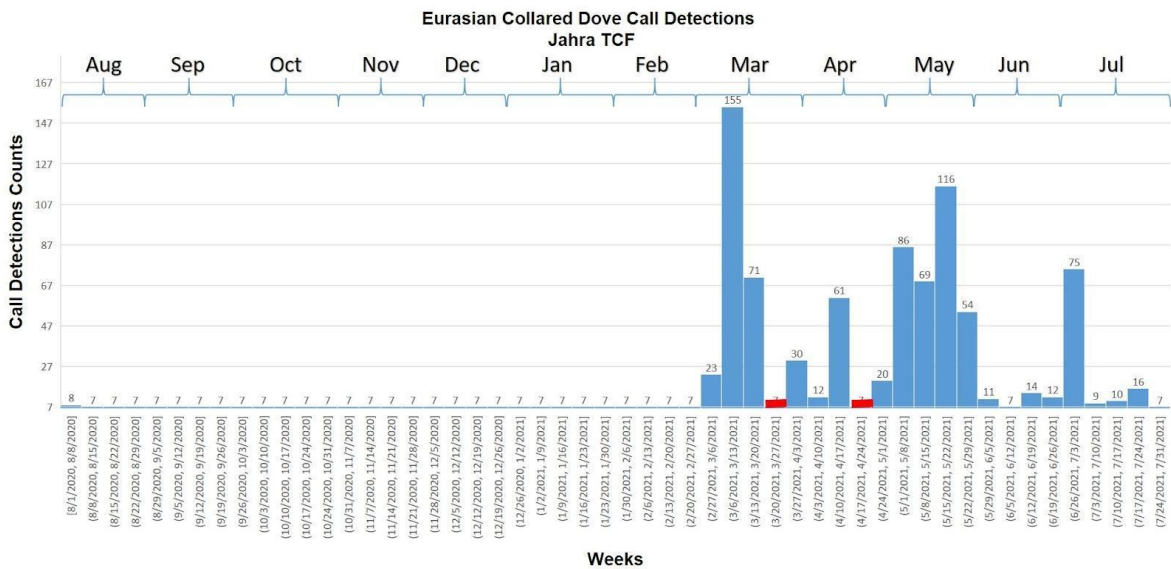
The highest dove detection quality was in Jahra Tree by 38%, followed by 30% in Jahra TCF. Jahra Freshwater had a quality of 23%, higher than Jahra Dry 15.15%. The lowest detection quality was in Jahra Coast and Kabd Open Desert.

Chapter 3: Estimation of annual phenology o using automated acoustic detection

a)

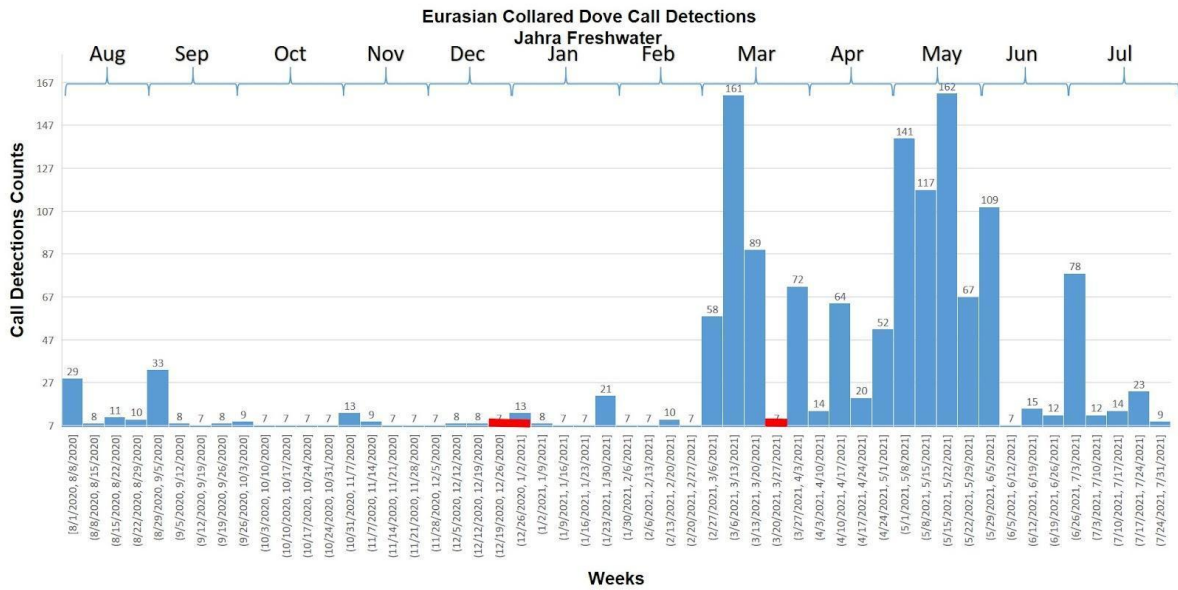


b)



Acoustic monitoring of wetland habitats in dry regions (Kuwait)

c)



d)

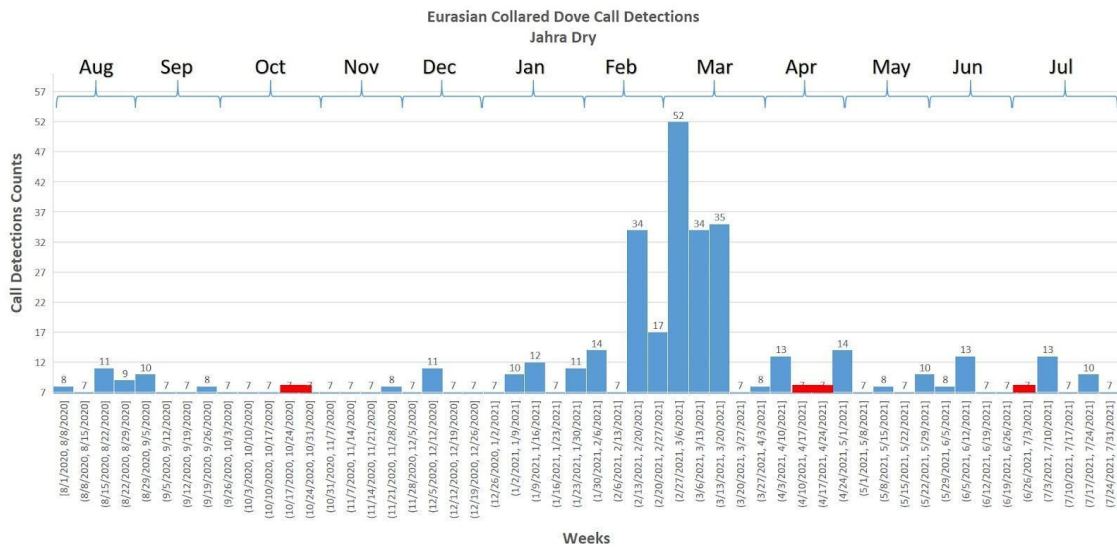
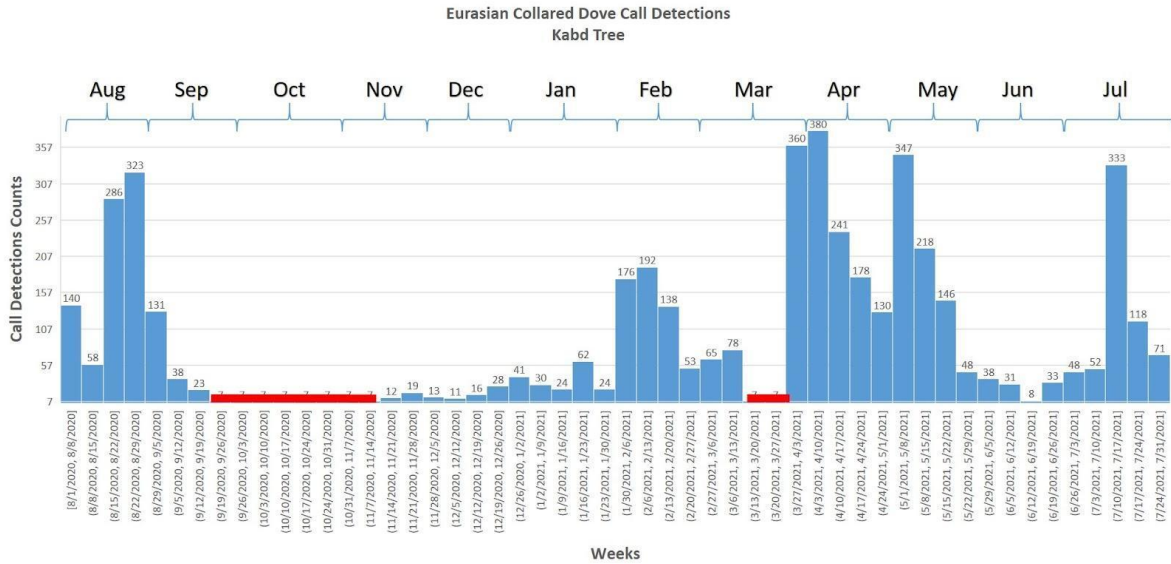


Figure 33. Eurasian Collared Dove acoustic detections in Jahra Freshwater during the period from 1st of August 2020 till end of July 2021. a) Jahra Coast, the highest peak, appears in March. b) Jahra TCF, the highest peak appears in March, followed by another peak in May. c) Jahra Freshwater, two high peaks appear in March and May. d) Jahra Dry, the highest number of detections were during February and March, with scattered detection during the rest of the year. Red bars indicate the periods of recorder deficiency.

