Movement and species composition of sharks and rays in the Israeli Mediterranean Sea

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A THESIS SUBMITTED FOR THE DEGREE "DOCTOR OF PHILOSOPHY"
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Abstract

Sharks and ray around the world are experiencing drastic population declines. Despite many conservation efforts, declines have been persistent during the last decade. Overfishing is considered the main threat to the populations of sharks and rays, and substantial research efforts have been invested to better understand and minimize its effect.

Nonetheless, our natural environment is also undergoing many changes. Sea water temperatures are increasing, especially in the Mediterranean Sea, thereby altering migration routes as well as entire ecosystems, and affecting survivability and habitat compositions. Rapid coastal and marine construction and development substantially alter coastal habitats and may result in loss of entire habitats such as estuaries. Moreover, given the scarcity of space on land and the growing demand for food and food security, mariculture is developed in many areas around the world, which facilitates many new interactions, some of which are familiar in terrestrial agriculture, and some that are not. Finally, geographical barriers have been removed and sea crossings have been connected as part of the construction and development efforts, such as the Suez Canal which it’s opening has substantially altered the biodiversity in the Mediterranean Sea.

All of these affect the ecosystem in many ways and sharks and rays among them. In this work I focused on the anthropogenic effects on coastal shark populations. I examined the changes in the movement of requiem sharks (Carcharhinus obscurus and Carcharhinus plumbeus) attracted to warm water released from coastal power plants and what we can learn from their behaviour in the water of the stations. I described how fish breeding cages centre opportunistic sharks around them, and finally if there are changes in the composition of cartilaginous fish species in the Israeli Mediterranean waters using molecular tool.

In order to examine the movement of requiem sharks at the effluent, sharks were fitted with acoustic and satellites tags equipped with temperature and depth gauges.

Regular daily movement of the weas observed in both shark species. The individuals rose to shallower water at night and descended deeper during the day. Water depth of the water near the power plant

reaches only a few meters, and the observed vertical movement of C. obscurus was from a depth of 2 meters at night to a depth of 4 meters during the day. For C. plumbeus, a movement between 4 and 6.5 meters was found. In addition, the difference in depths between the two species of sharks was maintained throughout the season at an approximately two meters.

Temperature data from the tags showed that sharks maintain a temperature range between 19^{o}C and 27 oC and gather at the station only when the sea water temperature is below 20^{o}C. The long presence of sharks near the station is most likely motivated by thermoregulation, allowing them to stay in coastal waters during winter when water temperature is beneath 20^{o}C. An examination of changes in the temperature of the Mediterranean Sea in recent decades shows that based on the preferred temperature range found here, the coastal waters become more suitable for adult requiem sharks in the transitional and winter seasons.

Other aggregations of requiem sharks have been observed around fish breeding farm in open sea, where opportunistic sharks await accidental feeding. Sharks mostly arrive at the cages during the summer and documentation from the last decade indicates the presence of injured sharks gathering around the farm, with one individual being observed at the station for over 7 years. Feedings around the farms sometimes occur due to breaks in the nets, storms that damage the net, or improper conduct. It is possible that this unplanned feeding station allows the survival of sharks with serious injuries, and these choose to risk getting closer to humans and unfamiliar structures over searching for prey in the sea.

Molecular study of the shark and ray species caught of the Mediterranean coast of Israel showed that, apart from C. plumbeus and C. obscurus, another similar requiem shark is present in Israeli waters, C. brevipinna, and its presence around the power plants should be explored as well. Molecular tool revealed the presence of the invasive leopard whipray (Himantura leoparda) and a not yet described species of spiny shark (Squalus) which was also found in Malta in 2017.

This work aims to increase the knowledge about the distribution and behaviour of sharks and rays in the Mediterranean coast of Israel and to serve as a scientific source for the local conservation efforts and the management of interactions between the cartilaginous fish and humans.

General introduction:

Dating back about 400 million years to the time near the boundary of the Devonian-Silurian eras (Corrigan & Beheregaray, 2009), Elasmobranchii (class of Chondrichthyes), belong to one of the most ancient lines of vertebrates, and one of its most successful (Corrigan & Beheregaray, 2009). Chondrichthyes (cartilaginous fish) includes 1,226 Elasmobranchii species dived between 537 shark species (belonging to 34 families) and 689 batoid (rays and skates) species (belonging to 20 families) (Ebert et al., 2013; Last et al., 2016; Nelson et al., 2016; Roskov et al., 2020; Scharpf & Lazara, 2019), although taxonomic classifications for several species and genera remain unclear and are still debated (Compagno et al., 2005; Ebert & MFW, 2013). Elasmobranchs can be found in some freshwater environments and are widely distributed in marine ecosystems worldwide (Ebert et al., 2013). Most elasmobranchs are upper trophic level predators (Heithaus et al., 2010), and as such they have probably had an influential role on the structure of marine ecology and evolution for millions of years, to date, however, few studies provide detailed insights into the role of elasmobranchs in their ecosystem. This lack of knowledge is alarming in a time when more and more elasmobranchs are finding themselves belonging to one of the IUCN threatened categories: vulnerable, endangered, or critically endangered, and nearly half of all elasmobranch species are data deficient. Data deficiency paired with a lack of detailed expert knowledge, hinders, and slows effective protection and conservation measures, making the future of many elasmobranchs' bleak.

Elasmobranchii

Elasmobranchii (class of Chondrichthyes) includes all living sharks (infraclass Selachii), rays, and skates (infraclass Batoidea). They are carnivorous vertebrates with a skeleton consisting of a cartilage core stiffened by a mineralized collar (Dean & Summers, 2006; Seidel et al., 2017) and are characterized by the absence of a swim bladder and sets of five to seven pairs of uncovered gill slits whose flat appearance gave rise to their name (Klimley, 2013). Sharks have a general body shape that is bilaterally cylindrical with two firm dorsal fins, paired pectoral fins, and one set of anal fins (although some sharks lack the second dorsal or anal fin)(Klimley, 2013). Rays and skates on the other hand have a general dorsoventrally flattened body shape with flexible disclike pectoral fins, no anal fins, and many species lack defined dorsal fins (Klimley, 2013). The placement of the gill slits in batoids differs from sharks and is ventral (Klimley, 2013). As opposed to bony fish, elasmobranchs fertilization is internal and facilitated by physiological adaptations of the male's pelvic fins to a pair of claspers. The claspers are erectile copulatory organs that allow males to deposit sperm into the female's cloaca (oviduct) (Ballantyne & Robinson, 2011). The fertilized eggs are retained by female elasmobranchs, protecting the embryos, for varying periods of time depending on species. The time of fertilized egg retention divides elasmobranch reproductive modes into one of two groups: viviparous (live-bearing) or oviparous (egg-laying). Oviparous species deposit or attach their eggs to the substate or bottom structures after a short retention period, whereas viviparous give birth to young that have completed embryonic development. In both cases the young emerge as perfect miniatures of their parents and are fully developed (Carrier et al., 2012). On a geological timescale, the evolutionary success of sharks is partly due to internal fertilization and having large, developed young in small numbers (Castro, 1983). Although much is still unknown when it comes to elasmobranch reproduction on the species level, it is becoming increasingly apparent that despite having gained evolutionary benefits from slow growth, late maturation, low fecundity, and long gestation periods, these features make elasmobranchs sensitive to overexploitation (Camhi et al., 1998; T. I. Walker, 1998).

Elasmobranchs worldwide – a current taxonomic overview of orders.

Elasmobranchii consists of the subclass Neoselachii (modern sharks) (Froese and Pauly, 2022a) that splits into two infraclasses: Selachii (sharks) and Batoidea (rays and skates). Batoidea consists of five orders: Myliobatiformes (stingrays), Pristiformes (saw fishes), Rajiformes (skates) , Rhinopristiformes (shovelnose rays), Torpediniformes (electric rays) (Froese and Pauly, 2022b). Selachii consists of nine orders: Carcharhiniformes (ground sharks), Heterodontiformes (bullhead sharks), Lamniformes (mackerel sharks), Orectolobiformes (carpet sharks), Hexanchiformes (cow and frilled sharks), Pristiophoriformes (saw sharks), Squaliformes (sleeper and dogfish sharks), Squatiniformes (angel sharks), and Echinorhiniformes (bramble sharks) (Froese and Pauly, 2022c,d,e).

Importance to eco systems

Many elasmobranchs are large pelagic predators (LPP) who occupy high positions in marine food webs. Their direct (predation) and indirect (intimidation/competition/risk) interactions with their ecology creates important regulation of lower trophic level species and even seagrass (Bornatowski, Braga, et al., 2014; Bornatowski et al., 2018; Ferretti et al., 2010; Gallagher et al., 2022; Heithaus et al., 2002, 2008, 2012, 2014; Navia et al., 2016). Due to their role in in maintaining functioning and structured marine food webs, some LPPs, and in extension elasmobranchs, are sometimes considered as keystone species in their environments (Baum & Worm, 2009; Bornatowski, Navia, et al., 2014; Libralato et al., 2006). Marine ecosystems present complex challenges to researchers due to their inaccessibility and lacking ease to survey, but also in understanding the trophic effects of top predators disappearing from them (Hussey et al., 2014; Hussey, MacNeil, et al., 2015) and data deficiencies in basic knowledge of elasmobranchs impairs assessment of their role.

Although some studies have found that the removal/disappearance of sharks and other LPP has profound impact on food webs (e.g. Stevens, 2000; Myers et al., 2007; Ferretti et al., 2010; Britten et al., 2014), others indicate such loss isn't persistent on trophic relationships (e.g. Kitchell et al., 2002; Griffiths et al., 2010). Yet some studies found that food webs rich in top predatory species occupying similar trophic positions and levels, were more resistant to loss of some of those same predators (Walker, 1992; Okey, 2007; Naeem, 2008; Griffiths et al., 2010).

Worldwide status of elasmobranchs

Due to elasmobranch life characteristics (such as late maturation and low fecundity) they are vulnerable to human exploitation and more susceptible to overfishing than most teleosts (Bonfil, 1994). In addition to overfishing, elasmobranchs are highly sensitive to pollution and habitat degradation (Stevens, 2000; Myers and Worm, 2003; Dulvy et al., 2014). Worldwide elasmobranchs (hereafter sharks) are targeted in fisheries for their fins, meat, gill plates, and liver oil, and their numbers have been rapidly declining (e.g. Brander, 1981; Myers and Worm, 2003; Clarke et al., 2006; Dulvy et al., 2008, 2014; McCauley et al., 2015; Pacoureau et al., 2021). Although, once regarded as less desirable commercial take or bycatch, declines in teleost targeted species paired with a rising demand, resulted in higher retention, and landing of sharks (Clarke et al., 2006; Lack and Sant, 2011). Based on data from 1950 (first year of data collection) and onward reported shark landings increased with 227% to their peak in 2003, followed by a decline of 15% by 2011 (FAO 2013). Rising concerns regarding the sustainability of shark fisheries (e.g (Bonfil, 1997; Hoff & Musick, 1990; Holts et al., 1998) and in 1999 the United Nations Food and Agriculture Organization (FAO) recommended development and implementation of National Plans Of Action for sharks (NPOA SHARK) by its signatory nations with a recommendation to be completed within two years (UN FAO 2013). Despite hopes (FAO 2010) that reported declines in shark landings post 2003 were a direct result of rising sustainability in fisheries taking smalling landings, (Davidson et al., 2016) showed that management measures had little influence on shark landing trajectories.

NPOA SHARK is just one recommended action plan, other examples of global conservation initiatives for chondrichthyans include: 1) Introducing bans on removing fins and disposing carcases at sea (Clarke et al., 2006, 2013; Biery and Pauly, 2012). 2) Application of trade regulations through the Convention on International Trade in Endangered Species (CITES) (Vincent et al., 2014). 3) International agreements to prevent illegal, unregulated, and unreported (IUU) fishing (Field et al., 2009; Witbooi, 2014). 4) Management and conservation of migratory shark and ray species trough the convention of migratory species Memorandum of Understanding for sharks (Fowler, 2012). Non-binding agreements and plans, aimed, among other things, at encompassing: reporting of catch, landing and trade, sustainability, threatened species, ecosystem considerations and improved monitoring (Davidson et al., 2016) and advances in applied fisheries management aside, concerns regarding the chondrichthyans fisheries following the predictable patterns seen in unregulated, open-access fisheries resulting in collapse and serial depletion have been voiced (e.g. Pitcher and Hart, 1982; Lam and Sadovy de Mitcheson, 2011; Dulvy et al., 2014, 2021). Three main spots have been identified where elasmobranch biodiversity is especially threatened: the Indo-Pacific Biodiversity Triangle, the Red Sea, and the Mediterranean Sea (Dulvy et al., 2014).

Elasmobranchs of the Mediterranean

Historically known to be rich in elasmobranch biodiversity (Simpfendorfer & Dulvy, 2017), the Mediterranean Sea (MS) is today recognised as a region of special concern regarding marine conservation and threats to elasmobranch abundance (Dulvy et al, 2016; Fernandes et al., 2017; Abdulla, 2004). Although the presence of some species is uncertain to date, close to 50 species of sharks have been recorded in the MS (Serena, 2005). Yet more than a decade after their first assessment by the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species, no sign of improvement has been found in MS elasmobranch populations (Dulvy et al, 2016). Among the 73 species of chondrichthyans included in the 2016 IUCN regional assessment in the MS, 39 species, more than half, are listed as regionally threatened, 31 of which are listed as Critically Endangered (CE); 13 remain Data Deficient (DD) (Dulvy et al, 2016).

Considering these facts, and despite repeated mentioning of the negative effects on research and conservation efforts (e.g. Clarke et al., 2006; Fernandes et al., 2017; Cashion, Bailly and Pauly, 2019; Bargnesi, Lucrezi and Ferretti, 2020), it may be surprising that, accurate, research-based, species specific data regarding movement, growth, feeding habits, mating, and nursing grounds etc, still is deficient for the MS in general and for the easternmost Levantine basin in particular. This data is urgently needed to inform and form a base for future conservation management plans and their implementation.

The future of elasmobranchs in the Mediterranean and the world

To address some of these needs, telemetry (Hussey, Kessel, et al., 2015; Lennox et al., 2017) and molecular models are being developed to understand biological indicators such as movement, growth, mortality, and nutrition (Gilman et al., 2022) as well as resolving taxonomic uncertainties (Kousteni et al., 2021; Naylor et al., 2012; Pavan-Kumar et al., 2020). Citizen science programs focused on monitoring the occurrence of elasmobranchs in the MS have been around since 1980's and to date 33 national and international initiatives are joined in the effort and showing promising opportunities for data gathering (Bargnesi, Lucrezi and Ferretti, 2020).

Carcharhinid sharks in Israeli waters

Large costal predatory sharks have almost disappeared completely from the Northwestern Mediterranean. Worse off are sharks from the genus Carcharhinus (requiem sharks) which have been depleted to undetectable levels in the northwestern Mediterranean. In Israel on the other hand *C. plumbeus* and *C. obscurus* are seen in large numbers year-round(Barash et al., 2018). Other frequently observed large sharks include hammerheads, Makos, six-gills, spinner sharks and big-eye thresher sharks. These observations have led the GFCM to conclude that Israel might be a hotspot for large sharks (GFCM, 2014). Many batoids species (skates, rays, and sawfish) that are evaluated in the Mediterranean as endangered (*Rhinobatos* spp.), critically endangered (*Gymnura altavela*, *Rhinoptera marginata*), or data deficient (*Pteromylaeus bovinus*, *Taeniura grabata*) are frequently sighted and reported in Israeli Mediterranean waters. This inconsistency alone between local richness and abundance compared to what is known about global trends merits a comprehensive evaluation of batoid biodiversity and status assessment.