Chapter 3: Estimation of annual phenology o using automated acoustic detection

a)



b)

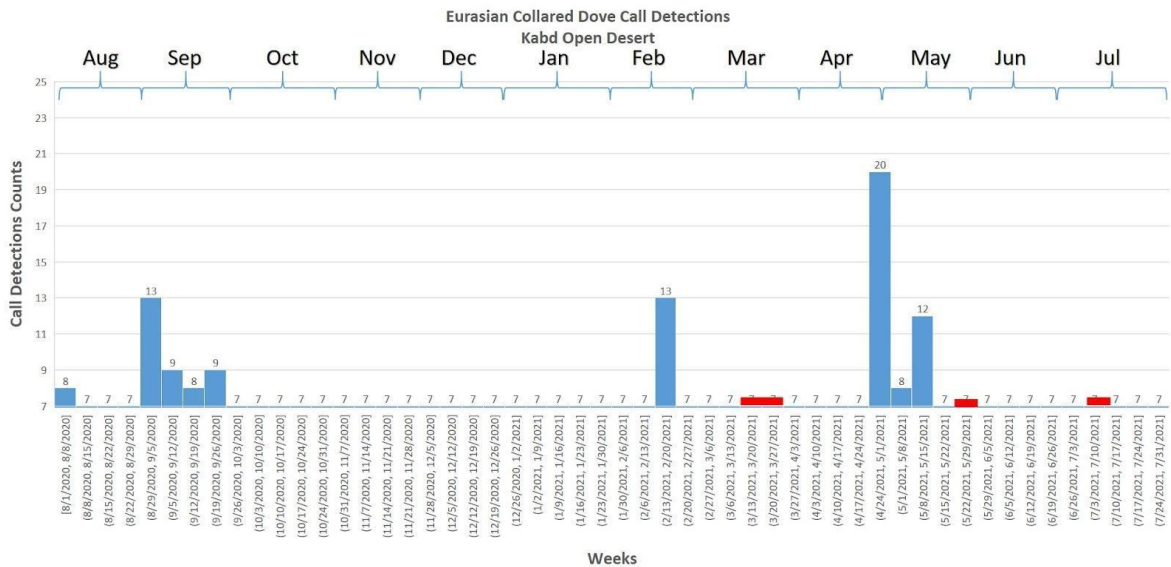


Figure 34. Eurasian Collared Dove acoustic detections counts in Kabd Tree during the period from 1st of August 2020 till end of July 2021. a) Kabd Tree, the highest peak appears in February, April, July, and August. b) Kabd Open Desert, there were three peaks of activity, in February, April-May, and August-September. Red bars indicate the periods of recorder deficiency.

3.4.2 Correlation between microhabitats

3.4.2.1 Eurasian Curlew

Jahra

Detections of the curlew from the two recorders in both microhabitats in Jahra showed almost the same pattern (Spearman correlation, $R=0.87$, $p = 0.0002$), but with a shift of the autumn peak from September in Jahra Coast to October in Jahra TCF (Figure 35). This could be due to the deficiency of the recorder in October, or the high level of background noise in Jahra Coast.

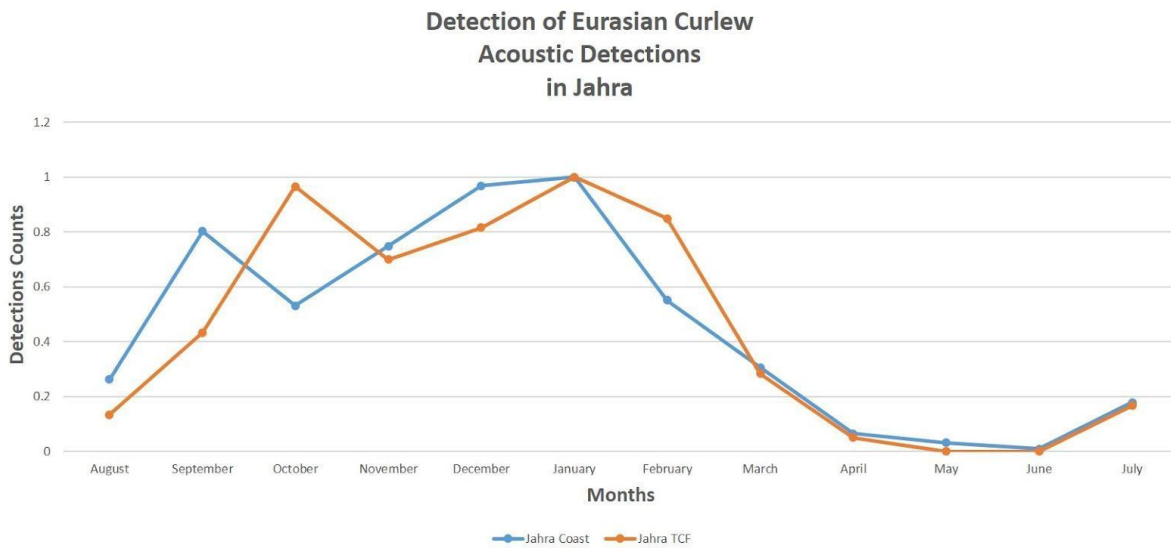


Figure 35. Comparison of acoustic detections of Eurasian Curlew between Jahra Coast and Jahra Transition Coast-Freshwater (TCF). Blue line indicates the detection curve at Jahra Coast sites, with two peaks in September and January. Detections at Jahra TCF indicated by the orange line show a shift in the first peak from September to October, the second peak joins the peak of Jahra Coast in January.

3.4.2.2 Eurasian Collared Dove

Jahra

We found the same pattern of acoustic detections of doves at the Jahra sites with a peak in March, but the two microhabitats Jahra TCF and Jahra Freshwater had additional peaks during May (Figure 36). Jahra Coast and Jahra Dry showed significant correlation (Spearman correlation, $R = 0.68$, $p = 0.014$) and Jahra TCF and Jahra Freshwater showed a significant similarity (Spearman correlation, $R=0.79$, $p < 0.002$).

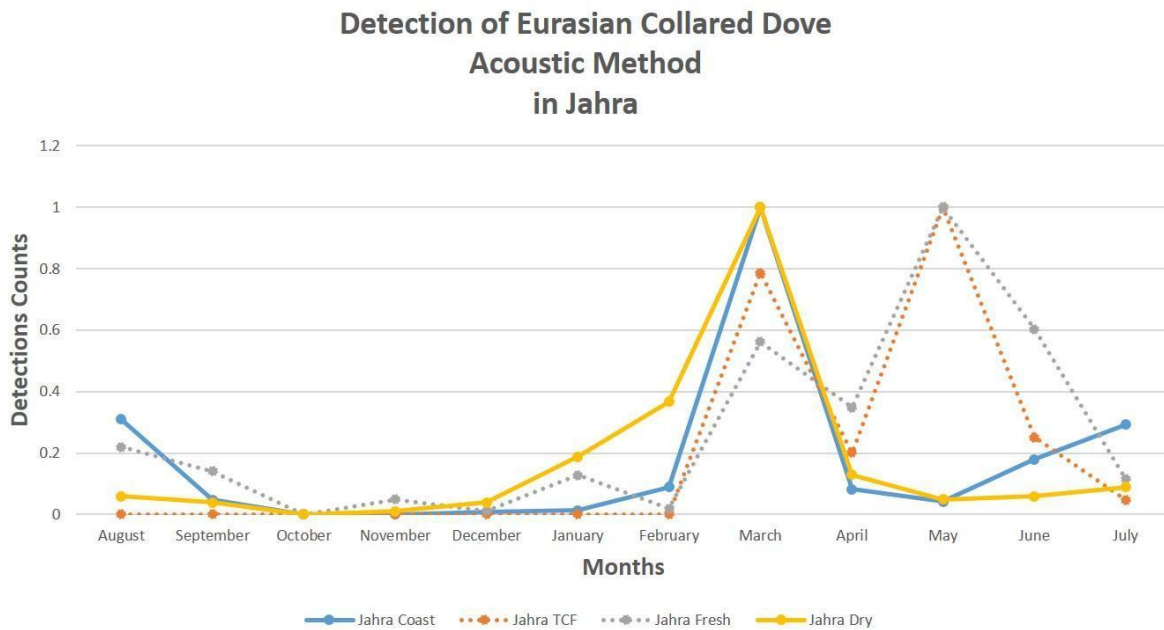


Figure 36. Comparison of acoustic detections of Eurasian Collared Dove between Jahra Coast, Jahra Transition Coast-Freshwater TCF, Jahra Freshwater, and Jahra Dry. Blue and yellow lines indicate the acoustic detection curve of Eurasian Collared Dove at Jahra Coast and Jahra Dry, with almost the same pattern with one peak in March. The dotted orange and gray lines represent the acoustic detection of the dove at Jahra TCF and Jahra Freshwater; the pattern here differs with additional peak in May.