The un-typical occurrence of carcharhinid sharks along the Israeli shore is mostly apparent near two types of coastal anthropogenic activity- commercial fish farms and power plants. Coastal power plants along the shore discharge warm water used to cool down their turbine systems. At the larger plants, sharks are seen aggregating on an annual basis during wintertime near the outflow of warm water. Unlike the described trends of declining populations, especially in the Mediterranean, the number of shark observations at the power plants has increased over the last twenty years, and while the aggregation has been documented to have a clear seasonal pattern, the mechanism driving it has not yet been explained (Barash et al., 2018).

At summertime on the other hand, sharks are seen near fish farm located off the shore of Ashdod. Normally the farm workers report the presence of a few dozen individuals, but on several occasions, more than a hundred sharks have been reported to circle the cages. The presence of sharks in the Ashdod farms has been documented although not methodically quantified. In general, information about the relationship between sharks and aquaculture is scarce, and no research has yet been done to describe the presence of sharks near fish farms, and the nature of these interactions (Snir & Barash, 2015).

Despite their key role within the ecosystem and their endangered status, populations of elasmobranchs are poorly studied along the Israeli Mediterranean coast. This research will be a first comprehensive study of elasmobranchs in Israel, describing their ecology, molecular taxonomy, phylogeography, and responses to anthropogenic disturbances.

Key objectives

This study aims to provide first insights into the diversity of elasmobranch (sharks and rays), their distribution and ecology along the Israeli Mediterranean coast. Specifically, my objectives are:

- Assess the effect of centers of anthropogenic activity (i.e. coastal power plants and fish farms) influences on the movement and resident time of carcharhinid sharks.
- Create an up-to-date genetically verified check list of elasmobranch species found in Israeli Mediterranean waters.

Statement of Authorship

Principal Author

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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the dissertation

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Communication

Depth Partitioning and Diel Movement of Two Large Carcharhinid Sharks in Extremely Shallow Waters

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Abstract: Two species of carcharhinid sharks aggregate every winter at the warm water effluent of a coastal power plant on the Israeli Mediterranean coast. The two species (*Carcharhinus obscurus* and *Carcharhinus plumbeus*) cooccur in a highly confined area for several months every year and are highly associated with the area in and around the hot water effluent. Niche partitioning has recently been suggested as a mechanism that enables the coexistence of similar shark species by resource partitioning, spatial partitioning, and temporal partitioning. In this study, we used acoustic telemetry to study the individual diel movement and activity patterns within this enclosed area and examined the differences between the two species sharing it. Although this location only reaches a maximum depth of 7.5 m, we found both species perform a diel vertical movement, rising closer to the surface at night and moving deeper during daytime. Furthermore, the two shark species swam at different depths both day and night, with *C. obscurus* swimming in the upper column, about 2 m shallower than *C. plumbeus*. The very small scale of movement, which nearly equals the sharks' body length, suggests movement patterns might be conserved at the species level. Moreover, spatiotemporal differences between the two species may reflect a mean of interspecific partitioning that occurs even in a highly confined and shallow habitat.

Keywords: partitioning; spatial patterns; predators; selacii; elasmobranch; habitat selection; *Carcharhinus obscurus*; *Carcharhinus plumbeus*; competition; behavioural plasticity

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1. Introduction

In the Eastern Mediterranean, carcharhinid sharks aggregate near the coast of Israel at warm water effluents of coastal power stations [1]. Every year for the last two decades, dozens of sharks of two species, the dusky shark *Carcharhinus obscurus* (Lesueur, 1818) and the sandbar shark *C. plumbeus* (Nardo, 1827), aggregate in this relatively small area between November and May, most likely due to elevated temperatures and their thermoregulatory advantages [1]. Both species are large coastal sharks (*C. obscurus* up to 4.2 meters and *C. plumbeus* up to 2.5 meters [2]), with similar food preferences and trophic levels [3], and seem to coexist in large numbers in a small and extremely shallow area.

Niche partitioning has been found to be a significant mechanism allowing multiple species to share common space or resources [4]. Studies have shown that in areas where different species of large sharks coexist, differences were found in the use of space among species. For example, in Queensland, Australia, two shark species inhabit close but separated areas along the same river [5]. Around a small, elongated island near Mexico, four species of sharks have been documented with high affinity to only one site on the island, suggesting spatial partitioning for some of the species [6]. Six shark species in the Gulf of Mexico showed a diel temporal partition when each species utilized the same space at a different time of the day, with minimal overlap between the activity hours [7].

Little is known about niche partitioning in terms of depth distribution. Based on isotope analysis of mercury accumulation, reference [8] suggested that foraging depth can explain resource allocation between species, and reference [6] described the varied use of depth among individuals of different species on the same site.

In this study, we used acoustic telemetry to examine how two large coastal shark species coexist within a small area of a few kilometres, limited by extremely shallow water. We also examine the hypothesis that niche partitioning facilitates their coexistence.

2. Materials and Methods

2.1. Study Site

Orot Rabin (OR) power station (32.466814 N, 34.880232 E), located near the city of Hadera, Israel, on the easternmost Mediterranean Sea coast, is one of three coastal power stations found to attract sharks to their warm water effluent [1]. OR pumps seawater to cool its turbines and discharges the water back into the sea at approximately 8 °C above ambient temperature. The discharge creates a heated plume expanding a few kilometres along the coast, with a strong temperature gradient between the point of release and the ambient sea temperature (Figure 1).

In addition to OR, a desalination plant operates on-site and discharges its brine into the same effluent. As a result, the mixed water reaches the sea with a salinity about 3 PPT higher than the ambient seawater. The bottom depth at the discharge site ranges from 0 to 4 meters in most places and reaches a maximum depth of 7.5 m in a certain area excavated by the discharge current.

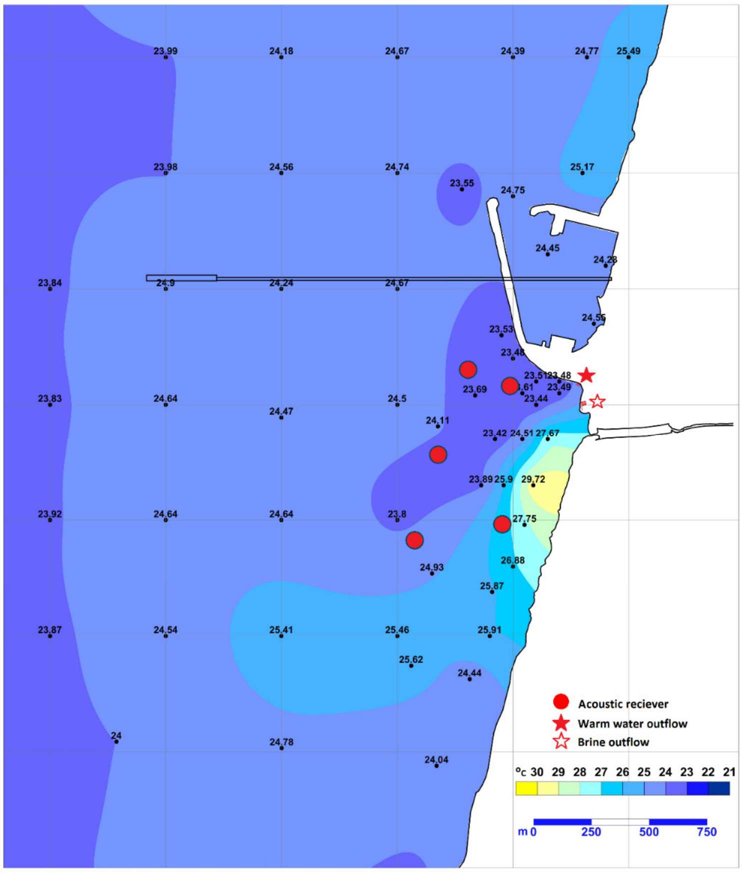

Figure 1. Map of the study site. Temperature is shown as measured by IEC staff on 22 May 2018, at 2 m depth. Circles (●) represent receiver locations; star (★) represents the discharge point for warm water and star with no fill (☆) for warm saline water. Adapted from the IEC monitoring report 2018.

2.2. Shark Tagging and Receivers' Deployment

Carcharhinid sharks were caught and tagged on-site in the warm effluent, between November 2017 and April 2018, using baited drumlines. The sharks were pulled close to the boat and were strapped around the tail base and behind the pectoral fins. Once secured, the sharks were measured, sexed (according to appearance or absence of claspers), and fitted with an external Floy tag in the dorsal fin. HP16 tags equipped with a depth sensor (Thelma Biotel, Trondheim, Norway; 69 kHz; delay range: 30–90 s; depth range: 0–51 m; resolution: 0.2 m; battery life: 90 months) were surgically implanted into the peritoneal cavity of 4 *C. plumbeus* and 9 *C. obscurus* sharks. Transmitters were set to nominally transmit every 60 s.

An acoustic receiver (VR2W, Vemco Ltd., Halifax, NS, Canada) was placed in the effluent on 15 January 2017, and four additional receivers (TBR 700, Thelma Biotel, Trondheim, Norway) were added on 7 March 2018.

2.3. Data Analysis

Data aggregation of a two-minute time frame was chosen to reduce the effect of the transition from one receiver to five and to even the number of detections. Mean depth (DM) was calculated for each aggregated data point. Detections from the first 24 h after tagging were discarded for each individual to eliminate tagging's effect on the movement analysis [9].

Day in the season (DIS) was used to describe the number of days starting 1 November for each season (an arbitrary date before the start of the tagging season), and a daily mean ambient seawater temperature (SWT) was calculated to check thermal changes. Time of day (TOD) was defined using the SUNCALC package [10], with the day divided into four time segments—Day, Night, Dawn, and Dusk—such that dawn was defined as the time between night's end (morning astronomical twilight start) to the end of the golden hour, approximately two hours later, and dusk was defined as between the beginning of the evening's golden hour and the beginning of night (dark enough for astronomical observations), which was approximately two hours later, as well. Lunar phase (LP) was added from the Lunar package. Total length (TL) represents the measured length of the shark on tagging. Data were then aggregated once more per Shark, DIS, and TOD. An aggregated data line based on three data points or less was removed, and the median (DM) value was chosen to describe the depth. Finally, a linear mixed model (LM, lmer function, Package lme4) was used to determine which factors affected the DM choice of the sharks. The model included interactions between the species and the TOD, and a random effect was included for individuals in order to control for possible dependences. A scale function was used to transform data to fit the same scale for all factors.

$$\text{DM Median} \sim \text{Species} \times \text{TOD} + \text{SWT} + \text{DIS} + \text{LP} + \text{TL} + (1 \mid \text{Shark})$$

Model selection was made by the Dredge function (Package MuMIn) with 5000 bootstrap resamples, showing 3 models with delta AIC < 2. Hedges G test was performed as post hoc for the model-chosen factors. Data analysis was performed in R (v. 1.8–12; R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Sharks of the two species were caught along the tagging period and often in the same tagging event (three out of the four *C. plumbeus* sharks were tagged in the same event as a dusky shark. Table 1), providing proof of coexistence and mutual use of the heated area. All tagged *C. plumbeus* sharks were males, and all *C. obscurus* were females considerably larger than the *C. plumbeus* males (mean length ± SE: 298.2 ± 12.5 cm vs. 180 ± 4.5 cm respectively). These findings correspond with additional sharks caught and measured on site (Table A1, Appendix A) and with photographed observations showing mainly large female *C. obscurus* and smaller male *C. plumbeus* (unpublished data).

Table 1. Summary of biological and detection data for sharks tagged with depth sensors at the warm effluent of Orot Rabin (OR) power station, ordered by the tagging date. Detection rate stands for the number of detections per hour per receiver.

Shark Serial	Species	Sex	TL (cm)	Detections	Tagging Date	Catch Time	Last Detected	Min Depth (m)	Max Depth (m)	Days Tracked	Detection Rate
CO 21	*C. obscurus*	F	289	318	27 November 2017	10:30	11 March 2018	1	6.8	105	3.2
CO 23	*C. obscurus*	F	276	737	12 December 2017	14:34	24 April 2018	1	15	134	6.3
CO 22	*C. obscurus*	F	315	482	27 December 2017	7:17	2 April 2018	1	7	97	6.1
CO 14	*C. obscurus*	F	355	424	27 December 2017	10:43	13 March 2018	1	7.4	77	7.4
CO 20	*C. obscurus*	F	300	267	2 January 2018	13:00	8 May 2018	0	9.2	127	3.1
CO 26	*C. obscurus*	F	275	1051	5 February 2018	NA	22 April 2018	1	17.6	77	8.2
CP 15	*C. plumbeus*	M	169	17117	12 March 2018	13:00	14 May 2018	0.6	13.8	64	53.5
CO 25	*C. obscurus*	F	280	63	12 March 2018	13:00	23 March 2018	1.6	7.4	12	1.1
CP 10	*C. plumbeus*	M	191	17231	14 March 2018	10:55	10 May 2018	0.6	17	58	59.4
CO 11	*C. obscurus*	F	294	969	28 March 2018	8:52	27 April 2018	1	38.6	31	6.3
CP 17	*C. plumbeus*	M	180	4706	28 March 2018	11:59	14 May 2018	0	11.2	48	19.6
CO 12	*C. obscurus*	F	300	1895	2 April 2018	11:33	2 June 2018	0.8	7.6	62	6.1
CP 27	*C. plumbeus*	M	180	4348	2 April 2018	13:49	21 April 2018	1.4	10.8	20	43.5

A linear mixed-model analysis found movement in DM best explained by three top models, which included the species, time of day (TOD), and day in the season (DIS). The model did not find the ambient temperature, lunar phase, or the shark's total length to significantly affect the DM. Residuals distribution for the model appears in figure A2.

The Akaike information criterion (AIC) was similar to the first 3 models (delta < 2), and all 3 models were able to account for 58% of the variance (Table 2).

Table 2. Model selection results only include models with ΔAIC < 2. DM represents median depth, TOD represents the category time of day, DIS represents day in season, and Shark represents an individual shark.

Model Formula	AICc	ΔAICc	df	Log Likelihood	adjR^2
DM ~ Species + TOD + (1 | Shark)	1562.2	0	7	−774.010	0.579
DM ~ Species + TOD + DIS + (1 | Shark)	1563.1	0.9	8	−773.453	0.583
DM ~ Species × TOD + (1 | Shark)	1564.1	1.9	10	−771.883	0.585

C. plumbeus were deeper than *C. obscurus* at all times of the day, with a mean difference of 1.5 m during the day and at night (Figure 2). In crepuscular times, this number changes towards a higher number (1.8 m) at dawn and a lower number (1.26 m) at dusk, suggesting *C. plumbeus* might start the movement earlier than *C. obscurus*, thus creating a bigger gap in the morning and a smaller one going back up at night.

This result was repeated when comparing DM at the different TOD within each species. Compared to DM at night, *C. obscurus* ventured 1.39 m deeper during the day (there was no significant difference between DM at night and the transient times), whereas *C. plumbeus* changed their DM significantly early at dawn and continued moving 2 m deeper for the day. DM at dusk was not significantly different from the night (Table 3).

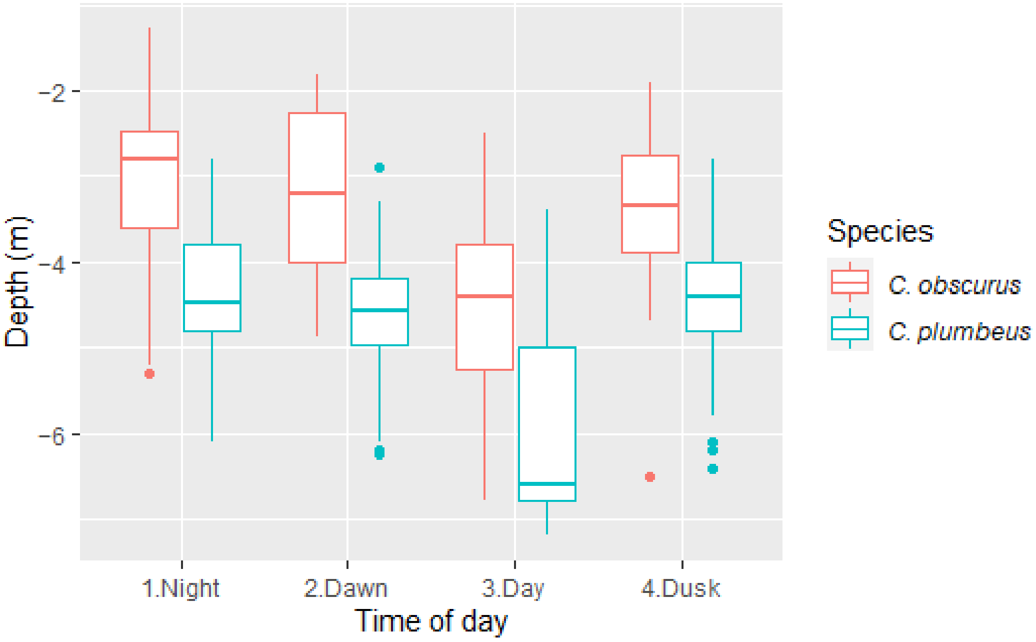

Figure 2. Median depth by the time of day for *C. obscurus* and *C. plumbeus*. The upper and lower limits of boxes represent the 75th and 25th percentiles, respectively. Horizontal lines represent the median value.

Table 3. Unpaired Hedges' g test among species and time of day groups.

Species	Test	Difference (m)	95 CL	Sig
C. obscurus	Dawn (*n* = 21)—Night (*n* = 95)	0.0689	[−0.382; 0.549]	−
C. obscurus	Day (*n* = 87)—Night (*n* = 95)	1.39	[1.05; 1.73]	+
C. obscurus	Dusk (*n* = 24)—Night (*n* = 95)	0.312	[−0.152; 0.774]	−
C. plumbeus	Dawn (*n* = 66)—Night (*n* = 125)	0.351	[0.0516; 0.639]	+
C. plumbeus	Day (*n* = 116)—Night (*n* = 125)	2	[1.67; 2.34]	+
C. plumbeus	Dusk (*n* = 82)—Night (*n* = 125)	0.166	[−0.122; 0.434]	−
TOD	**Test**	**Difference (m)**	**95 CL**	**Sig**
Night	*C. plumbeus* (*n* = 125)—*C. obscurus* (*n* = 95)	1.48	[1.11; 1.84]	+
Dawn	*C. plumbeus* (*n* = 66)—*C. obscurus* (*n* = 21)	1.80	[1.15; 2.42]	+
Day	*C. plumbeus* (*n* = 116)—*C. obscurus* (*n* = 87)	1.51	[1.19; 1.85]	+
Dusk	*C. plumbeus* (*n* = 82)—*C. obscurus* (*n* = 24)	1.26	[0.556; 1.87]	+

4. Discussion

The aggregation of sharks at OR's effluent provides a unique opportunity to examine how human development causes a change in the movement and behaviour of certain shark species, as well as the behavioural adaptations of the sharks to the new conditions in terms of competition and use of space. In this study, we describe this aggregation behaviour, and the vertical movement patterns within it, at an individual level, as well as offer a possible explanation for the observed coexistence between these species at the site.

Clear and constant diel vertical movement was found for both species at the site. All sharks swam in the upper water column at night and ventured deeper during the day, although the shift of DM between day and night was characterized by a seemingly minor difference for sharks of that size (i.e., a change of no more than 2 m for 2–3.5 m long sharks). A distinct difference in utilised DM was found between the species, showing *C. plumbeus* swam deeper than *C. obscurus*, displaying spatial partitioning of the species. Moreover, the only place within the heated area to reach a depth greater than 5 m is underneath the discharge current, where *C. plumbeus* sharks have been documented repeatedly (Figure 3). The utilised DM (for each species) was not related to the ambient SWT, the lunar phase, or the individual size of the sharks, suggesting a species-specific spatial partitioning at the study site. These results are further reinforced by the swimming profile recorded by an archival tag attached to one of the *C. plumbeus* sharks (Figure A1).

Figure 3. *Carcharhinus plumbeus* swimming under the current at 7 m. (The photo was reprinted with permission from Ilan Elgrably).

The idea of spatial partitioning is further supported by the order of magnitude that was found in the difference in the detection rate of *C. plumbeus* (Table 1), suggesting different utilization of the space by *C. obscurus* and *C. plumbeus* at the study site. The number of detections, however, may be affected by the acoustic noise the artificial current causes in shallower waters.

In this study, the scale of DM variation was very small (due to the nature of the study site), as was the difference in sizes within each species. All *C. obscurus* individuals were considerably larger than the *C. plumbeus* individuals, and therefore, it is impossible to fully determine whether the daily changes in spatial occupation were due to individual size, species, or sex. Here we observed a few dozen sharks of each species coexisting in “close quarters”, seemingly facilitated by a daily “shift-change” in terms of time and DM locations. Recently, temporal shifts have been shown between sharks of different species in Tampa, Florida, demonstrating robust temporal partitioning of foraging times [7]. This might also be the case here, with *C. plumbeus* waiting their turn to feed.

Diel movement may be driven by prey behaviour [8,11]. *C. plumbeus and C. obscurus* mainly feed on teleost fish and cephalopods [12–15] and are considered to be at the same trophic level (4.1 for *C. plumbeus* and 4.2 for *C. obscurus*, Cortés, 1999), but size differences between the species at the study site could be driving differences in feeding preferences, as has been suggested for other species [16–18].

Inter-species competition can also explain the difference between the movements of the sharks. The larger *C. obscurus* spent time at the site freely during the day, while the smaller *C. plumbeus* entered the "preferred" depth at night when *C. obscurus* individuals were not there. The slight change in the timing of the transition between deep and shallow supports the theory that one species "responds" to the movement of the other species.

The idea of division in depth utilization according to sharks' size has been suggested by [19], where smaller sixgill sharks *(Hexanchus griseus)* used shallower sites than larger individuals; however, this was only observed in individuals of the same species. In this study, the total length of individual sharks was not significant, but it could be overshadowed compared to the size variation between the two species.

Salinity has also been found to be a driver in shark movement. Reference [5] found two species of river sharks segregated spatially along a salinity gradient. This possibility should be further explored at the study site in terms of salinity tolerance and/or preference for both species and whether it plays a part in the species' depth distribution.

The unique circumstances provided by the shark aggregations at OR allow us to examine changes in DM on a scale that is rarely possible. It seems that diel vertical movement was maintained, even though functionally, the differences in depth are considered minor compared to the vertical movement reported for sharks of the same species in different areas. These findings may suggest that vertical diel movement is an inherently basic behaviour in sharks of these species and is maintained, even in cases when it is not essential.

Author Contributions: Conceptualization, A.B. and D.T.; data curation, A.B., A.S., E.B., Z.Z.S., and S.M.; formal analysis, A.B.; investigation, A.B.; methodology, A.B. and A.S.; supervision, D.T.; visualization, A.B.; writing—original draft, A.B.; writing—review & editing, A.S. and S.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Shark tagging was conducted under permit numbers 2017/41714 and 2018/42027, issued by The Israeli Nature and Parks Authority (INPA), and according to European ecological standards.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available from the authors upon reasonable request and with permission of the "Top Predator Lab" at Morris Kahn Marine Research Station, Department of Marine Biology, Leon H. Charney School of Marine Sciences, University of Haifa, Israel.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

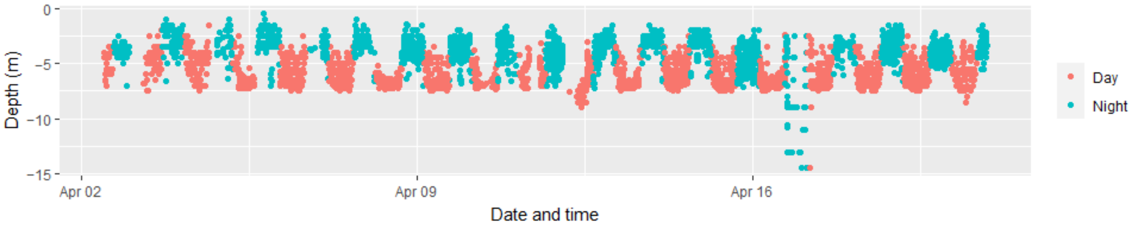

Figure A1. Depth data as was recorded in an archival tag of a *Carcharhinus plumbeus* male. Points are coloured according to the time of day (day in red, night in blue).

Table A1. Size measurements of untagged sharks captured within the study site between 2016–2017.

Species	Catch Date	TL (cm)	Sex
C. obscurus	25 February 2016	322	Female
C. obscurus	25 February 2016	328	Female
C. obscurus	23 March 2016	309	Female
C. obscurus	23 March 2016	325	Female
C. obscurus	23 March 2016	299	Female
C. obscurus	17 January 2017	200	Female
C. obscurus	20 February 2017	250	Female
C. obscurus	21 February 2017	290	Female
C. obscurus	23 February 2017	280	Female
C. obscurus	6 March 2017	280	Female
C. obscurus	8 March 2017	390	Female
C. obscurus	28 March 2017	320	Female
C. obscurus	19 December 2017	283	Female
C. obscurus	9 January 2018	303	Female
C. plumbeus	8 March 2017	170	Male
C. plumbeus	23 February 2017	177	Male
C. plumbeus	6 April 2017	198	Male
C. plumbeus	6 April 2017	179	Male
C. plumbeus	1 May 2018	178	Male

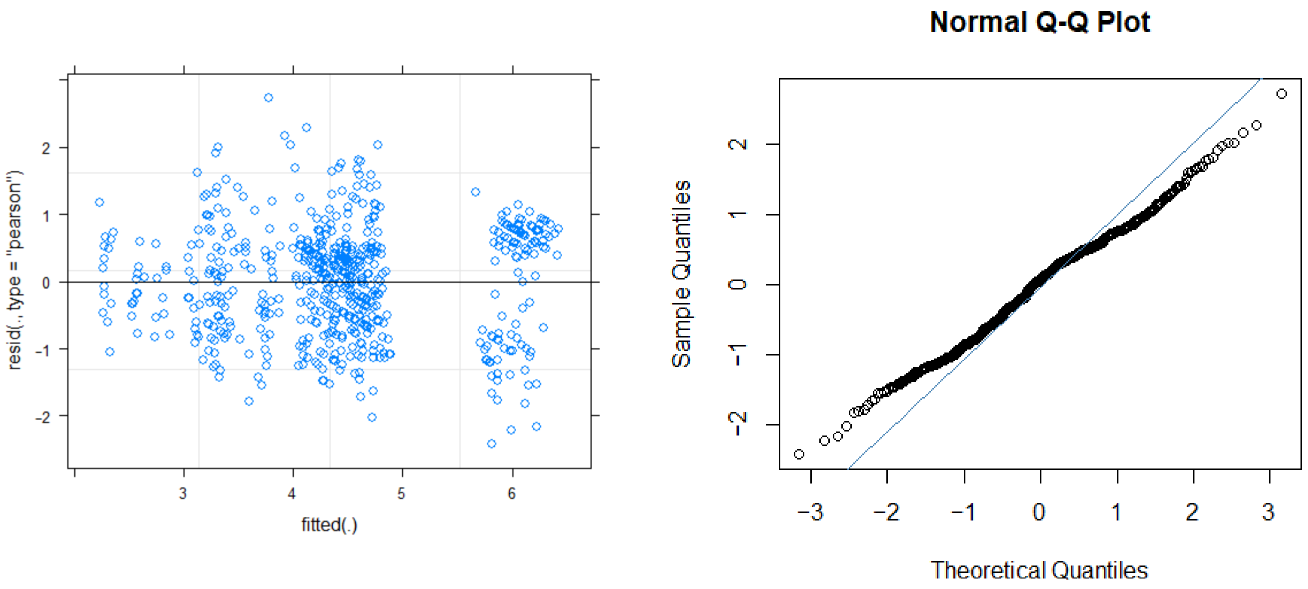

Figure A2. Residuals distribution for the LM model.

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Statement of Authorship

Principal Author

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Contribution to the Paper	Conceptualization, Data curation, Formal analysis, Investigation, Methodology,; Visualization, Writing – original draft.		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

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Article

Some like it hot: Investigating thermoregulatory behaviour of carcharhinid sharks in a natural environment with artificially elevated temperatures.

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Abstract: Global warming raises seawater temperatures and creates changes which have been found to affect the movement of large migrating species. Understanding the thermal niche of species could be proven essential to anticipate how the future climate will alter migrations, and how conservation efforts will have to change accordingly. Orot Rabin power station in Hadera, Israel, uses seawater to cool its turbine and releases the warm water into the sea. As a result, a marine area with artificially elevated temperatures is created around the effluent. Every winter in the past two decades, this area attracts sharks of two species, *Carcharhinus obscurus* and *C. plumbeus* presumably to spend the cold months at a higher temperature. In this study, we concentrated on this point of artificial heat dissipation, which maintains a wide gradient of surface temperatures and allowed us to examine the temperature preferences of these species when given a larger range than what is naturally found in the sea. Between 2016 and 2018, 16 sharks were tagged with acoustic tags, three of which had temperature sensors, and two were additionally tagged with pop-up archival tags also logging temperature data. Results show that the sharks stayed in the elevated temperature, while the ambient sea was cold during the winter, spending several months in the heated area. Both species displayed a similar preferred range, spending 90 percent of their time at a temperature between 21.8°C and 26.05°C while the surrounding sea was 15.5-25.5°C. Considering this chosen thermal niche and the rise in water temperature, it seems that during the last 40 years the eastern shores of the Mediterranean have become more suitable for these species, especially during transitional seasons. The question that arises, however, is whether these shark populations will benefit from the expanding range of preferable temperatures, or whether this proximity will put them at greater risk in terms of human activities as fishing and pollution.

Keywords: Climate change; thermal niche; Predators; Range shifts; Selacii; Elasmobranch; Habitat selection; *Carcharhinus obscurus*; *Carcharhinus plumbeus*; Global warming

Key Contribution: Seasonal aggregations of Carcharhinid sharks are driven by a thermoregulatory behaviour in which sharks remain within a specific range of temperatures. These findings provide valuable insights as to mechanisms that form these unique aggregations, and to further study the behaviour and distribution of these species under global warning scenarios.