Kabd

The phenology trend of acoustic detections of the dove in Kabd Tree and Kabd Open Desert were almost similar (Figure 37). Only the September peak of Kabd Open Desert might be referred to the deficiency of the device in Kabd Tree during this period. The correlation was significant (Spearman Coefficient $R=0.62$, $p = 0.021$).

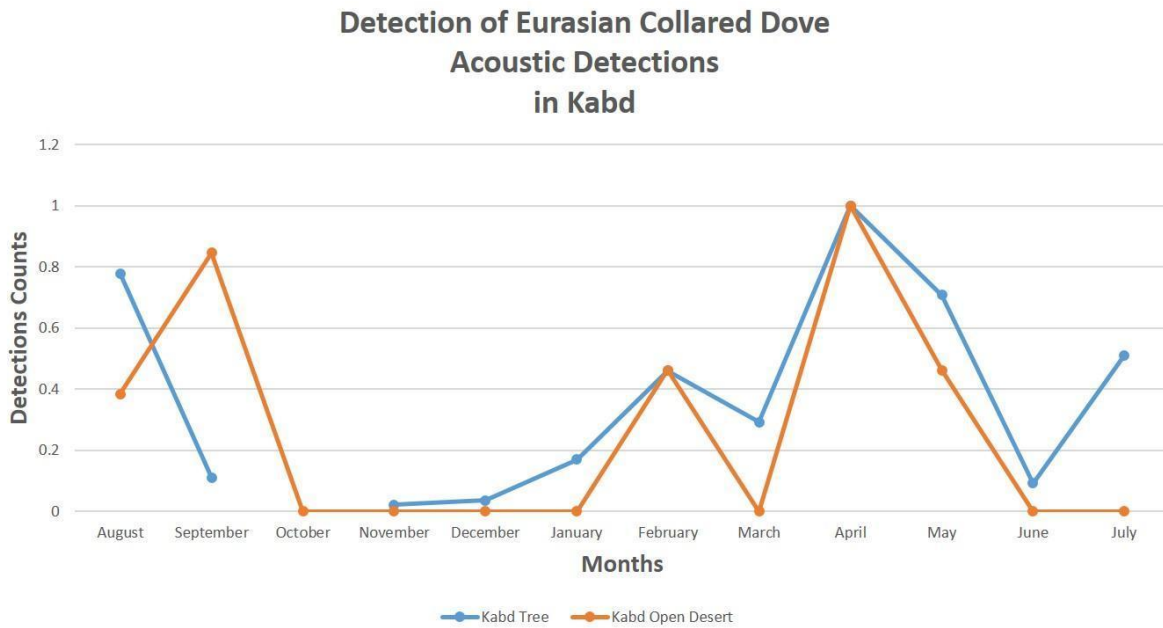


Figure 37. Comparison of acoustic detections of Eurasian Collared Dove between Kabd Tree and Kabd Open Desert. Kabd Tree curve, in blue line, indicates two peaks in August and April, and lower peak in February. The Kabd Open Desert curve, in orange, shows a similar pattern, but with a shifted first peak from August to September.

3.4.3 Correlation between Acoustic detection and Visual detection

3.4.3.1 Eurasian Curlew

Jahra

When comparing the visual with the acoustic detections of the curlew, we also found similarities in the phenology of the species. Only the January peak of visual detection matched with peaks from the acoustic detections, while the March peak stood out from the acoustic detection trend (Figure 38).

Spearman test showed a significant correlation between the Jahra Coast and visual detection Spearman Coefficient value of 0.72 p-value of **0.008**. And between Jahra TCF and visual detection with Spearman Coefficient value of 0.79 p-value of **0.002**.

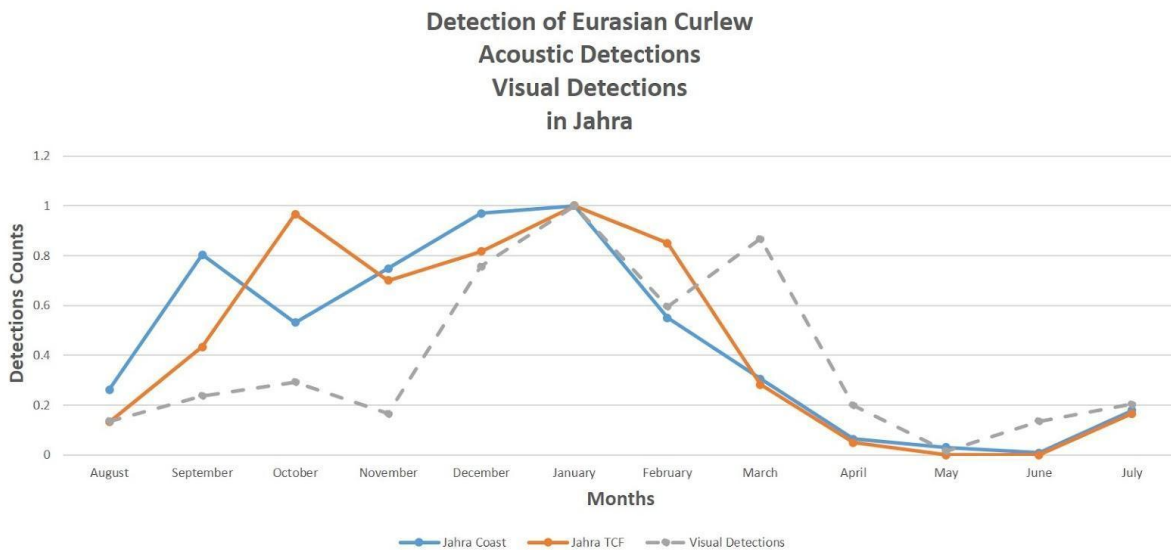


Figure 38. Comparison of Eurasian Curlew detection at Jahra sites between two methods, the acoustic detections and visual detections.

3.4.3.2 Eurasian Collared Dove

Jahra

In Jahra, the peaks of higher acoustic detection shifted from April to March, following December-January-February peaks in the visual detections of doves in JPR (Figure 39). There was no significant correlation between the four microhabitats with the visual detection method. The correlation between acoustic detection at Jahra sites and visual detection showed Spearman Coefficient values ranging from -0.61 to 0.06, and p-values ranging from 0.03 to 0.83. The results of the Spearman correlation test of dove detections at Jahra sites are presented in Table 3.

Kabd

When we compared the two microhabitats with the eBird visual detection of the dove in KRS, there was an obvious difference (Figure 40). Also, the Spearman test showed that there was no correlation between the two methods. Correlation between acoustic detection at Kabd Tree and visual detection resulted in a Spearman Coefficient value of -0.23 with a p-value of 0.45.

Correlation between acoustic detection at Kabd Open Desert and visual detection resulted in a Spearman Coefficient value of -0.13 with a p-value of 0.68.

It was interesting to notice that the peaks of January and October of the visual detection met with low peaks of acoustic detection. However, these higher peaks were followed by higher peaks of acoustic detections (Figure 39). All the results of the correlation analysis are summarized in Table 13.