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1. Introduction

Large coastal sharks are known to perform seasonal migrations for the purpose of feeding, reproduction, and thermoregulation. For example, for requiem sharks such as *Carcharhinus falciformis*, movement patterns have been shown to differ in response to variations in resource abundance between distinct geographical regions [1]. In bull sharks (*Carcharhinus leucas*) females have been reported to undergo seasonal migrations to give birth [2], and many other species are known to travel and migrate in sex-segregated cohorts (e.g., [3–5]). Migration in sharks can also constitute a mode of thermoregulatory behaviour as they travel according to changes in ambient seawater temperatures while remaining within a specific temperature range (also referred to as a thermal niche (e.g., [6,7]). Understanding what drives and shapes migration patterns of large coastal sharks can prove essential for conservation efforts and predicting shark movements and distribution under predicted global changes in seawater temperatures.

Carcharhinus obscurus and *Carcharhinus plumbeus* are among the requiem sharks (Carcharhinidae) with a cosmopolitan distribution that are also found in the Mediterranean Sea. Both species are large predators found in coastal and offshore waters [8–10] and are listed as endangered globally [11,12], with numbers of *C. plumbeus* reportedly declining by> 70% over a period of 69 years [13].

For decades, large aggregations of carcharhinid sharks, comprised of *C. plumbeus* and *C. obscurus* occur every winter at Orot Rabin (OR) power station near Hadera, Israel in the Eastern Mediterranean and are not sighted at all during the rest of the year [14,15]. Arrival and departure of sharks at OR coincide with seasonal declines and elevations in seawater temperature, respectively. During the winter season, sharks at OR remain within a large plume of hot water discharge, which suggests that these aggregations are driven by a thermoregulatory behaviour aimed at remaining within the sharks' thermal niche [14]. A similar seasonal pattern in the presence of *C. plumbeus* has also been reported in other parts of the Eastern Mediterranean – where sharks aggregate between May and August while sea water temperature ranges (20 – 28°C).

Dusky sharks (*C. obscurus*) are rare in the Mediterranean Sea and are not observed aggregating anywhere aside from Israel [8,16,17]. The species was rarely encountered before the aggregations began, with less than 20 observations recorded [18], raising the question of whether their "new" appearance in the Mediterranean Sea is related to the possibility of spending the winter in a warm area. *C. plumbeus* are more common than *C. obscurus* in the Mediterranean Sea and are reported to aggregate in Bonçuk Bay, in Gökova Special Environmental Protection Area, southwestern Turkey. [19] found that sharks arrive at Bonçuk in spring and fall, during a temperature range of 20-27°C.

While water temperature has been shown to correlate with the appearance of these aggregations [14,19], it remains unknown if individuals remain at OR for the duration of winter, as would be expected in the case of thermoregulatory behaviours, or if individuals remain for a far shorter time and are replaced by other individuals arriving throughout the season. The adjacent warm water discharge (10°C above ambient sea temperature) also enabled us to empirically evaluate a thermal niche for the sharks at OR, as it enables individuals to easily control the temperature of their surroundings (i.e., by varying their distance to and from the outflow). Using acoustic telemetry and satellite tags equipped with temperature sensors we examined the preferred water temperature of individual sharks on site and examine what drives seasonal aggregations of sharks at OR.

2. Methods

2.1. *Study site*

"Orot Rabin" (OR) station (32.466814N, 34.880232E) is a coal-fired power plant located near Hadera, Israel. OR has a long coal conveyor stretching two kilometres into the sea and uses six turbines to generate electricity. OR's turbines are cooled down by six double cooling systems pumping water from the sea. Water is used to cool down the turbines and is then discharged back to sea at up to 10°C warmer than local conditions.

The resulting warm water plume forms a heated marine area along the coast a few kilometres south of OR and spreading approximately one to two kilometres west out to sea. The water temperature in the heated area is affected by the direction of currents, waves, winds, and turbine workload which is determined by temporary fluctuations in electricity demand. This results in a study site where temperatures can change considerably from one day to the next.

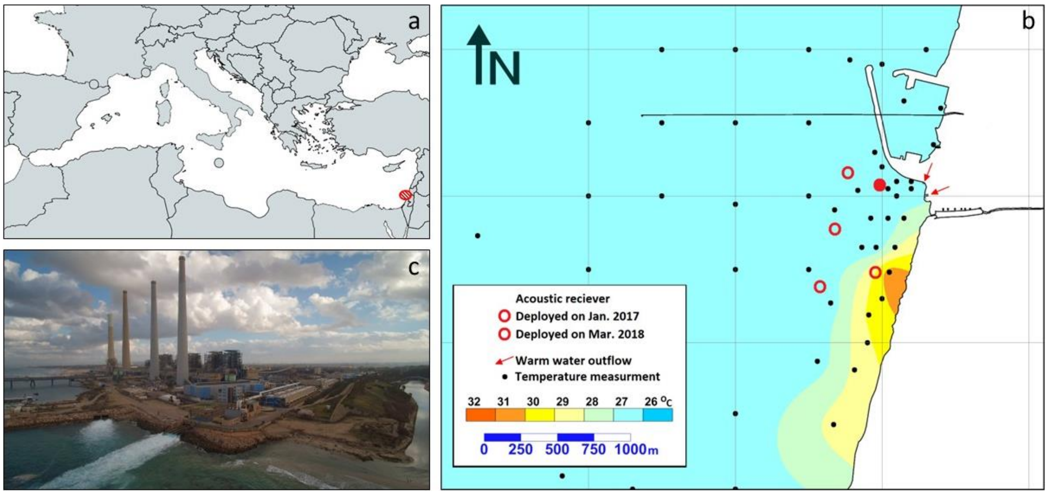

Figure 1. Study site map. a) Study site location at the easternmost end of the Mediterranean Sea. b) Receivers' deployment at Orot Rabin power plant (OR) in Hadera. Temperature is shown as measured by IEC staff on 18 Oct. 2018, at 2 m depth. Adapted from the IEC monitoring report 2018. c) The warm water discharge at OR (Moshe Mittlman, Jan. 2017).

2.2. *Shark Tagging*

Carcharhinid sharks at OR are being tagged since 2016 as part of an ongoing monitoring program conducted by the Morris Kahn marine research station, Israel (https://marsci.haifa.ac.il/en/the-morris-kahn-marine-research-station/). Shark movement in this study was monitored using acoustic transmitters and Pop-up Satellite Archival Tags (PSATs, MiniPAT-247A, Wildlife Computers, WA, USA). A total of 16 sharks were tagged during two aggregation seasons: between January to February 2017 and between November 2017 to April 2018 (see Table 1 for details). All acoustic tags had a transmission interval of 30 – 90 seconds (nominal interval of 1*min.) and operated on 69 kHz. PSATs were programmed to detach and transmit data after 192 days. Five of the sixteen sharks that were tagged also had sensors that provided *in-situ* measurements of ambient water temperature (see Table 1). The first acoustic receiver (VR2W, Vemco Inc., Nova Scotia, Canada) was deployed in OR's effluent on January 2017, and four additional receivers (TBR700, Thelma Biotel AS, Trondheim, Norway) were added in March 2018 (See Figure 1).

Carcharhinid sharks, *C. obscurus* and *C. plumbeus* were caught from a research vessel at OR's warm water effluent using baited lines. Once caught, sharks were pulled near the boat and strapped around the caudal peduncle and behind the pectoral fins to be measured and sexed. Sharks were then turned over and held in a state of tonic immobility, while acoustic tags were surgically implanted into the peritoneal cavity through a small incision. PSATs were attached externally to the dorsal fin. Incisions were sutured immediately after the insertion of the acoustic transmitter, after which each tagged shark was released.

2.3. *Water temperature measurements*

Water temperatures at OR are regularly measured by the Israel electric company (IEC) at the intake point of each pump and at the discharge point, aka the warm water effluent. Water temperature measurements were supplied by the IEC environmental department and were measured every 30 minutes.

In this study, the median water temperature at the intake points represents ambient seawater temperatures close to shore whereas the temperature at the discharge point represents the maximum water temperature available at the site. The maximum temperature at the effluent fluctuated in conjunction with changes in pump operation so a median temperature of all functioning pumps was calculated for each 30-minute time stamp, on both the intake and outtake data.

Individual temperature measurements were taken from two different tags. In the 2016-2017 season, three sharks were tagged internally with temperature sensors, providing data while the sharks were in the detection range of the receivers. In the 2017-2018 season, two sharks were successfully fitted with an external satellite tag, providing data regardless of the shark's location. The bottom depth near OR doesn't exceed 7.5 meters, therefore data points from greater depths were removed for the temperature analysis.

2.4. Mediterranean water temperature measurements and predictions

Sea Surface Temperature (SST) measurements for the Mediterranean were downloaded from Copernicus Marine Service using the "SST MED SST L4 REP OBSERVATIONS 010 021" product which provides high-resolution optimally interpolated SST for the Mediterranean Sea on a daily (night-time) scale [20]. Temperature distribution maps were plotted for November, the month when sharks begin to aggregate at the power station (as previously reported in [14]). Three five-year periods were chosen to investigate thermal distribution in the Mediterranean: 1985-1990, 2000-2005, 2015-2020 the later corresponding to the time the data was collected in this study.

For future predictions, Representative Concentration Pathway (RCP) data were downloaded from the bio-oracle.org dataset [21] using RCP8.5, which is often used for predicting mid-21st century (and earlier) emissions based on current and stated policies [22]. Data for these scenarios are provided annually and not monthly, with the given options of maximum, minimum or mean annual predictions. The mean annual temperature was chosen to best describe the temperatures in November (as a median between the lowest temperatures in February and the highest temperatures in August) in accordance with the maps of the previous time periods.

Thermal maps were created using Python Software [23]. The mean temperature was calculated for each time period but was only shown within the 90% quantiles of the temperature that sharks were found to inhabit in this study, to show the potential distribution area of *C. plumbeus and C. obscurus* on each map.

3. Results

3.1. Residency and date of departure

A total of 16 sharks (12 *C. obscurus* and 4 *C. plumbeus*) were caught at OR and tagged with internal acoustic tags. Out of the 16 tags three were equipped with temperature sensors (11941, 11942, 11943). During the second tagging season (2017-2018) two sharks were tagged with Pop-up archival tags in addition to the acoustic tags. All caught *C. obscurus* sharks were females, ranging from 2.75 to 3.55 meters and all caught *C. plumbeus* sharks were males ranging from 1.69 to 1.81 meters, therefore, there was no overlap between species/sexes in size (Table 1).

Tracking duration after tagging ranged from 12 days up to 134 days. Individual sharks, especially the females *(C. obscurus)*, were found to spend months at the station (Table 1) with a mean value for the tracked periods of 69.62±9.02SE days. We recognise that our tracking period was limited due to tagging date in mid-season, therefore the actual time spent on site could be longer (Table 1).

Individual CP 27 left the area shortly before the final exit and swam back in within a few hours. Depth and Temperature measurements show a very clear separation between time spent in the heated area and out of it (Appendix 1).

Table 1. Acoustic tagging study details. TL-total length. Temperature was measured by acoustic sensors for the first three individuals. Temperature ranges for individuals marked with asterisks were measured by archival tags tagged in addition to an acoustic transmitter with no temperature sensor. A nominal interval 60s.

Shark serial	Tagging season	Species	Sex	TL (cm)	Transmitter type (sensors)	Detections	Tagging Date	Last detected	Min Temp (°C)	Max Temp (°C)	Days tracked	Detec. /Day/Rec	Transmitter model
11941	2016-2017	*C. obscurus*	F	307	Acoustic (temperature)	1532	17/01/2017	12/04/2017	19.48	26.69	86	3.7	V16T
11942	2016-2017	*C. obscurus*	F	285	Acoustic (temperature)	1709	24/01/2017	18/04/2017	19.16	27.32	85	4.2	V16T
11943	2016-2017	*C. obscurus*	F	289	Acoustic (temperature)	242	28/02/2017	30/03/2017	19.48	24.50	31	0.6	V16T
CO 21	2017-2018	*C. obscurus*	F	289	acoustic	318	27/11/2017	11/03/2018	NA	NA	105	3.2	HP16
CO 23	2017-2018	*C. obscurus*	F	276	acoustic	737	12/12/2017	24/04/2018	NA	NA	134	6.3	HP16
CO 22	2017-2018	*C. obscurus*	F	315	acoustic	482	27/12/2017	02/04/2018	NA	NA	97	6.1	HP16
CO 14	2017-2018	*C. obscurus*	F	355	acoustic	424	27/12/2017	13/03/2018	NA	NA	77	7.4	HP16
CO 20	2017-2018	*C. obscurus*	F	300	acoustic	267	02/01/2018	08/05/2018	NA	NA	127	3.1	HP16
CO 26	2017-2018	*C. obscurus*	F	275	acoustic	1051	05/02/2018	22/04/2018	NA	NA	77	8.2	HP16
CP 15	2017-2018	*C. plumbeus*	M	169	acoustic	17117	12/03/2018	14/05/2018	NA	NA	64	53.5	HP16
CO 25	2017-2018	*C. obscurus*	F	280	acoustic	63	12/03/2018	23/03/2018	NA	NA	12	1.1	HP16
CP 10	2017-2018	*C. plumbeus*	M	191	acoustic	17231	14/03/2018	10/05/2018	NA	NA	58	59.4	HP16
CO 11*	2017-2018	*C. obscurus*	F	294	Acoustic, PSAT	969	28/03/2018	27/04/2018	22.3*	26.6*	31	6.3	HP16
CP 17	2017-2018	*C. plumbeus*	M	180	acoustic	4706	28/03/2018	14/05/2018	NA	NA	48	19.6	HP16
CO 12	2017-2018	*C. obscurus*	F	300	acoustic	1895	02/04/2018	02/06/2018	NA	NA	62	6.1	HP16
CP 27*	2017-2018	*C. plumbeus*	M	180	Acoustic, PSAT	4348	02/04/2018	21/04/2018	20.4*	26.8*	20	43.5	HP16

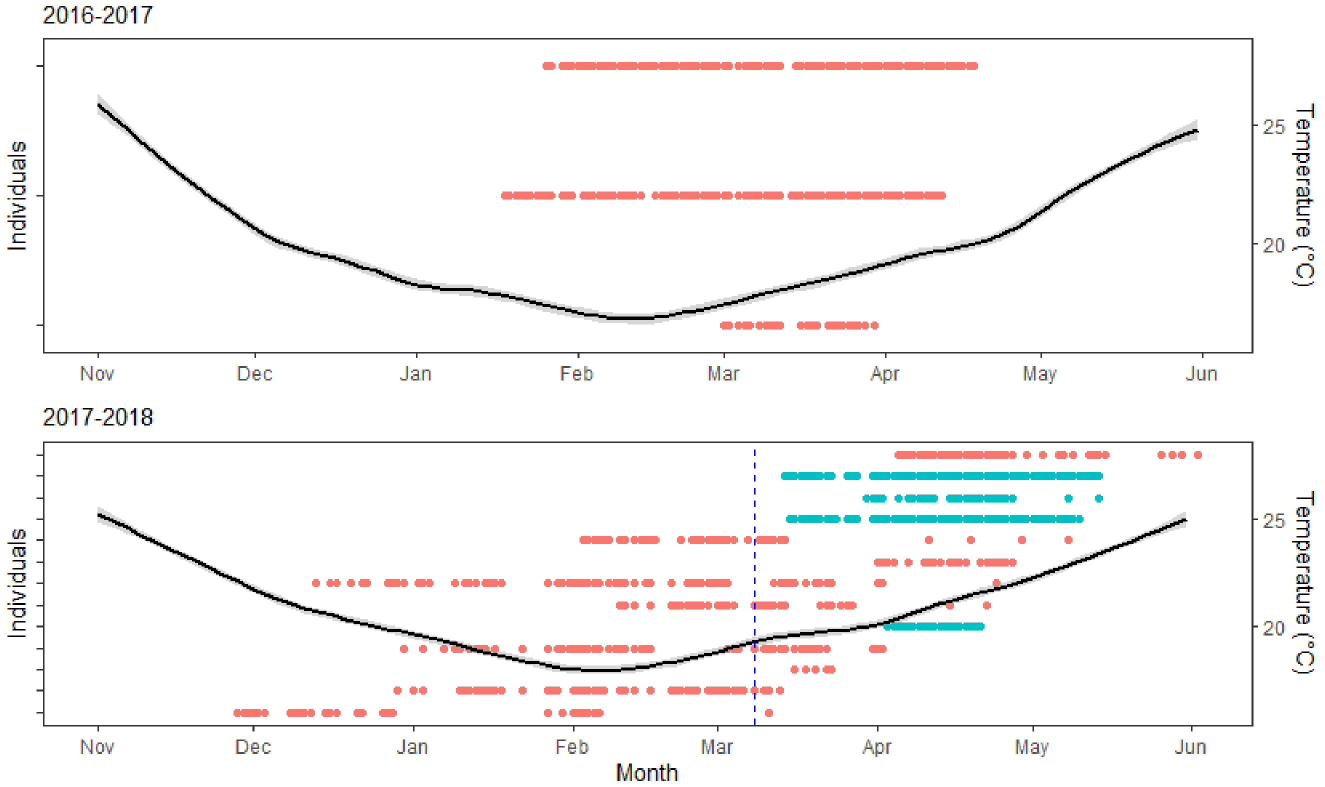

Figure 2. Shark detections and ambient sea water temperature. Shark detections are marked in blue for *C. plumbeus* and pink for *C. obscurus*. Smooth line of water temperature marked in black. The blue dashed line marks the addition of four receivers to the study site.

3.2. Temperature

Temperatures for individuals 11941,11942,11943 were extracted from the acoustic sensors, while temperature measurements for individuals 11 and 27 were extracted from the archival tags and corresponded with the periods these sharks also transmitted acoustically. None of the tagged individuals left the study area prior to the annual sea temperature warming period in spring (Fig. 2). Throughout the tagged period sharks swam in a temperature between 19.16°C and 27.32°C and preferred swimming in the artificially elevated temperature, consistently keeping away from the ambient temperature (Fig. 3). Sea temperature on time of departure (last detection) ranged from 18.62°C to 24.91°C showing the same preferred range of temperature which individuals kept throughout the season (Fig. 4). Temperatures on day of leave were lower in the first season, probably due to having only one receiver, thus a smaller detection range. Individuals spent 90% of the time in a temperature between 21.8°C and 26.05°C and left the receivers' area only after the ambient temperature reached 19°C and before the water temperature in the heated area reached 25°C (Fig. 2 and 3).

The only exception to this was shark 11943 which was last detected in the area when the water temperature was 18.62°C. This could be affected by having only one receiver in the water at that time, and therefore a reduced area was covered for detections.

During the second tagging season sharks appeared to be leaving the study area later in the season (Fig. 2), when the ambient temperature is higher (Fig.4). The later time of the last detection is probably also related to the added receivers and increased coverage of the array – which detected the tags while being farther away from the water discharge.

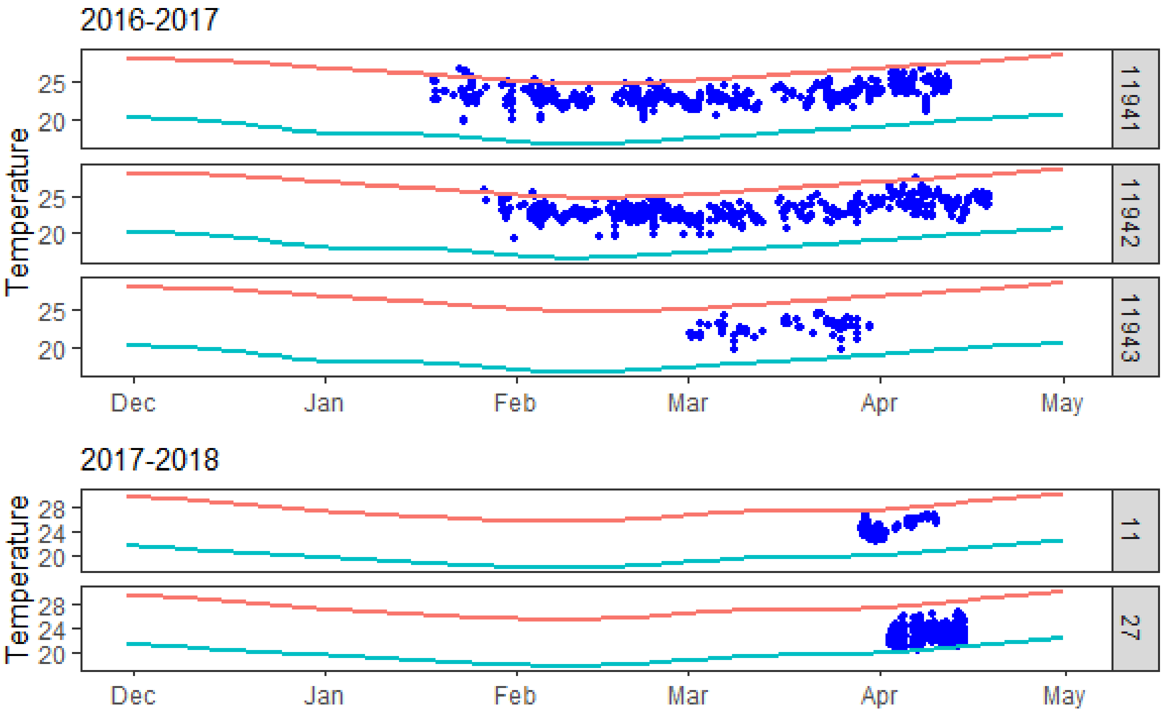

Figure 3. Temperature measurement for sharks within the warm effluent. Temperature measured by the shark tags shown in Blue. Water temperature of the ambient sea is shown in the smoothen light blue line and heated water temperature in the smooth red line.

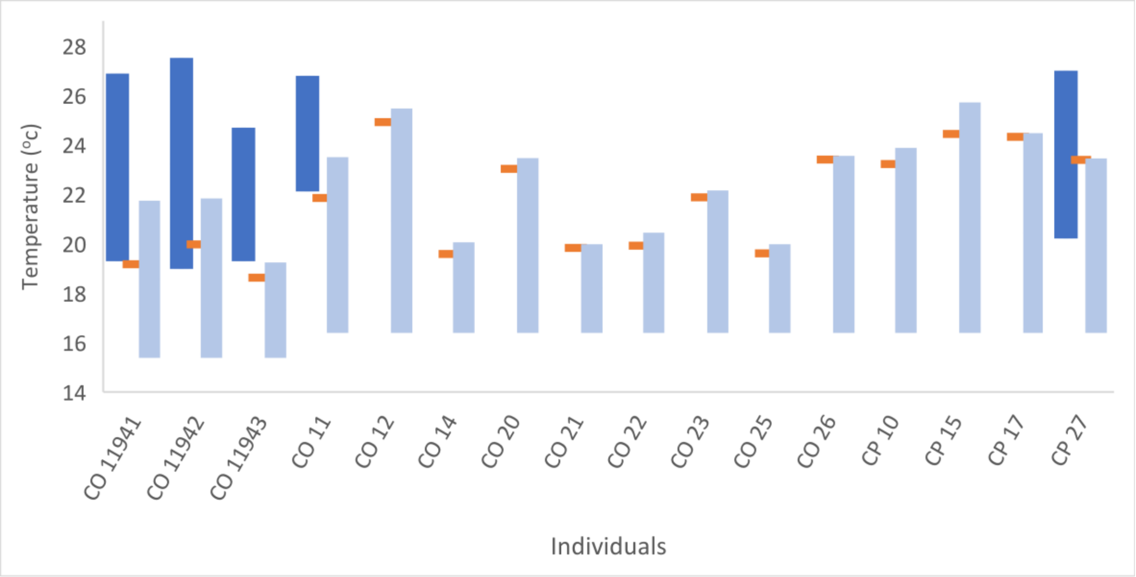

Figure 4. Water temperature (range) for each of the tagged sharks during their tracking time at OR, showing ambient sea water temperature (light blue), and temperature measured *in-situ* by the transmitters (dark blue). Orange markers represent the ambient sea temperature at the time of last detection (i.e., on leaving the study site). Sharks appear as CP for *C. plumbeus* and CO for *C. obscurus*.

4. Discussion

This study provides the first mechanistic explanation to a seasonal aggregation of sharks at a coastal power plant in the Eastern Mediterranean. By use of in-situ temperature measurements of the sharks, we present evidence for sharks actively maintaining a thermal niche, and the possible role that interacting with the warm water discharge might play in the movements and migrations at a regional scale.

Sharks were observed at OR throughout the winter and all of the individuals were detected at the study area at least until sea water temperature began to rise. A clear temperature range of 19-27°C was observed to be maintained throughout the season, a range made possible only due to the heated water of the effluent. This now-recorded behaviour reinforces the notion that thermoregulation is the underlying reason for shark aggregations at the site and explains the arrival and departure of sharks from the station as suggested in [14].

Similar conditions across individual arrival and departure (temperature), such as those observed at OR, have also presented in Bonçuk, Turkey [19], possibly indicating part of migration at a regional scale (i.e., all arriving from somewhere at a particular time, and moving on close together in time). Sharks are known to migrate and aggregate in sex-segregated cohorts [4,5,24], and indeed we find within our data only females *C. obscurus* and only males *C. plumbeus*. This may reinforce the assumption that these aggregations are also related to reproduction. Gestation periods in these species stretch well over the time spent in the aggregation (approximately 2 years in *C. obscurus* [25]) – therefore disentangling the two factors is problematic, and although the elevated temperature may benefit pregnant females, it is unlikely to be the sole driver, as males are also present at these aggregations. Higher prey densities or abundant resources cannot be eliminated as a factor in the sharks' attraction to the area. While Anecdotal evidence from fishermen and divers suggests that teleost species may also be attracted by the hot water effluent, it is as of yet undermined whether prey availability is a contributing factor in attracting sharks to the area. Since sharks are strong swimmers and can easily come in and out of the area, our findings suggest this is unlikely as it would not explain the long residency of sharks, especially in light of substantially increased intra and interspecific competition. In cases where several species shared mutual feeding grounds, different species often tend to arrive at a specific time of the day, thus avoiding competition and high densities [26–28].

The power plant may facilitate or provide improved conditions for migrating sharks, but also suggest a problematic dependency, especially given that these aggregations have been occurring for several decades [14]. Prolonged stay in an artificial location poses a significant effect on the life course of individuals within the population or even on the population as a whole. Spending extended periods of time in coastal waters in a highly urbanized area may subject sharks to sewage effluent, chemical pollution (e.g., heavy metals, pesticides), and noise pollution [29,30]. Research from Florida found juvenile nurse sharks (*Ginglymostoma cirratum)* exhibit lower levels of omega-6 highly unsaturated fatty acids and higher levels of both saturated and bacterial fatty acids as a result of proximity to urbanized areas [31]. Another study [32], also from Florida suggests that the high numbers of infertility in bonnethead sharks *(Sphyrna tiburo)* in Tampa Bay may be linked to exposure to organochlorine contaminants.

Proximity to human activity exposes the sharks to uncontrolled tourism. The gathering of people at the power stations, swimmers, divers and small vessels creates a permanent disturbance to the natural behaviour of sharks in the limited space they inhabit. The constant interaction between dozens of people and dozens of sharks can lead to unwanted interactions thus damaging to the image of sharks and the public's willingness to protect them. The constant presence close to the shore in an accessible and well-known location also places sharks in danger of targeted fishing and bycatch of coastal fishing. Since all shark species are protected in Israel and fishing is prohibited, intentional fishing events have been rare in recent years. On the other hand, sharks are caught on a daily basis, and many are documented entangled with fishing hooks and other fishing gear. [33–35]

In the marine environment, temperature plays a role in fish migratory movement and habitat selection [36–39]. Thermal niches for fish (defined as their preferred temperature

±2°C or ±5°C, Magnuson et al., 1979) differ among species [41], and sometimes among life stages [42,43] and/or sexes [44,45] within species.

Temperature was found to play a significant factor in triggering the emigration of juvenile *C. plumbeus* in South Carolina [46] and similar temperature preferences were found for the two species globally (western Australia - [47], Hawaii - [48], North Carolina - [49]). For *C. plumbeus*, most studies were investigating the movement behaviour of juvenile sharks. While *C. plumbeus* sharks were found in a large range of temperatures, the majority of their time was spent in temperatures similar to those found in this study, or even higher (up to 30°C).

Two of the tagged sharks in this study were equipped with PSATs which provide movement data beyond the study site. However, one detached as soon as the shark left the heated area, and therefore only one PSAT kept logging data beyond the study site. Given the very small sample size and the scope of this study, it remains unclear where sharks arrive from or leave to when they are not found at OR. Understanding the spatiotemporal context in which sharks aggregate at OR, can provide clues as to the risks and benefits of such thermoregulatory behaviour (e.g., [50]).

Several studies give evidence of the emerging effect of climate change and global warming on migratory species and observe changes in migratory patterns and seasonal distribution of terrestrial and avian animals due to changes in local temperatures worldwide (e.g., [51–55]).

Marine environments are not spared from these rapid global changes (e.g., [55,56]), and the impact changing ocean temperatures have on marine ecosystems may be substantial [57,58], especially on ectothermic [59], k-selective, top predators such as sharks[60]. Recent research observes that rising sea temperatures have brought on changes in migratory timing and enabled some shark species to alter their distributional range [61–63].

Increasing temperatures in the Mediterranean Sea have been measured throughout the past four decades and are predicted to continue [64]. Changing sea temperatures can lead to significant differences in predator migration routes and consequently change the composition of entire ecosystems at a rapid rate [65]. Determining the preferred range of temperatures for these species is an important step in building estimation models for the expected distributions of the species in the future. Considering global warming and the high rate of sea water temperature rise in the Mediterranean Sea [66], these preferences could help predict changes in shark movement on a large scale.

With rising sea water temperature in the Mediterranean Sea, we found that the eastern coast of the Mediterranean is becoming more accommodating for some carcharhinid sharks.