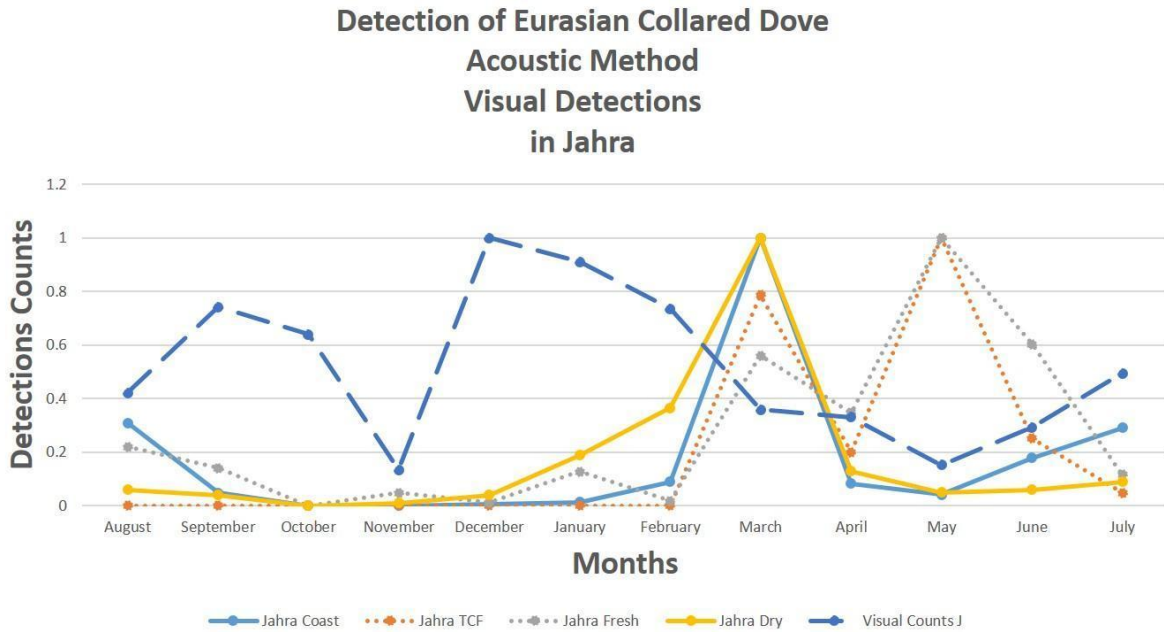


Figure 39. Comparison of Eurasian Collared Dove detections at Jahra sites between two methods, acoustic detections and visual detection. Light blue and yellow lines represent the acoustic detections at Jahra Coast and Jahra Dry, while the dotted orange and gray lines represent the acoustic detections at Jahra TCF and Jahra freshwater. The dark blue dashed line represents the visual detection curve of the dove at Jahra site. The two peaks of visual detections during September and December correspond with lower acoustic detections, on the contrary acoustic high peaks of detections meet lower visual detections.

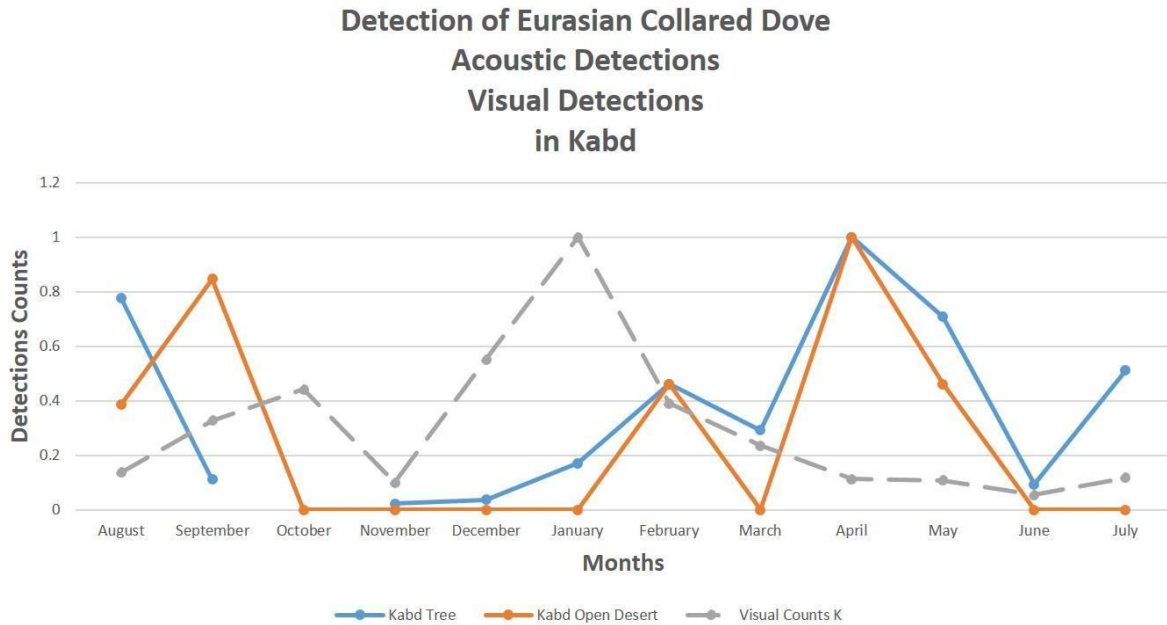


Figure 40. Comparison of acoustic detections at Kabd Tree and Kabd Open Desert and visual detections of the Eurasian Collared Dove between. Blue and orange lines represent the curve of acoustic detections at Kabd Tree and Kabd Open Desert. The dashed gray line represents the curve of visual detection of the dove at Kabd site. The peaks of High visual detection during January meet with lower acoustic detections. February peak joins all detection methods values. Peaks of higher acoustic detections at Jahra Tree and Jahra Open Desert are in April. The Second peak of higher acoustic detection at Kabd Tree is during August, and at Kabd Open Desert is During September.

Table 13. The Spearman Coefficient results show the correlation significance between habitats, and between detection methods.

Microhabitats/method	Spearman coefficient	p-value
Eurasian Curlew		
Jahra Coast + Jahra TCF	0.872155	0.000216
Jahra Coast + eBird	0.721542	0.008074
Jahra TCF + eBird	0.787719	0.002347
Eurasian Collared Dove		
Jahra Coast + Jahra TCF	0.413757	0.181201
Jahra Coast + Jahra Freshwater	0.491193	0.104873
Jahra Coast + Jahra Dry	0.684414	0.014082
Jahra TCF + Jahra Freshwater	0.795395	0.001980
Jahra TCF + Jahra Dry	0.352143	0.261611
Jahra Freshwater + Jahra Dry	0.357896	0.253351
Jahra Coast + eBird	-0.09188	0.77642
Jahra TCF + eBird	-0.60824	0.03586
Jahra Freshwater + eBird	-0.57342	0.05126
Jahra Dry + eBird	0.066667	0.836905
Kabd Tree + Kabd Open Desert	0.617385	0.021608
Kabd Tree + eBird	-0.23776	0.456801
Kabd Open Desert + eBird	-0.13286	0.680625

3.5 Discussion

Our study examined the ability of automated acoustic recognition to detect the phenology of acoustic activities of two bird species and how acoustic activities can help to understand species phenology and behavior. The results showed that the patterns of acoustic activities were largely consistent with the phenological behavior of our two target species. In addition, the analysis revealed the quality of the Kaleidoscope software in detecting calls and what factors might influence its performance.

3.5.1 Automated Identification and Software Performance

Our study aimed to determine the efficiency of using the automated recognition software, Kaleidoscope, in detecting and identifying target species calls in our audio files. We found that the detection performance of the software was different for both species in different microhabitats.

Our assessment of the quality of call detections of both species showed a variation in the percentage of true positive detections. This finding suggested that automated recording performed more efficiently in habitats with bird assembly points, like a coast, water pool, and vegetation shelter. On the other hand, automated recording methods showed less ability to detect bird species in the open environment, where probabilities of recording calls are lower. The ARU position eventually has an effect on the attraction of more birds, so more calls are recorded. In addition, more precise, frequent calls in audio files led to better performance of the software to detect the bird species call. When the calling species is closer to an ARU, clusters of auto detections would contain more true positives. But, clusters had fewer true positives where calls were recorded far away from the recording units.

Microhabitat effect was shown in the case of the Eurasian Curlew, a species that prefers to use coastal habitat, automated passive monitoring performed better at locations closer to the coast. ARU recorded clear calls that were detected with higher percentage of true positive detections than recording units farther from the coast.

For the Eurasian Collared Dove, automated recording units could catch more dove calls in Kabd Tree, a microhabitat more suitable for this species, which uses to perch on trees and shrubs (Benghedier et al., 2020). The same case could be true for Jahra TCF and Jahra Freshwater, two microhabitats with dense vegetation and water source.

Another factor that affected the quality of call detection was the noise that were masking calls of the same frequency, or disturbing the software from detecting the target species. This effect was observed in the case of dove calls detection quality. We noticed that the quality of the software performance varied in detecting dove calls between Jahra Coast site and quieter Kabd sites. Jahra is a site with more anthropogenic noise than Kabd. Jahra is located near the city of Jahra, an inhabitant city in Kuwait, where many city sounds, like cars, sirens, and mosques announcements and calls, could reach the range of the recorders. In addition, the reserve is adjacent to the coast and coastal noise. Also, Jahra Pool Reserve is open to the public by permit. On the other hand, Kabd is an almost isolated desert reserve with restricted access; only KISR personnel are allowed. Lower quality performance in dove call detection in Jahra Coast could be referred to as the fact that doves have low-frequency calls, which are masked by the low-frequency anthropogenic noise.

In another aspect, acoustic methods and automated recognition showed a good performance in detecting the phenological differences even in close-by but different microhabitats. Acoustic activities of the Collared Dove in Jahra differed uniquely. The two far microhabitats, Jahra Coast and Jahra Dry, with diverse distinctive habitats, showed similar acoustic activities pattern. On the

other hand, the adjacent microhabitats, Jahra TCF and Jahra Freshwater, showed similar activity patterns but differed from the other two. An additional peak was noticed in the latter two during May. It is worth further investigating the effect of the interaction between different species' compositions on this bird's acoustic behavior. The different types of birds hosted by Jahra TCF and Jahra Freshwater could cause the dove to alter their vocal behavior during this time of the year. There is clearly more competition in these two microhabitats. Also, the performance of our acoustic methods revealed the similarities and slight shifting of acoustic activity peaks in two contrasting habitats, Freshwater and Desert.

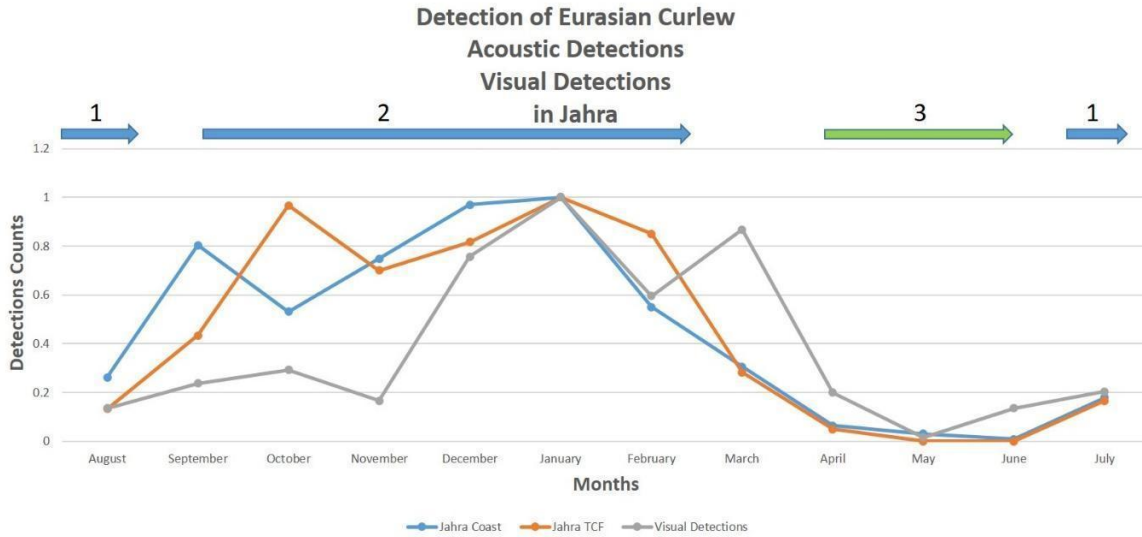
In addition, we found that the factors affecting acoustic behavior differ according to the species status at the deployment sites. For instance, nonbreeding species, as of Curlew, the breeding phenology is not affecting their acoustic behavior, while migration phenology is the major factor that alters their acoustic activities significantly during different phases of their migration status. On the other hand, a resident breeding species, such as Eurasian Collared Dove, breeding phenology is the factor that affects their acoustic behavior during the year.

3.5.2 Automated Identification and phenology of target species

Our results showed that the acoustic automated identifications could reveal the phenology of the two target species, one migrant, the other resident. For Eurasian Curlew's, the automated methods could detect the arrival of the individuals with an increase and plateau of the number of detections, then the departure with a decrease of the number of detections, with the period

between two events corresponding to the migration time (Figure 41). Curlews start their post-breeding migration to their wintering grounds around mid-June, for failed breeders. Most breeders arrive on wintering grounds in July. So, they start arriving in late June and accumulate during the summer. Then, juveniles migrate southwards from late July to mid-August, and join adults on wintering grounds from August onwards. Some birds will perform longer en route stopovers than others, so that the numbers of curlews on wintering sites, like Kuwait shores, increases until October, causing the first peak. Studies show that Curlew spend a long time in their wintering grounds, which explains the peaks from November to May. Spring migration starts in April, adult birds moving north to their breeding grounds (Pederson et al., 2022). As some tagging studies suggested, Curlews show fidelity to their wintering sites (Brown 2015). When we compared the two detection methods, we observed a high peak of visual detection during March, which did not correspond to the acoustic detection during the same period. Observers might record the far located species from the coast during the low tides. Low and high tide effects on the acoustic detection of coastal birds could be an interesting point to investigate further.

a)



b)

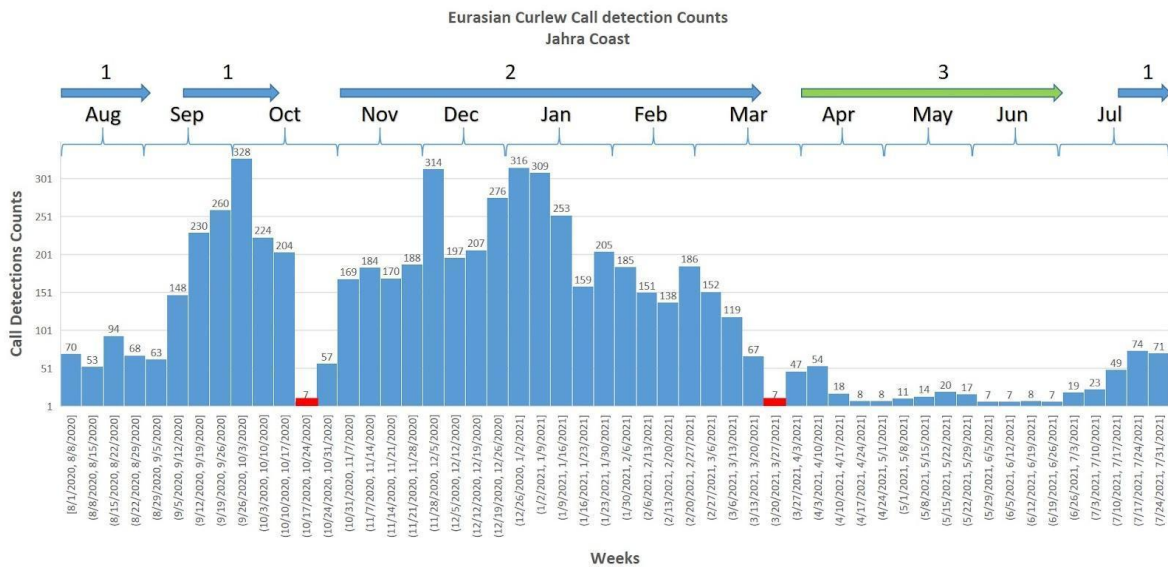


Figure 41. Comparison of acoustic detections and visual detections between Jahra Coast, Jahra Transition Coast-Freshwater TCF, and visual detection method. The arrow bars above indicate the migration status of the curlew: 1 Fall migration, 2 Wintering period, 3 Spring migration to breeding grounds. a) shows the monthly counts of Curlew detections, b) shows the weekly counts of Curlew detections.

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Determining the breeding phenology of collared doves is more complicated when using automated identification methods. Acoustic detection of this species was not correlated with visual detections. This discrepancy between the two monitoring techniques might be explained by the species breeding behavior. A study in the desert habitat of Saharan Algeria showed that the Eurasian Collared Dove has two peaks of nesting activities, a first one in March, and a second one in July (Benghedier et al., 2020). The second peak is linked to the rain season in the Sahel, and could be extended or shifted to June in Kuwait. Personal contact with the local birders in Kuwait also indicates a third peak of nesting during November (Figure 42).

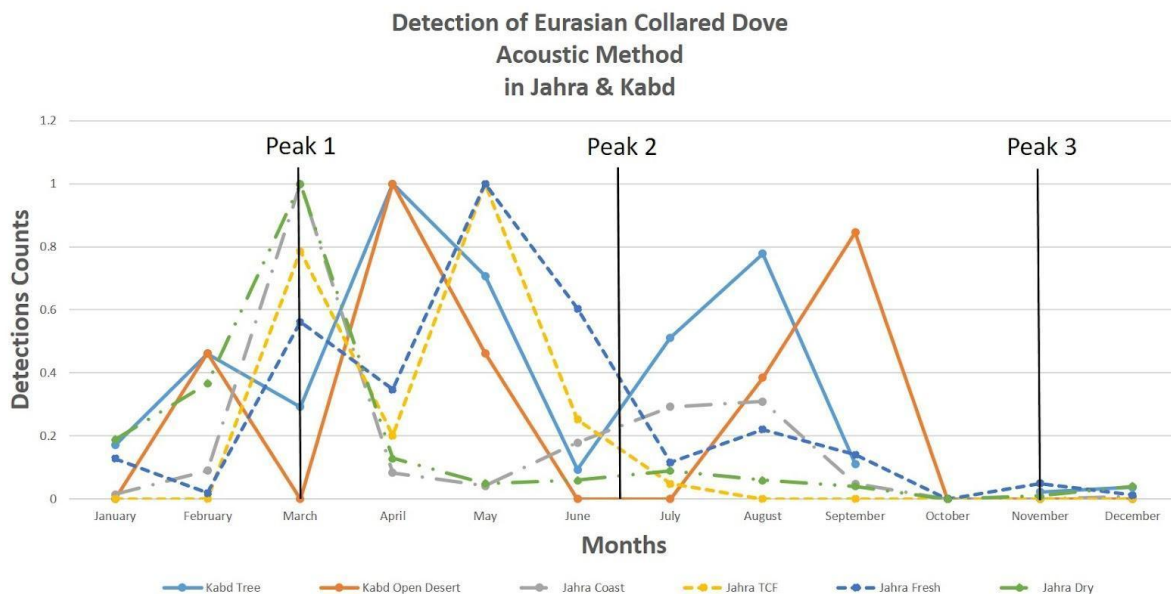


Figure 42. Comparison of acoustic detections of Eurasian Collared Dove between Jahra sites and Kabd sites. Vertical black lines indicate the peaks of nesting activities for the dove.