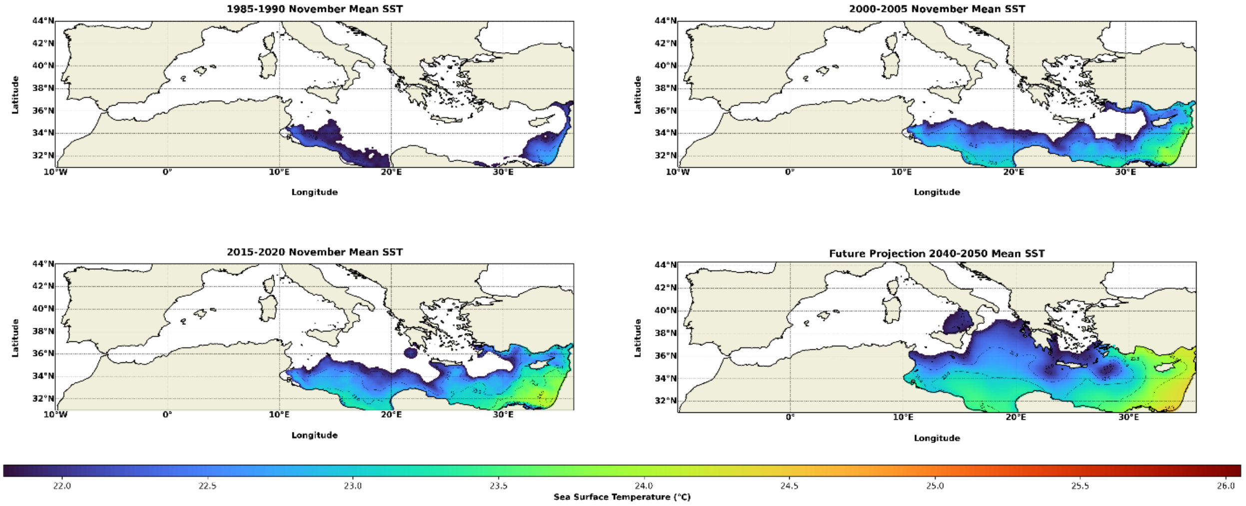

Figure 5. The mean surface temperature of the Mediterranean as measured by satellites for a) 1985-1990 b) 2000-2005 c) 2015-2020 and annual mean SST predictions by the RCP852050 scenario downloaded from bio-oracle.org. The range is shown only within the 90% quantile of temperature used by the sharks in this study (21.8°C and 26.05°C).

Between 1985 and 1990, only small areas in the east and south Mediterranean Sea exhibited the preferred temperature range for *C. obscurus* and *C. plumbeus*. Throughout the last 4 decades with the rise in SST, the compatible area has grown and stretches from Tunisia to west Turkey. The future scenario is predicting the preferred range will include almost the whole eastern basin, including areas in Italy and Greece (Fig. 5). It is possible, that this temperature change might explain how these sharks "found" the stations and learned to use them during winter.

The understanding that sharks are migrating to an artificially heated area along with the relative speed at which sharks have learned to utilize the place and change their natural trajectory, teaches us much in a time of changing environment and warming of sea temperature.

5. Conclusions

Timing of arrival and departure of Carcharhinid sharks at seasonal coastal aggregations is dictated by sea water temperature, wherein sharks wait out the winter within a warm water discharge from a coastal power plant. These findings provide the first evidence of thermoregulatory behaviour in sharks while undertaking seasonal migration, and valuable insights as to mechanisms that form these unique aggregations. Temperature measurements from tagged sharks provide information on their thermal niche and how it is maintained. Finally, these findings are essential to better understand how rising sea temperatures in the Mediterranean Sea might affect sharks' migrations and distribution in the future.

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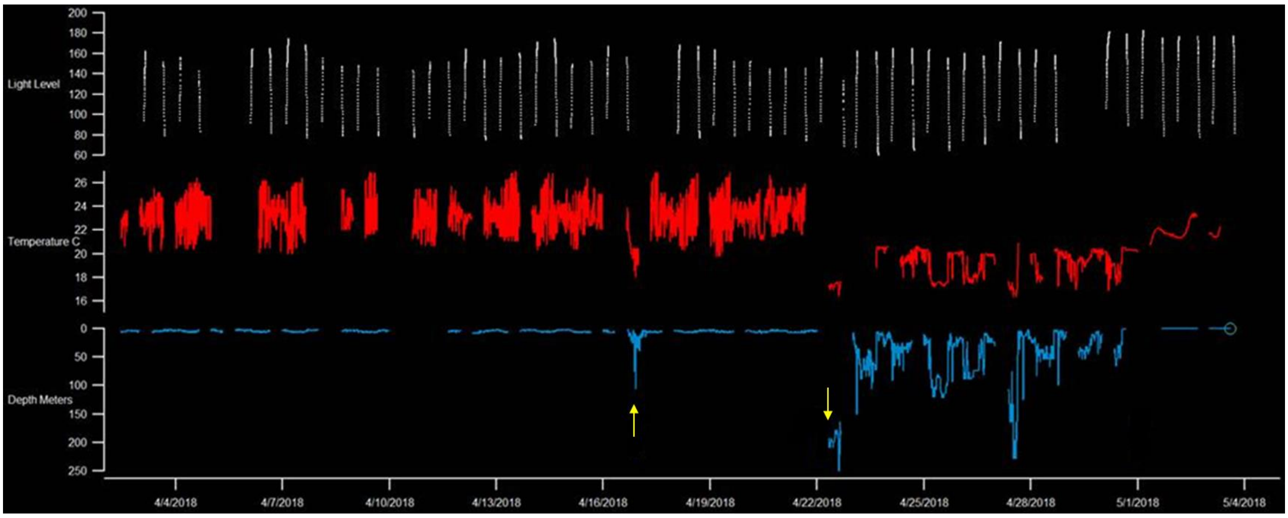
Appendices

Apendix 1: light, temperature and depth records of C. plumbeus shark (ind. CP27) while being in the study area and at open sea. Yellow arrows indicate exits from the heated site.



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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.

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i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the dissertation

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Chapter 3

Seasonal arrival and feeding of injured coastal sharks at fish farms in the Eastern Mediterranean

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Abstract

Every summer coastal sharks (mostly sandbar sharks, *Carcharhinus plumbeus*) come to feed at open-sea fish farms near the Israeli coast, ever since their opening. Three of these sharks appear to suffer injuries of various degrees. At least one of the injured individuals, which suffers from a broken lower jaw, has been sighted at the fish farms every year since 2011. Providing a constant source of food to supplement feeding of wildlife has been showed to have both negative and positive impacts on wild populations and individuals. It may be possible that injured sharks, who have reduced abilities to find food in the wild, rely on such human related food sources to survive. Implications on the long-term effect of provisional feeding on sharks are discussed.

Keywords: *Carcharhinus plumbeus*, provisional feeding, elasmobranch, aquaculture, Eastern Mediterranean

The decline in global shark population over the last few decades is well documented (Dulvy *et al*. 2014; Ward-Paige and Worm 2017). In the Mediterranean, large predatory sharks have become particularly scarce (Ferretti *et al.* 2008), largely due to overfishing in the region (Dulvy *et al.* 2016). Another cost incurred by sharks is fishing related injuries, due to longlines, fishing nets and fish handling (McAuley *et al*. 2007; Mandelman *et al*. 2008; Molina and Cooke 2012). It is estimated that 15% of released (non-finned) sharks die from fishing-related injuries (approximately 100 million sharks a year) (Worm *et al.* 2013). In long-lived animals, injury and mortality of adult individuals has a practically high impact on the reproductive rate of local populations (McAuley *et al.* 2007), which is of great concern for rare or endangered species.

Year-round and seasonal supplemental feeding of wildlife has been showed to have both negative and positive impacts on wild populations and individuals. For example, supplemental feeding may promote pathogen prevalence and dependency on human provided food (Orams 2002) but can have positive implications on individuals' health and survival (Murray *et al*. 2016).

Fish cages are a steady source of food that creates a dependency of the sharks on the latter to various degrees (Pemberton *et al*. 1991; Orams 2002). For example, sandbar sharks *Carcharhinus plumbeus* near the Island of Oahu, Hawaii, have been detected repeatedly at fish farms for up to 2.5 years. And though fish farms did not appear to disrupt seasonal movement patterns (e.g., for reproduction), individuals have repeatedly returned to the same site (Papastamatiou *et al.* 2011).

Since 2006, sea bream (*Sparus aurata*) are farmed in open-water fish cages, several miles off the Israeli Mediterranean coast (Figure 1). Approximately one year after the cages were stocked for the first time, carcharhinid sharks have been documented near the underwater enclosures. Large numbers of coastal sharks (mostly sandbar sharks, *Carcharhinus plumbeus*) and other large marine predators such as Atlantic bluefin tuna (*Thunnus thynnus*) are sighted every summer at the cages (Figure 2) ever since (with the exception of 2016 when the farm closed down, for which we have no data). Visual surveys of sharks at the cages are conducted as part of a long-term monitoring survey of marine apex predators. During the dives we documented three large sandbar shark females (*C. plumbeus*) with obvious injuries (Figure 3). Shark no. 1 was missing the upper lob of its tail. Shark no.2 had what seemed to be a fractured tail, and shark no. 3 had a full broken lower jaw. The injuries seemed to be old injuries, and the sharks were in good health condition otherwise. The shark with the broken jaw seems as if it would not be able to feed on its own, but this certain individual has been seen by the farm workers every summer since 2011.

If feeding at the fish cages has only the benefit of obtaining easy food, then one would expect to find sharks with higher competitive abilities (large body size, physically intact). The presence of injured sharks at the fish cages can indicate that feeding in the fish farms may be lesser alternative to feeding elsewhere.

Very few describe the individuals attracted to provisional feeding and the effect on natural selection. These studies refer to rising aggression and possible selection toward aggressive animals (Orams 2002; Murray *et al.* 2016). In the case of the sharks described above this is not likely to be the case, since they have not displayed aggressive behaviors, and have reduced competitive capabilities due to their injuries. Most animals avoid the presence of human out of an evolutionary instinct of self-preservation. An animal that habituates to humans does so at a high cost of incurring risk (Orams 2002). It is possible that the injured sharks mentioned above are more prone to forgo this instinct since their marginal value is higher.

Providing food to sharks that have fishing related injuries, could be considered to be a positive action – by reinforcing mature adults that have been harmed by human activity. However, it should be ruled out that such feeding does not tamper with selection processes by boosting not only sharks that were injured by fishing, but also certain individuals that otherwise would have been naturally selected out.

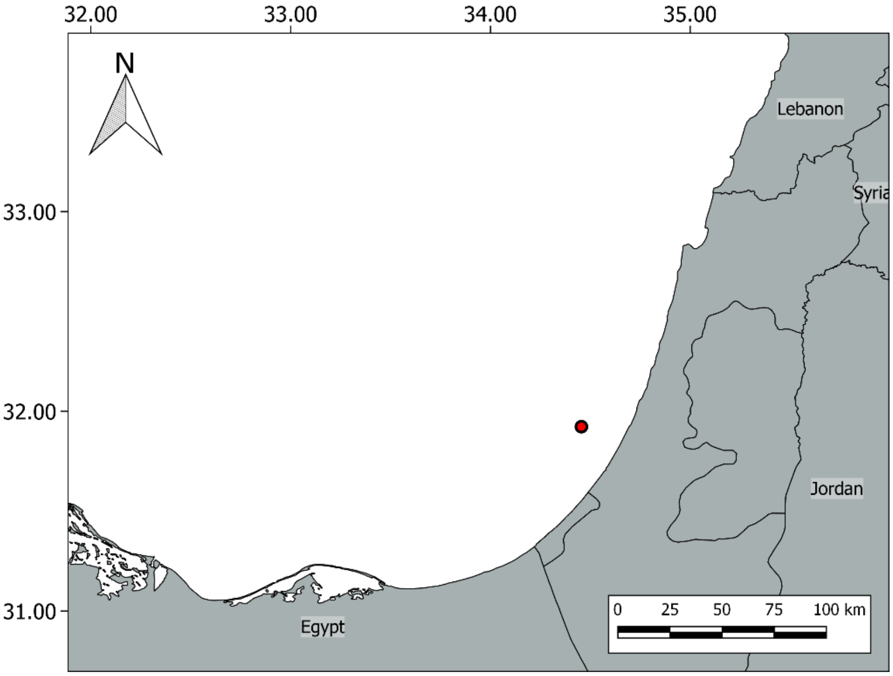

Figure 1: Regional map showing the general location of the fish farms (red dot)

Figure 2: A large number of sandbar sharks (C. plumbeus) (n=25) swimming around the fish cages (July 2017). Photographed by Hagai Nativ.

Figure 3: Injured sharks at the fish cages, A) A female shark missing the upper lobe of the caudal fin. B) A female shark with a deformed, likely fractured caudal fin and C) A shark with a broken jaw. Photographed by Hagai Nativ (A, C) and Shahar Malamud (B).

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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the dissertation

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Capture 4

Molecular identification reveals cryptic species within the species composition of sharks and rays in the Israeli Mediterranean Sea

Barash Adi and Tchernov Dan.

Abstract

Over half of the cartilaginous fish species are at elevated risk in the Mediterranean Sea. In order to develop accurate conservation plans at the species level, species specific information is needed on the distribution, movement and abundance of all occurring species.

Obtaining source information requires the ability to identify the species which can turn out to be a complicated and sometimes impossible task unless applying molecular methods.

In Israel, a check list of cartilaginous fish has been updated recently, but it has never been genetically evaluated in a comprehensive way, in order to find mismatches or cryptic species.

In this work, two genetic segments from the mitochondrial DNA were used: COI, which is widely used for animal barcoding, and NADH2, which was found to be particularly accurate in cartilaginous fish.

Over 450 tissue samples were taken from specimens of sharks and ray caught in fishing, extracted for DNA, and sent for sequencing of both sections.

The results yielded 14 species of sharks and 15 different species of rays out of 56 species previously reported in the Mediterranean Sea of Israel. *Centrophorus uyato* were identified, while *Centrophorus granulosus* were not within the sample. This was consistent with recent studies that found that *Centrophorus uyato* had been misidentified as *C. granulosus* in the Mediterranean. The invasive species *Himantura leoparda* were recorded for the first time from Israeli waters. In Genus Squalus the DNA indicated a new species previously reported only from Maltese waters in 2017 and has not yet been defined as a new species.

Genetic identification revealed cryptic species that so far were not known in the area. These results provide knowledge that will advance the proper monitoring of the populations, with the aim of improving conservation efforts. It is essential that molecular identification will continue to be performed even on common species in order to identify cryptic and rare species.

Background

Conservation efforts around the world are being made to stop the ongoing decline in cartilaginous fish populations (Dulvy et al., 2017). In the Mediterranean Sea, where over half of the species are defined as endangered (Cavanagh & Gibson, 2007; Dulvy et al., 2016; Milazzo et al., 2021), it is of immense importance to characterize distribution maps and population trends in order to create conservation plans at a species-specific level.

However, one of the biggest problems in cartilaginous fish research and monitoring, is the great similarity between species and the difficulties in identifying them (Bornatowski et al., 2013; Dulvy et al., 2017). Whether it is seafarers, such as fishermen; professionals, such as fisheries surveyors, researchers, or even cartilaginous fish experts, morphological identification is not always possible (Naylor et al., 2012; A. Vella et al., 2017). As a result, species data deriving from scientific surveys, observations, or fisheries, are often grouped to a higher taxonomic level, or misidentified. This practise creates a false representation of a higher than true abundance for some species, while others may not be counted or even included in species lists and monitoring or conservation plans.