When comparing the acoustic detection temporal profiles in the freshwater and desert habitats, we found a change in the pattern of high and low detection curves. In desert habitats, the reduction of detections corresponded with the nesting period. This could be linked to a reduction

of territorial calls when males have no territory to defend anymore but should spend time feeding their offspring. Conversely, high peaks of acoustic detection following quieter periods might reveal a recovery of parent acoustic activity and the beginning of fledgling juvenile sound production.

In freshwater habitats, the pattern of lower acoustic activity and higher acoustic activity periods had a change in their timing from the pattern at desert habitat. The quiet period shifted from March to January. This was followed by a shift of higher acoustic activities from April to March. This shift could be due to differences in breeding behavior between freshwater and desert habitats. In freshwater habitat, resource availability, such as food and water, differ from desert habitat, in timing and quantity. At freshwater habitats, water and food and nesting materials are available for parents and upcoming chicks at longer periods of the year. Also, freshwater doves could be trying to avoid hunting activities during spring season, by breeding earlier, and have mature offspring before March-April. Hunting activities, despite the restricted access, are higher at Jahra Pool Reserve.

During summer months, the number of visual detections were less numerous than acoustic detections in Kabd Tree, the desert habitat. There were acoustic activities during the period from June to August, while fewer visual detections were recorded at the same period. The detectability and visibility of doves may explain this phenomenon during summer. Desert birds, like the Eurasian Collared Dove, are less visible in summer due to sun radiation, mimetic feathering, and

shelter hiding behavior. The observation effort might also be reduced due to harsh weather conditions.

3.5.3 Suggestions for performance enhancement

Software settings must be tuned according to the call nature and characteristics, frequency, duration, syllabus, and surrounding environment. The software showed more accuracy when the call was in a frequency range outside the surrounding noise frequency range or other similar frequency call species. On the other hand, it showed lower accuracy with species of lower frequency calls, and maybe for higher frequency calls where the insect's noise occupies the frequency range bands.

For desert habitat, visual surveys are done mainly by line transect, where the birds are observed while moving along the transect, and point counts are less used as a visual survey method. Our results showed that stationary ARUs were able to detect desert birds calls, while deployed as a point station. This suggests the advantage of ecoacoustic methods compared to traditional visual methods in detecting desert bird species. However, an adjustment is required to fine-tune the automated recording deployment assignment in the study design. Recorders could be placed in a line transect, in an assembly point, or build an attraction near the recorder (water bath or feeding stand).

Automated passive monitoring methods together with acoustic detection software could be a good tool to survey target species in long-term studies and cover the desired study areas, with the possibility to repeat the survey and analysis with good results (Manzano-Rubio et al 2022).

Conclusion

This first test of acoustic tracking over a complete year of a migratory and a resident species revealed that ecoacoustic methods can offer new opportunities for bird population monitoring. Without the help of observers, migration and breeding periods could be detected, providing valuable information for conservationists and stakeholders. The procedure could be optimized by (1) limiting the spatial effort with, for instance, a reduced number of recorders, (2) reducing the daily temporal sampling by recording one every ten minutes instead of two minutes every ten minutes, and (3) sampling down to one recording session every two days instead of every day. This sampling would then open the possibility to extend the sampling over several years and, then, to estimate potential shifts in migration could be assessed in link with climate change. By repeating the procedure, it should also be possible to include additional species, such as the Eurasian Coot (*Fulica atra*), the White Wagtail (*Motacilla alba*), the Gray-headed Swamphen (*Porphyrio poliocephalus*).

To conclude, the ecoacoustic approach seems to be promising and additional effort in the future should be undertaken in Kuwait. We hope to deploy recording platforms that will work in the long-term for a better knowledge and conservation of bird populations.

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General Discussion

The main goal of this PhD thesis was to study and survey wetland bird communities in Kuwait through traditional and acoustic methods. Our results revealed the variations of species richness in various microhabitats in two sites, a freshwater and a desert and according to seasons and years. We could also evaluate the performance of two tools used, namely citizen science and acoustic techniques. We will first discuss the results obtained from the eBird platform, a citizen science resource and how it provided estimates of bird species richness in different habitats in Kuwait. Second, we will comment on the usage of acoustic indices in assessing the bird acoustic richness in two habitats. The objectives were the determination of the proper acoustic index and how it could provide an evaluation along a gradient of microhabitats. Third, we will see how an automated acoustic recognition tool was useful in target species identification, to further determine their annual phenology. Finally, we laid out some future plans for bird diversity monitoring in Kuwait using our study tools, and how we could enhance their performance.

1. Bird diversity assessment by citizen science in Kuwait

Kuwait possesses diverse ecosystems, from coast to desert, which are inhabited by a unique biodiversity. Some of these ecosystems suffered degradation due to urbanization, pollution, or war damages. For that reason, the Kuwaiti government is increasingly involved in rehabilitation projects in various parts of Kuwait. Environmental assessment studies are continuously conducted by governmental and scientific agencies to determine the effect of the rehabilitation programs on environment and biodiversity. The assessment plans include the abiotic parts like soil, air and water quality, and biotic parts which include fauna and flora. For fauna, avian

biodiversity is the major part that elevates the level of biodiversity in Kuwait with more than 400 species (Kuwait Institute for Scientific Research 9th Strategic Plan; KISR Final report, 2004).

There are several attempts in Kuwait to assess bird richness that are all conducted using visual survey methods. Some of these surveys were conducted by researchers working for scientific agencies but most of them were achieved by groups of volunteers, including visiting birdwatchers, who keep their records largely unpublished. Recently, more bird watchers, scientists and volunteers tend to participate in the eBird platform, a citizen science project collecting observation checklists submitted through an online platform (<https://ebird.org/>). A checklist is a list of all birds seen and/or heard at a given location. Such checklists include additional metadata beyond the species recorded, including location, time, date, and observation effort (Sullivan et al. 2009, 2014). The eBird dataset contains records back to 1953, but only recent years have seen extensive effort in data submission. Today the eBird community in Kuwait consists of 235 eBirders, who provided nearly 17,000 complete checklists. The checklists collected from 1953 recorded 414 species in 81 spots in Kuwait, with most of the activities at Jahra Pool Reserve with a total of 335 species recorded. Data records via eBirds could then offer a good assessment of bird species diversity in Kuwait through citizen observations. Even if the number of Kuwaiti bird watchers using eBird and citizen science is increasing, most of them are still involved in nature management. More citizens could be enrolled in nature monitoring, in particular bird watching. This will happen with education and mediation, and with the development of national nature citizen programs.

Our statistical analysis showed that eBird data can provide an appropriate estimation of Kuwait seasonal changes in bird biodiversity over six years. We found two major peaks of species richness along the year: a first one during March-April, and a second one during September-November. These peaks indicate that species richness is especially high in Kuwait during spring and fall migration seasons, indeed when Kuwait witnesses active bird migratory movements. The comparison of different locations across Kuwait revealed an important spatial variation of bird richness and species composition between the studied habitats, namely desert, farm, freshwater, and coastal habitats. This habitat diversity is crucial for the preservation of biodiversity in a region under a very dry and hot climate. In particular, the freshwater site of Jahra, even if being partly artificial, acts as an important refuge for birds. It is absolutely necessary to maintain its protected status and to limit human activity, including hunting, inside and around it. Other preserved areas with controlled access in the desert also act as good habitats for terrestrial birds. More detailed surveys could explore more bird areas, and imply preservation measures on these areas by the government. In addition, increasing the public awareness on the importance of biodiversity could encourage more people to offer their gardens or farms as bird refuges. Public awareness would also reduce the harm of overhunting, overgrazing and uncontrolled intrusions at important areas for biodiversity conservation.

Analyzing citizen science data raises many technical challenges, including data processing. Indeed, proper data processing of the records is necessary to find the right level of information. The R software package “auk” developed by eBird provided several options in data processing, to extract necessary information for further analysis. The coding and R package is manageable and

various adjustments can be applied with little effort. Data filtering could go to more detailed levels for specific objectives and the development of an online platform, for instance through an R shiny application (<https://shiny.rstudio.com/>). Thanks to this, users can directly see the results of their contribution.

The abilities offered by the eBird platform could be included in more scientific-led surveys in Kuwait, and could be more involved in the local scientific research, with some adjustments. The adjustments should involve collection of data, processing and modeling of the data records. The step of refining the data through processing and filtering is the most important step toward better description of bird populations (Kelling et al., 2018). In our study, data processing and filtering were performed to unify the observation effort, and led to a better balanced evaluation of species richness and community composition. It is also important to standardize the effort or include heterogeneities in the observer effort in such analyses (Van Strien et al, 2013; Zhang 2019).

So in this work, temporal variation in bird richness was assessed by analyzing eBird records. Species and their counts are available at some points. The filtering code could exclude some records which do not include counts of the species observed. We could assess the general phenology, and further filtering to the local level could assess the phenology in different habitats. We unified the sampling effort by focusing on complete checklists only, and taking the minimum number of checklists for each habitat. To do this, we measured the monthly minimum number of checklists in each habitat, then we took this number of checklists for analysis. We also only took

unique checklists, that is to exclude repeated checklists that were done by more than one observer.

eBird data analysis showed how different species preferred different habitats. We could find that freshwater attracts more species, while deserts have the least bird richness. The dissimilarity between habitats could be described by comparing the species occurrence (in fact, presence and absence) information given by the filtered checklists. The seasonal differences highlighted by our analysis reveal the importance of the availability of food, water, and shelter resources in attracting birds and inhibiting higher species richness. Freshwater habitats with abundance of food, water and shelter exhibited more species richness than others. Also, coastal sites with better protection, and availability of resources enhance the habitat for coastal birds. Furthermore, farm areas offered better habitat for desert birds by providing the essential resources. Although desert habitats have a reduced amount of resources, the protected areas of desert could be more suitable for desert birds. Protection of desert areas enhanced the growth of natural vegetation, which provided food and shelter to desert birds.

However, these results could not be inclusive. Observers with bias in using their previous knowledge of birds seasonal and spatial preferences, could lead to underestimate birds' population. Location preferences, and easy navigation could draw more attention for some locations than others. Also, visual ability limits the detections of some bird species at some locations. To overcome this problem, it is recommended to equalize the effort in field visits and checklists submission to eBird platform. Another recommendation is to organize awareness

programs on this issue in citizen science, and how to contribute properly for science when submitting checklists.

2. Can acoustics reveal the bird diversity in Kuwait?

Ecoacoustic methods have been broadly mobilized for studying bird diversity. Bird diversity is associated with acoustic diversity, and when it changed it would result in a change of acoustic activities. Bird acoustic activities can be tracked by acoustic indices (Krause and Farina, 2016). Acoustic indices have been used to illustrate diurnal acoustic pattern, seasonal phenology (Buxton et al., 2016; Phillips et al., 2018; Yip et al, 2020). In addition, acoustic indices were found to be able to detect spatial gradient patterns of biodiversity (Bradfer-Lawrence et al., 2020; McGrann et al., 2022), could be used to determine effect of conservation on birds acoustic vocalization (Lewis et al. 2021), and study environmental effect on acoustic behavior of birds (Ducrettet et al, 2020).

Evaluating several acoustic indices revealed the most appropriate index to study the acoustic diversity of birds in several locations in two habitats, freshwater and desert. The nROI index reported very well the annual and diurnal variation of acoustic activities of bird population in each habitat. The microhabitats, as well, showed different species richness and varied acoustic activities. This suggests that a change in microhabitat would lead to a change in species composition and acoustic activity. This could be a result of competition, and seasonal use of land and resources.

nROI diurnal variations revealed the areas of acoustic activities which were a result of dawn and dusk choruses or nocturnal migratory activities. This provided insight on the difference between habitat in using acoustic space, time of migration in each habitat, and time of rising species richness with elevation of chorus activities. Freshwater habitats were associated with higher acoustic activities at seasonal and diurnal level. The results from chapter one, indicating a higher species richness in freshwater habitats, supported the validation of this result.

Our results showed the ability of automated acoustic methods in bird diversity assessment in different parts of Kuwait. However, these methods faced some challenges. Deployment of automated recording units in the field required good design to cover habitat gradients and avoid sampling overlap. Installation required some precaution in mounting the unit at a proper place, avoiding wind and noise. Audio recordings were disturbed by wind which caused a reduction of the quality in some files. This reduction resulted in difficulty to identify species and detect an acoustic event. High temperatures could reduce the duration of battery life, thus requiring more time dedicated to check and manage the material. Some units were destroyed by intruders, which illustrates the need for more security measures accompanying the period of audio recording.

Our study suggested an adapted protocol to deploy ARUs in arid habitats. Shading is required to protect the units for better performance. It is recommended to visit the ARUs more frequently, for maintenance and data downloads. A visit every two weeks will be appropriate to avoid data loss more than this period of time. The ARUs should be hidden from human view to avoid

interference by intruders. It would be interesting to expand the recording schedule to cover the daytime activities.

3. Acoustic Signal Recognition in Bird Identification

Beyond using acoustics, which provided a quick but rough estimation of bird diversity, we ran species-specific automatic identification. The software Kaleidoscope exhibited its ability to detect target species calls and provided temporal information, which gave the possibility to estimate the acoustic activities of the species, in time and space. The information about the time of the call could be further used when studying the acoustic behavior of a species in more detailed daily phenology, like nocturnal migration acoustic activities.

The analysis of the audio files in the different habitats showed that automated passive monitoring could distinguish acoustic activities between two contrasted habitats, as well in adjacent different microhabitats. For example, we identified a gradual change in Curlew calls in Jahra, according to the distance from the coast. In addition, the variety of acoustic patterns of the dove among Jahra sites, and among Kabd sites could be well illustrated.

We found that the positioning of the ARUs could affect the ability of Kaleidoscope to detect target species calls. For instance, it must be closer to the known habitat of the species, like in the case of curlew, where the unit near the coast detected more calls, which the software showed more performance quality in call recognition. The recording unit must be away from any disturbance sources that contain noise with similar frequency ranges.

There were some shortcomings of the software in call recognition. Some false positives were found in a cluster. The percentage of finding false positives varies among recording units. As we previously mentioned, this resulted from variable conditions. This problem is found in all recognizers softwares; thus, additional tests on their performance should be done (Rydell et al. 2017) and several software recognizers could be run for comparison. In addition, the training process should only include audio detections from the same deployment habitat. There were some difficulties while we used detections from library audio files. The library audio files caused confusion in the clustering analysis because they were not pure to the species call, and they were different from the local species call to some extent.

4. General Challenges and Future Plans for Biodiversity Assessment in Kuwait

Kuwait's government scientific agencies are interested in studying major habitats and ecosystems because Kuwait is going through many development plans that need a continuous monitoring and assessment of biodiversity and environmental impacts. These monitoring plans require a proper tool which can be implemented in time, with manageable budget and effort. Both citizen science and acoustic methods offer good opportunities to monitor bird communities in several locations in Kuwait.

Acoustic methods should go under more trials to assess more habitats. It would be valuable to study the gradients in species richness and abundance along the Kuwait coastline. Coastline varies significantly in land use and disturbance levels. A study for such a widely spatial area

could be possible with long-term ecoacoustic methods. Such a study might result in shedding more insight on the effect of various factors on coastal bird populations.

In addition, management of some protected areas, such as Sabah Al-Ahmad Nature Reserve, use artificial water bodies to enhance the environmental conditions for wildlife (Al-Shehabi and Sorour, 2014). It is interesting to study the effect of these water bodies on desert birds, in particular how these birds use land and resources at different times of the year. The use of ecoacoustic methods could reveal how desert birds change their acoustic activities, as a result of competition and land use.

Ecoacoustic methods could also assess the breeding behavior of colonized birds in the remote areas of north Kuwait, like in Warba and Bubiyan islands. These islands are of political and economical importance to Kuwait. An harbor (Mubarak Port) will be built in the south part of the islands. Due to navigation difficulties, only a few surveys were organized to roughly describe site properties so that the ecology and phenology of these species could not be properly investigated (Figure 43). These islands offer a breeding habitat for several migratory species, such as crab plovers, spoonbills, white herons, gray herons, and tern species. These birds have an ecological importance as some of them are key species; for example, the only breeding site of Crab Plover *Dromas ardeola* in Kuwait holds the largest breeding colony of the species in the region (Bom and Al-Nasrallah, 2015). Crab plovers complete their annual life cycle along the gulf coasts (Behrouzi-Rad and Behrouzi-Rad, 2010; Tayefeh et al, 2013; Almalki et al, 2014). The study of such species could provide valuable knowledge on the ecology and biodiversity of the surveyed

sites for policy makers in Kuwait. An acoustic comparison between these sites and other coastal sites in Kuwait could be developed to study the effect of potential disturbance on coastal breeding birds. ARUs could be deployed in several locations in Warba, along the sea channels north of Bubiyan, and others along several locations along the coastline of Kuwait. As suggested by our observations, recording schedules could be set to record dawn/dusk time when birds are the most active. Besides, other times of the day could be disturbed by anthropophony acoustic activities at several deployment sites. In our results, a year time was efficient to detect acoustic activities variations, but we could extend this period, and compare the effect of year on the acoustic activities. The analysis will deal with audio file processing, manual intonation of subsamples, and test the proper acoustic indices. Automated acoustic recognition tools could be used to identify the target species, and their different vocalizations in different breeding stages. The results could provide a view on the breeding behavior of several species, their phenology, habitat use, and the effect of several environmental factors, including the consequences of climate change, on these aspects.