In the Mediterranean Sea, the genus *Carcharhinus* is considered particularly challenging in terms of identification (Pank et al., 2001), especially in the early stages of life. In the genus *Dasyatis* there are several similar species (i.e., *Dasyatis pastinaca*, *D. Tortonesei*, *D. Chrysonota*, *D. Marmorata* and *Bathytoshia centroura*) and there is confusion and lack of clarity regarding how many species are found in the Mediterranean and in its different regions, (Ebert & Dando, 2020; Serena, 2005). The invasive species of the genus *Himantura*, compose of several similar species whose external differences are minor, and these challenges occur in many other taxa.

For that reason, it is important to constantly examine species composition with molecular tools and to update the species lists, research aims, and conservation plans according to the genetic results.

Species barcoding uses the sequencing of the mitochondrial gene cytochrome c oxidase subunit 1 (COI) to identify fish according to differences in the mitochondrial DNA among species (Ward et al., 2005). In shark and ray species it was found that the separation does not always appear using the barcoding method, and therefore to ensure detection of cryptic species an additional mitochondrial sequence is used: the NADH dehydrogenase subunit 2 (NADH2) (Naylor et al., 2012)

In Israel, all cartilaginous fish are protected, and landing is prohibited since 2005, therefore the scope of sampling and the encounter with them is relatively low and sporadic. A genetically confirmed Mediterranean species list has never been published but there are publications as part of more extensive fish and fisheries surveys, which have carried out bar coding in details of cartilaginous fishes. In this article we will gather genetic results of cartilaginous fish species sampled in Israel in the current study, combined with bar coding results from other publications, to produce an up-to-date species list that has been genetically tested. We will examine whether there were mistakes in the previous species lists and whether there are species that cryptically hid behind other species.

Materials and methods

Sample collections

Tissue samples from 476 specimens of elasmobranch species, were collected from 2011 to 2017. Sampling locations were the two main fish mongers in Tel Aviv (53) and Haifa (113), specimen landed on trawl surveys conducted in Ashdod as part of the national monitoring project (Paz et al., 2018) (166), and sporadic sampling (143) (Figure 1 and 2)

When possible, specimens were measured and photographed (depending on the fish monger approval and the state of the specimen) and approximately 100mg of white muscle was collected from each specimen and preserved in 96% ethanol.

DNA isolation

DNA extraction was performed using a high pure PCR template preparation kit (Promega Wizard® Genomic DNA Purification Kit) following instructions of the manufacture.

DNA was then diluted to a final concentration of 100 ng/ml using a Nanodrop 2000 c spectrophotometer.

Amplification and sequencing

The identification of elasmobranch species based on morphology can prove most difficult. As molecular methods evolved, the identification at the species level vastly improved. The main method for species identification used today was set by (Ward et al., 2005) who suggested the COI region of the mitochondrial DNA to be an effective tool in differentiating between species. In 2012, Naylor et al. published their extensive work on elasmobranch phylogeny using the NADH region of the mtDNA. In my work I use both regions.

The two genes were used for the species identification using the following primers:

For the amplification of the NADH segment the following primers were used: ILEM (5'-AAGGAGCAGTTTGATAGA GT-3') and ASNM (5'-AACGCTTAGCTGTTAATTAA-3') (Naylor et al., 2012). PCR was carried out in a 50µl reaction containing: 25 µL of PCR ready mix gotaq, 18 µl of ultrapure water, 2 µl of each primer (0.1 mm), 2 µl of BSA and 1 µL of DNA template. PCR cycling program was: 3 min at 95°C, 30 cycles of 45s at 95°C, 45s at 55°C and 45s at 72°C, followed by 5 min at 72°C, using BioRad C1000™ Thermal Cycler.

For the amplification of the COI segment the following primers were used: FishF2 (5'-TCGACTAATCATAAAGATATCGGCAC GT-3') and FishR1 (5'- TAGACTTCTGGGTGGCCAAAGAATCA -3') ((Ward et al., 2005). PCR was carried out in a 50µl reaction containing: 25 µL of PCR ready mix gotaq, 18 µl of ultrapure water, 2 µl of each primer (0.1 mm), 2 µl of BSA and 1 µL of DNA template. PCR cycling program was: 3 min at 95°C, 30 cycles of 15s at 95°C, 15s at 57°C and 45s at 72°C, followed by 5 min at 72°C, using BioRad C1000™ Thermal Cycler.

Sequencing was performed by Macrogen Sequencing Service (Macrogen, Europe). In cases where results were of low quality, DNA was amplified again and sent to sequencing, in both forward and reverse directions.

Sequence analysis

DNA sequenced were assembled and edited using the BioEdit sequence alignment editor, version 7.0.5.2 (Hall, 1999). For each taxonomic family published sequences were downloaded from NCBI molecular database, using ClustalW clean sequences were trimmed to the start and length of the published sequences. When needed due to law quality sequences were farther trimmed while Neighbor-joining (NJ) trees were created with 1000 bootstrap replications to verify the species identification and make sure sequence length provides enough variation among species within the family.

Results

Out of the 476 specimens collected, amplification and sequencing yield 421 sequences of the NADH2 segment and 426 of the COI segment. A total of 29 species were found in the analysis belonging to 14 shark species (9 families) and 15 ray species (6 families) (tables 1 and 2).

NADH2 is a longer segment and provides more variability, thus can differentiate among cryptic species, but was more difficult to analyse with much lower success rate in many species group, and especially within the batoid species.

Himantura leoparda, previously described in the Mediterranean Sea (Adib et al., 2021; Hight & Lowe, 2007; Yucel et al., 2017) is described here for the first time in the Israeli Mediterranean waters.

An additional species was found within the Squalus genus. Most of the *Squalus'* samples (9 out of 11) were not compatible with any known species but matched a probable new species in the genus which was also collected in Malta (A. Vella et al., 2017) and has not been described yet as a species.

Table 1: Species list of the sharks in the Israeli Mediterranean as appears in (Golani, 2021) *and samples taken and identified by two genes (COI and NADH2) in this study. Species added to the list appear in blue non valid species or species which may need to be removed from the list appear in red.*

Order	**Class**	**Species**	**Samples**	**COI**	**NADH2**
HEXANCHIFORNES	HEXANCHIDAE	*Heptranchias perlo* (Bonnaterre, 1788)	2	1	
		Hexanchus griseus (Bonnaterre, 1788)	2	1	
LAMNIFORMES	ODONTASPIDIDAE	*Carcharias taurus* (Rafinesque, 1810)			
		Odontaspis ferox (Risso, 1810)			
	LAMNIDAE	*Carcharodon carcharias* (Linnaeus, 1758)			
		Isurus oxyrinchus Rafinesque, 1810	2	2	1
		Lamna nasus (Bonnaterre, 1788)			
	CETORHINIDAE	*Cetorhinus maximus* (Günnerus, 1765)			
	ALOPIIDAE	*Alopias superciliosus* (Lowe, 1839)	3	3	3
		Alopias vulpinus (Bonnaterre, 1788)			
CARCHARINIFORMES	SCYLIORHINIDAE	*Galeus melastomus* Rafinesque, 1810	1	1	
		Scyliorhinus canicula (Linnaeus, 1758)	1	1	1
	TRIAKIDAE	*Mustelus asterias* Cloquet, 1821			
		Mustelus mustelus (Linnaeus, 1758)	1	1	
	CARCHARHINIDAE	*Carcharhinus altimus* (Springer, 1950)			
		Carcharhinus brevipinna (Müller & Henle, 1841)	6	4	6
		Carcharhinus limbatus (Valenciennes, 1839)			
		Carcharhinus melanopterus (Quoy & Gaimard, 1824)			
		Carcharhinus obscurus (Lesueur, 1818)	30	26	29
		Carcharhinus plumbeus (Nardo, 1827)	78	70	73
		Prionace glauca (Linnaeus, 1758)			
	SPHYRNIDAE	*Sphyrna zygaena* (Linnaeus, 1758)			

Table 2: Continued

Order	Class	Species	Samples	COI	NADH2
SQUALIFOMES	ETMOPTERINAE	*Etmopterus spinax* (Linnaeus, 1758)			
	SOMNIOSINAE	*Somniosus rostratus* (Risso, 1826)			
	OXYNOTINAE	*Oxynotus centrina* (Linnaeus, 1758)	5	5	
	DALATIINAE	*Dalatias licha* (Bonnaterre, 1788)			
	CENTROPHIDAE	*Centrophorus granulosus* (Schneider, 1801)			
		Centrophorus uyato (Rafinesque, 1810)	22	22	13
	SQUALIDAE	*Squalus acanthias* Linnaeus, 1758			
		Squalus sp.	11	9	
		Squalus blainville (Risso, 1826)	2		
SQUATINIFORMES	SQUATINIDAE	*Squatina aculeata* Cuvier, 1829			
		Squatina squatina (Linnaeus, 1758)			

Table 2: Species list of batoids in the Israeli Mediterranean as appears in (Golani, 2021) and samples taken and identified by two genes (COI and NADH2) in this study. Species added to the list appear in blue non valid species or species which may need to be removed from the list appear in red..

Order	Class	Species	Samples	COI	NADH2
PRISTIFORMES	PRISTIDAE	*Pristis pectinata* Latham, 1794			
TORPEDINIFORMES	TORPEDINIDAE	*Tetronarce nobiliana* (Bonaparte 1835)			
		Torpedo marmorata Risso, 1810	7	7	0
		Torpedo torpedo (Linnaeus, 1758)	8	8	0
RAJIFORMES	GLAUCOSTEGIDAE	*Glaucostegus cemiculus* (Geoffroy St. Hilaire 1817)	13	13	8
	RHINOBATIDAE	*Rhinobatos rhinobatos* (Linnaeus, 1758)	83	83	41
	RAJIDAE	*Dipturus oxyrinchus* (Linnaeus 1758)	2	2	1
		Raja asterias Delaroche, 1809			
		Raja clavata Linnaeus, 1758	91	78	73
		Raja miraletus Linnaeus, 1758	34	33	25
		Raja montagui Fowler, 1910:468			
		Raja radula Delaroche, 1809			
		Raja undulata Lacepède, 1802			
	DASYATIDAE	*Bathytoshia centroura* (Mitchill, 1815)			
		Dasyatis marmorata (Steindachner, 1892)	15	15	2
		Dasyatis chrysonota (Smith, 1828)			
		Dasyatis pastinaca (Linnaeus, 1758)	17	15	7
		Dasyatis tortonesei Capapé, 1975			
		Himantura uarnak (Gmelin, 1789)			
		Himantura leoparda Manjaji-Matsumoto & Last, 2008	2	2	0
		Pteroplatytrygon violacea (Bonaparte, 1832)	8	8	3
		Taeniurops grabatus (Geoffroy Saint-Hilaire, 1817)	13	12	12
	GYMNURIDAE	*Gymnura altavela* (Linnaeus, 1758)	1	1	1
	MYLIOBATIDAE	*Myliobatis aquila* (Linnaeus, 1758)			
		Pteromylaeus bovinus (Geoffroy Saint-Hilaire, 1817)	2	2	0
	RHINOPTERIDAE	*Rhinoptera marginata* (Geoffroy Saint-Hilaire, 1817)			
	MOBULIDAE	*Mobula mobular* (Bonnaterre, 1788)			

Table 3: List of DNA samples collected and percentage of successful sequencing for each species.

Species		**Samples (n)**		**Success**	
Morphology	**DNA results**	**CO1**	**NADH2**	**CO1**	**NADH2**
Heptranchias perlo	*Heptranchias perlo*	2		100%	
Hexanchus griseus	*Hexanchus griseus*	2	1	100%	0%
Isurus oxyrinchus	*Isurus oxyrinchus*	2	4	100%	75%
Alopias superciliosus	*Alopias superciliosus*	3	3	100%	100%
Galeus melastomus	*Galeus melastomus*	1	1	100%	0%
Scyliorhinus canicula	*Scyliorhinus canicula*	1	1	100%	100%
Mustelus sp.	*mustelus mustelus*	1	1	100%	0%
Carcharhinus brevipinna	*Carcharhinus brevipinna*	6	6	83%	100%
Carcharhinus obscurus	*Carcharhinus obscurus*	24	31	79%	90%
Carcharhinus plumbeus	*Carcharhinus plumbeus*	75	88	95%	93%
Oxynotus centrina	*Oxynotus centrina*	5	6	80%	0%
Centrophorus granulosus	*Centrophorus uyato*	25	24	100%	71%
Squalus acanthias	*Squalus sp. and S. blainville*	11	8	100%	75%
Torpedo marmorata	*Torpedo marmorata*	6	5	100%	20%
Torpedo torpedo	*Torpedo torpedo*	6	2	100%	0%
Glaucostegus cemiculus	*Glaucostegus cemiculus*	11	12	100%	75%
Rhinobatos rhinobatos	*Rhinobatos rhinobatos*	81	72	93%	56%
Dipturus oxyrinchus	*Dipturus oxyrinchus*	2	2	100%	50%
Raja clavata	*Raja clavata*	77	84	90%	92%
Raja miraletus	*Raja miraletus*	36	29	89%	86%
Dasyatis chrysonota	*Dasyatis marmorata*	9	7	100%	14%
Dasyatis pastinaca	*Dasyatis pastinaca*	17	13	94%	54%
Himantura uarnak	*Himantura leoparda*	2	2	100%	0%
Pteroplatytrygon violacea	*Pteroplatytrygon violacea*	5	4	100%	75%
Taeniurops grabatus	*Taeniurops grabatus*	13	13	100%	77%
Gymnura altavela	*Gymnura altavela*	1	1	100%	100%
Pteromylaeus bovinus	*Pteromylaeus bovinus*	2	1	100%	0%

Comments on individual taxa by families

Order: HEXANCHIFORNES

HEXANCHIDAE

In the Mediterranean three species of this order are listed: *Heptranchias perlo*, *Hexanchus griseus* and *Hexanchus nakamorai* (Serena, 2005; Serena et al., 2020). *Hexanchus nakamorai* has never been recorded in Israeli waters (Golani, 2021), for the two other species two samples were collected each, which verified the identification (Table 1).

Order: LAMNIFORMES

ODONTASPIDIDAE

No specimen was found of this family. The two species (*Carcharias taurus* and *Odontaspis ferox)* were recorded in the past in Israel but are rare in the Mediterranean and their current presence in Israeli waters needs to be revaluated.

LAMNIDAE

The other species listed in the Mediterranean are *Carcharodon carcharias, Isurus paucus, Isurus oxyrinchus* and *Lamna nasus,* and are often not easy to tell apart (especially *Isurus paucus* and *Isurus oxyrinchus)*. Two lamnid sharks where sampled and both were identified as *Isurus oxyrinchus*.

CETORHINIDAE

Only one genus and one species in this family. No specimen was acquired in this study.

ALOPIIDAE

The family has one genus listing three species, two of which are known in the Mediterranean: *Alopias vulpinus* and *A. superciliosus*. These species are relatively easy to distinguish between and in this study only the latter was encountered and authenticated by the DNA analysis.

Figure 1: Alopias superciliosus.

Order: CARCHARINIFORMES

SCYLIORHINIDAE

In the Mediterranean four species are known in the family, and in the Israeli waters two were described. In this study both species were sampled once, probably due to the large depth they inhabit.

TRIAKIDAE


Figure 2: Mustelus mustelus.

In the family four species are found in the Mediterranean and two were described in Israel. One mustelus shark was encountered and identified as *Mustelus mustelus*. *Mustelus asterias* was found in this study.