Automated passive acoustic recording appears as a suited method to study these remote areas. As our results showed, the quieter areas showed more clear audios, easier to analyze later on. Ecoacoustics offer appropriate tools to cover large areas, with less effort and manpower. Kuwait's coastal line gradient of bird's populations and biodiversity could be assessed by acoustic methods.

Desert birds of Kuwait also require better tuning of the acoustic methods. The sampling design could still be improved. In particular, we could compare between two designs: 1) aggregation points and 2) line transects to investigate the best practice of acoustic methods in linearly homogeneous desert habitats.

As a final point, acoustic techniques were found to be capable of spatially and temporally capturing the ecological and biological aspects of ecosystem components. These techniques were able to detect variation among microhabitats at the same sites and among different habitats (Buxton et al., 2016; Phillips et al., 2018; Yip et al, 2020). For example, acoustic behavior of birds was shown to vary within a site (Lewis et al. 2021; Ducrettet et al, 2020). This could not be observed or noticed using traditional methods. The development of new and existing protected areas in Kuwait is ongoing and requires rapid and valid methods to monitor the environment on a long time scale and in space. The management and construction of reserves would involve the construction of water bodies and tree plantations that would create various microhabitats. These new constructions of the reserve or construction of facilities near existing reserves (such as ports and residential areas in urban areas) obliged the policymakers to conduct continuous monitoring research. Acoustic methods could offer the possibility of long-term monitoring that covers more habitats (Brandes, 2008) and could provide policy makers with insights into the various ecosystem impacts of new construction. Future plans include a variety of possibilities to incorporate these techniques into the actual implementation of feasible environmental impact assessments to decide where, how, and when new urban constrictions or new reserves should be built by policymakers. The Kuwait Institute for Scientific Research is one of the main scientific

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agencies in Kuwait consulted by the government on new development projects (Kuwait Institute for Scientific Research 9th Strategic Plan; KISR Final report, 2004). The Institute is sincerely expanding its human resources to achieve the goals of Kuwait's development plans. My research and scholarship are one of these efforts to gain knowledge of the latest innovations in the scientific fields and to expect the benefits of new skills to meet the requirements of the development plans in science, economy and society.

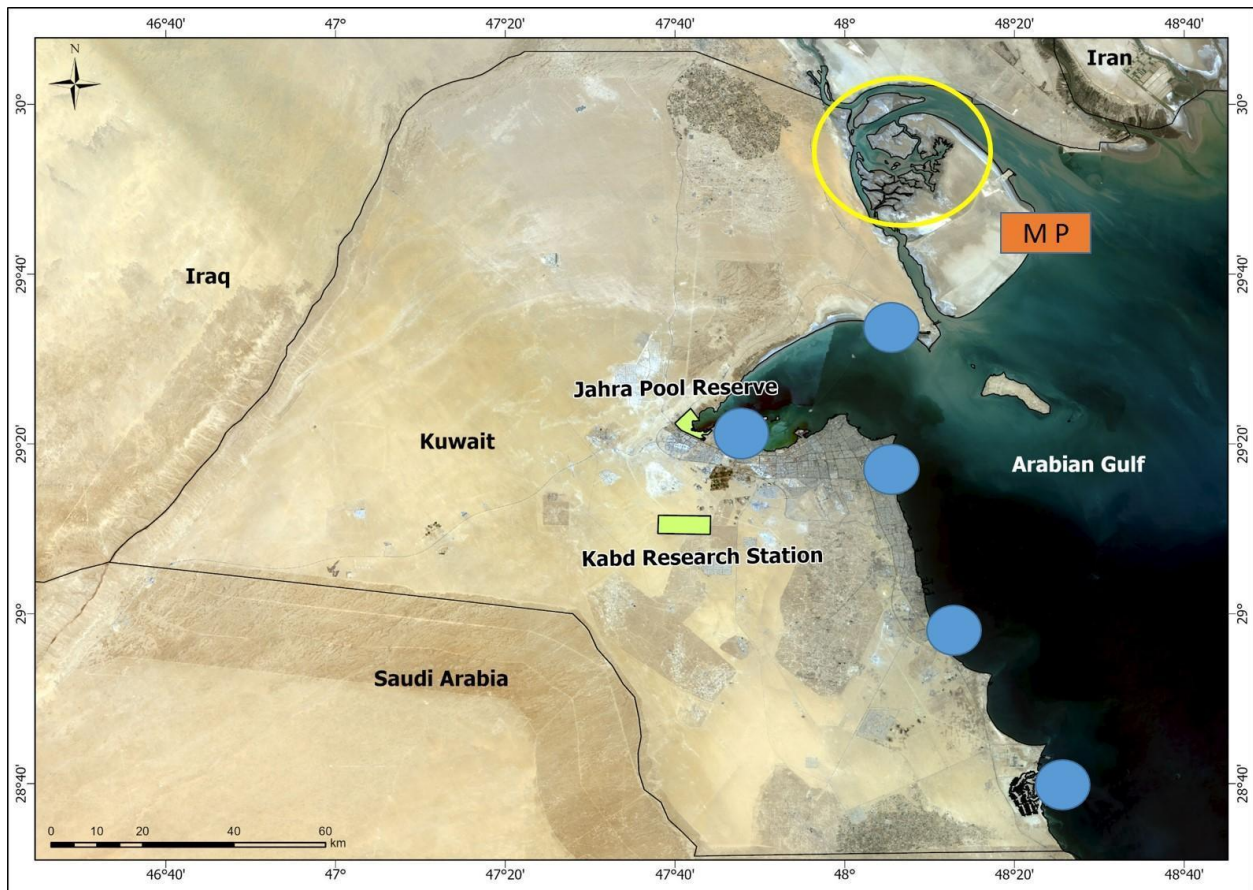


Figure 43. Suggested additional study sites along the Kuwait coastal line. The yellow ellipse indicates Warba island and the northern part of Bubiyan island, with the sea channels. The orange square indicates the location of the Mubarak Port. Blue circles indicate the suggested location of study along Kuwait coastal lines. The green areas indicated the two sites here studied.

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Acoustic monitoring of wetland habitats in dry regions (Kuwait): bird community dynamics related to migration

Abstract: Wetlands in Kuwait play a significant role in biodiversity as a shelter for many migrant birds, a breeding habitat for residents, and a non-breeding habitat for wintering birds, a foraging resource for many species. In addition, constructed wetlands have helped restore several species that avoided coming to Kuwait. With the availability of shelters and food these new wetlands offer, some species return to winter or/and breed again. So far, terrestrial eco-acoustic studies have mainly focused on tropical and temperate habitats but rarely on open habitats such as wetlands. The main objective of this project is to use the eco-acoustic approach to monitor wetland and desert sites in Kuwait to understand the local ecological dynamics better and help preserve nature.

Interested birders who continuously record bird occurrence and abundance in Kuwait usually use the platform offered by eBird. This resulted in an enormous amount of valuable data that can reveal the distribution and phenology of birds in Kuwait. Analysis of these datasets led to a clearer view of the status of Kuwaiti avifauna, their locations, and seasonality. The assessment showed two seasons of high species richness in all four habitats, Spring and Fall. The main components of Kuwait's avian richness are owing to migratory species. That is a result of Kuwait's location, which made many birds visit it en-route or for refueling during their migration journey. Furthermore, we found differences in species richness among habitats, where freshwater habitats had the highest species richness, while desert habitats had the lowest.

In our study, we monitored the soundscapes of freshwater and desert habitats in the Arabian peninsula for the first time. We mainly aimed to estimate the diversity of bird communities inside these soundscapes to document their dynamics throughout a year. Several acoustic indices have been proposed to measure acoustic diversity within audio recordings without species identification. Here, we first applied a set of 62 indices on a labeled subsample of recordings to assess the correlation between the indices and the acoustic diversity estimated by an expert. This pre-test revealed that the nROI and aROI indices were the best acoustic diversity estimators so that they could be calculated confidently on all recordings. We found a variation of acoustic activities among different habitats. Also, the nROI results revealed the annual and diurnal phenology of the bird community in two main habitats, freshwater, and desert.

Our first test of acoustic tracking over a full year of a migratory and a resident species revealed that ecoacoustic methods could offer new opportunities for bird population monitoring. Without the help of observers, migration and breeding periods could be detected, providing valuable information for conservationists and stakeholders. Our results showed that the automated acoustic identifications could reveal the phenology of the two target species, one migrant, the Eurasian Curlew, and the other resident, the Eurasian Collared Dove. Automated passive monitoring methods and acoustic detection software could be excellent tools to survey target species in long-term studies and cover the desired study areas, with the possibility of repeating the survey and analysis with good results.

Keywords: ecoacoustics – acoustic index – birds community – acoustic recognition – acoustic monitoring – citizen science

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