CARCHARHINIDAE


Figure 3: Carcharhinus plumbeus.

The largest family of sharks in the Mediterranean, including 11 species, seven of which are described locally. Genus Carcharhinus is notorious for misidentifications, especially if the fins are removed. Nevertheless, molecular identification did not reveal additional species to the morphologic identification. The considerable number of samples collected from carcharhinid sharks (114) suggests the rarity of the other species. *C. plumbeus* and *C. obscurus* amounted for most of the samples with the exception of one *C. brevipinna,* a female with 5 embryos which provided 6 identical sequences.

SPHYRNIDAE

Out of the four described in the Mediterranean, only one species was ever described in Israel, and none were encountered in this study.

Order: SQUALIFOMES

ETMOPTERINAE

One species listed in the Mediterranean and in Israel *Etmopterus spinax.* No specimen was sampled in this study, but a local genetic verification was performed on the species recently (Paz et al., 2018).

SOMNIOSINAE

Two species listed in the Mediterranean and one in Israel none were sampled in this study.

OXYNOTINAE

Figure 4: Oxynotus centrina.

One species listed in the Mediterranean and in Israel, *Oxynotus centrina*, and specimens were caught on three occasions with three embryos carried by a gravid female.

DALATIINAE

One species listed in the Mediterranean and in Israel. None were sampled in this study.

SQUALIDAE

Figure 5: Centrophorus uyato.

Two species are known from the Mediterranean. *Squalus acanthias* and *S. blainville*. Out of the 13 samples, two matched *S. blainville* and the other 11 did not match any known species. The sequences did match two samples caught in Malta (A. Vella et al., 2017) which probably belong to a new undescribed species. Given the different localities and the number of samples found this does not seem to be a rare species and requires further taxonomic and molecular work. *S. acanthias* was not present in this study and might have been misidentification of this additional species.

CENTROPHIDAE

Only one species was found in this study. While *Centrophorus granulosus* was thought to be the only *Centrophorus* species which occur in the Mediterranean, in the last decade it was found that *C. uyato* is inhabiting the Mediterranean and had been misidentified so far.

White et al., (2022) took samples from Israel and used them it the revision of the genus, also showing *C. uyato*. Samples collected and barcoded in Israel before were misidentified as *C. granulosus* (Paz et al., 2018) and needs to be corrected.

Order: SQUATINIFORMES

SQUATINIDAE

The family is presented by 3 species in the Mediterranean Sea, all are critically endangered globally. *Squatina aculeata* and *Squatina squatina* have been listed to occur in the Israeli waters in the past but were not encountered during this study, an expected result considering the grave status of these species in the Mediterranean Sea (Lawson et al., 2020).

Order: PRISTIFORMES

PRISTIDAE

Two species reported in the Mediterranean Sea in the past. In Israel, a single specimen of *Pristis pectinata* was found in 1953, and together with a single specimen from Syria, these are the only records from the eastern basin (Ferretti et al., 2016). It is possible the species was never established in the region; on any case it should not be listed in an updated species list.

Order: TORPEDINIFORMES

TORPEDINIDAE

Two species of electric rays *Torpedo torpedo* and *T. marmorata* were sampled and genetically verified. *Tetronarce nobiliana* was not encountered during this study.

Order: RAJIFORMES

GLAUCOSTEGIDAE & RHINOBATIDAE

Although in different taxonomic families, *Rhinobatos rhinobatos* and *Glaucostegus cemiculus* are easy to misidentify. The sequences analysis found the two species and verified their presence.

Figure 6: Raja miraletus.

RAJIDAE

Only two raja species were found in the analysis *Raja clavata* and *R. miraletus*. None of the four other similar species were caught in this study. Additionally, two samples of *Dipturus oxyrinchus* verified its identification.

DASYATIDAE

Species within genus *Dasyatis* and genus *Bathytoshia* are extremely difficult to identify (N. Vella & Vella, 2021). *Dasyatis marmorata* was first recorded in Israel in 2004 (Golani & Capapé, 2004 as *D. chrysonota*), in turkey only in 2014 (Erguden et al., 2014) and in Greece in 2020 (Chatzispyrou et al., 2020). The 32 samples taken in this study were of *D. pastinaca* and *D. marmorata* alone. *D. chrysonota* is no

Figure 8: Dasyatis marmorata.

Figure 7: Dasyatis pastinaca.

longer considered to be in the Mediterranean and there for can be removed from the list (Cowley & Compagno, 1993).

In genus *Himantura* only *H. uarnak* was listed in the list. In this study only two samples were collected and resulted as *H. leoparda*, which was recently reported from the Mediterranean (Adib et al., 2021; Yucel et al., 2017) but not from Israeli waters, and therefor is now added to the check list. Both species have migrated into the Mediterranean from the Red Sea.

Thirteen samples of *Taeniurops grabatus* verified the species appearance.

GYMNURIDAE

Only one species inhabits the Mediterranean and the analysis verified the species.

MYLIOBATIDAE

Two species listed in the Mediterranean and in Israel. In this study only *Pteromylaeus bovinus* was sampled and verified.

RHINOPTERIDAE

One species listed in the Mediterranean and in Israel. None were sampled in this study.

MOBULIDAE

Mobula mobular is the only species known from the Mediterranean. While no sample was found in this study, a recent revision of the *Mobula* genus used five samples of *M. mobular* caught in the Gaza strip and verified the species (Hosegood et al., 2020). Given the close proximity to Israel the species identification could be considered as verified.

Discussion

The use of molecular tools to assess species composition and abundance is essential in order to include and monitor species. Within elasmobranch species many taxa are challenging using only morphological tools for identifications and may not always be available.

DNA identification of the sharks and rays in Israeli Mediterranean waters revealed two additional species which had not been reported yet. The invasive whipray *Himantura leoparda*, and a new species of the genus *Squalus*, yet to be described.

The analysis also approves misidentifications reported in the Mediterranean. The gulper sharks – *C. uyato* was so far mislabelled as *C. granulosus*, the blue marbled sting ray *D. marmorata* was mislabelled as *D. chrysonota*.

As sharks and rays, especially in the Mediterranean are facing great risk is highly important to further advance genetic identification together with fisheries surveys and it is of great importance to locate rare species, unknown species and endemic species in order to enable effective conservation efforts (Bornatowski et al., 2013).

Taxonomic research is further required following the genetic research, in order to find applied morphological differences between the different species in the genus *Dasyatis*, *Squalus*, and in the whiprays *Himantura*.

The study also highlights species that may no longer be common in the region, although being on list of species in the past, such as hammerheads, skates and other species.

While fishing surveys and the collection of observations gives us information on the distribution and abundances of species, they must be complemented regularly with genetic identification that verifies the data.

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General discussion

Human development creates new habitats and changes existing ones. The aggregation of sharks at the warm effluent of the power plants may have a great impact on the ecology and life course of the species as well as effects on the entire biosystem they inhabit or are absent. The long stay in the station's water puts them at increased risk for coastal chemical pollution, fishing, noise and light pollution. Analysis of the movement data showed that individual sharks stay at the site for a long period of time, through the whole winter.

During their stay, distance in depth was kept between the two species, *C. plumbeus* and *C. obscurus*, which might have been dictated by the coexistence of the two species in the relatively small area. Such niche partitioning had been reported in several locations and in different shark species.

A daily vertical movement was observed and characterized both species at the site. Sharks ascended the water column during the night and descended back during the day. Vertical movement had been reported in many shark species but never in such shallow waters. Due to the dispersion of warm water, a temperature gradient is formed allowing the selection of the desired temperature. For this reason and in light of the mild movement in depth between night and day, it is not likely that this movement has a temporal gain. It is possible that vertical movement is a conserved trait in the species and exists even when there is no significant physiological gain.

The aggregation of the individuals in the warm waters, is mainly formed by male *C. plumbeus* and female *C. obscurus*. This composition makes it difficult to understand whether the separation between the groups is according to species or sex. As *C. plumbeus* sharks are significantly smaller than *C. obscurus* which may also have an effect on the spatial distribution between the groups. In any case, within the groups, no significant effect of individual size on vertical movement was found.

Sharks were found in a stable temperature range of 19-27°C, which was made possible due to the warm water discharge. Regardless of the ambient temperature, sharks maintained a constant range of temperature and did not leave the station until ambient sea water temperature reached this range. Using this temperature range as the temperature preference for the species we could assess their distribution potential in the Mediterranean Sea.

The appearance of shark at the power plants' effluent has only been occurring in the last two decades. An examination of the sea water temperatures in the last three decades shows that the waters of the Mediterranean have become warmer, tuning transition seasons more suitable for these shark species, according to the preferred temperature range. It is possible that for this reason the sharks approached the shore and "located" the coastal power stations to begin with. According to the Representative

Concentration Pathway (RCP) projections of the sea water temperature for the next 50 years, it seems that the coastal water of the eastern Mediterranean Sea will become more suitable for sharks in transient seasons as in winter, and they may not be searching for warm water in the same way or for shorter periods of time. In the summer months, on the other hand, the sea will be too hot for these species, and we will not expect to see sharks at coastal waters.

The presence of *C. obscurus* in the Mediterranean Sea is extremely rare outside Israel. It was found that the genetic origin of some *C. obscurus* sharks Indo-Pacific and have probably migrated from the Red Sea through the Suez Canal. It is possible that the power station enables their migration and establishment in the area by creating an alternative place for the cold winter periods.

Similar to the power plants, fish cages also create a new reality in the marine environment. While interactions between wild animals and agriculture are well known and studied on land, in marine environments there is little information and research, while aquaculture is growing and developing. The fish cages become a gathering point for opportunistic sharks that have learned to exploit the food source. Injured individuals were observed in the area with an emphasis on a single female frequenting the fish cages during almost a decade. Given the severe jaw injury this female endures, it is possible that spontaneous feeding in the fish cages allows her to survive for such a long time.

These changes affect not only the movement and behaviour of species but also species composition and abundance. In order to investigate what changes occurred in the variety of species, I examined the genetic composition of the elasmobranch species in Israel and updated the species list. Over 450 individuals were sampled, and two genes were sequenced. The results yielded 29 species composed of 14 sharks and 15 batoids. In addition to a list of known and now verified species we found a new species of the genus *Squalus* reported in Malta on 2017 which has yet to be described taxonomically, and an invasive *Himantura* species not yet reported from the Israeli Mediterranean waters. The test confirmed adjustments in the species list for species in the genus *Centrophorus* and *Dasyatis* as reported in the literature from other locations around the Mediterranean.

The absence of species on the list should be farther investigated to assess whether the lack stems from being deep, rare, or suggests a significant decrease in the population.

In conclusion, *C. plumbeus* and *C. obscurus* are showing to be opportunistic sharks that learn to take advantage of new situations that humanity creates. This adaptation needs to be farther studied in order to learn about the effects anthropogenic disturbances on sharks while at the same time move to as much as possible the unnatural factors that change their natural behaviour. With the expansion of the Suez Canal, and the warming of sea water, we shall expect further changes in the behaviour of individuals, distribution, and the composition of the cartilaginous fish society.

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תנועה והרכב מינים של כרישים ובטאים במי הים התיכון בישראל

עדי ברש

תקציר

כרישים ובטאים בעולם חווים ירידות דרסטיות באוכלוסיות. על אף מאמצי שימור רבים, הירידות ממשיכות גם בעשור האחרון. דיג יתר נחשב למפגע העיקרי לאוכלוסיות דגי הסחוס, ומאמצי שימור ומחקר רבים נעשים בכדי להבין ולצמצם את התופעה.

עם זאת, שינויים רבים אחרים משנים את העולם הטיבעי שלנו. טמפרטורת מי הים עולה כל שנה, במיוחד בים התיכון, משנה מסלולי נדידה של בעלי חיים כמו גם מערכות אקוסיסטמיות שלמות, שרידות של בעלי חיים, והרכב בתי הגידול. בנייה מואצת בחופים ובים יוצרת שינוי משמעותי בבתי הגידול החופיים ואובדן של בתי גידול ספציפים כמו שפכי נחלים. בהעדר מקום על היבשה ולאור הצורך הרב במזון ובבטחון מזוני, חקלאות ימית מפותחת בכל העולם ויוצרת סביבה חקלאית בסביבה הימית עם אינטרקציות חדשות, חלקן מוכרות מהעולם היבשתי וחלקן לא. בנוסף, כחלק מהבנייה והפיתוח נפרצים גבולות ומעברי ים חדשים כגון תעלת סואץ ששינתה משמעותית את מגוון המינים בים התיכון.

כל אלו משפיעים על האקוסיסטמה בדרכים רבות ועל דגי הסחוס ביניהן. בעבודה זאת בחנתי חלק מההשפעות האנתרופוגניות על אוכלוסיות הכרישים החופיים, את השינויים בתנועה של כרישים אפורים (*Carcharhinus spp.*) הנמשכים לחום המשוחרר מתחנות כח חופיות. כיצד תנועתם מושפעת ומה אנחנו יכולים ללמוד מההתנהגות שלהם במי התחנות. תארתי איך כלובי גידול דגים מרכזים סביבם כרישים אופרטוניסטים, ולבסוף אם ישנם שינויים בהרכב מיני דגי הסחוס בחוף הישראל הים תיכוני כולל אישור גנטי לרשימת המינים הקיימת.

על מנת לבחון את התנועה של הכרישים האפורים בתחנות הכח תוייגו כרישים בתגים אקוסטים ולוויינים המצויידים במודדי טמפרטורה ועומק.

בתחנות הכח החופיות נצפו תנועות יומיות קבועות של הכרישים האפורים. הפרטים עלו למים הרדודים יותר בלילה וירדו עמוק יותר במשך היום. כיוון שעומק המים ליד מוצא המים החמים מגיע לכמה מטרים בודדים התנועה היומים שנצפתה בכריש העפרורי היתה מעומק של 2 מטרים בלילה לעומק של 4 מטרים ביום. בכריש סנפירתן התנועה היתה מעומק של 4 מטרים לעומק של 6.5 מטרים. בנוסף נמצא כי ההפרש בעומקים בין שני מיני הכרישים נשמר לאורך כל העונה ועמד על בערך שני מטרים.

מניתוח נתוני הטמפרטורה התברר כי הכרישים שומרים על טווח טמפרטורה בין 19 מעלות צלסיוס ל27 מעלות צלסיוס ומתאספים בתחנה רק כאשר טמפרטורת מי הים מתחת ל20 מעלות בקירוב. השהייה בקרבת התחנה מונעת ככל הנראה ממניעים טרמורגולטורים המאפשרים לכרישים להשאר בקרבת החוף כשהים התיכון קר

בחורף. בחינה של שינויים בטמפרטורת מי הים התיכון בעשורים האחרונים מראה כי על סמך טווח הטמפרטורה המועדף חופי הים בישאל הופכים למתאימים יותר עבור כרישים אפורים בוגרים בעונות המעבר ובחורף.

התקבצויות נוספות של כרישים אפורים נצפו סביב כלובי גידול דגים בלב ים, שם כרישים אופרטוניסטים מצפים להאכלה מקרית. עיקר הנוכחות של הכרישים מופיעה בקיץ ותיעוד מהעשור האחרון מצביע על נוכחות של כרישים פצועים המתקבצים סביב הכלובים, כשפרט אחד נצפה בתחנה מעל 7 שנים. כיוון שהאכלות מתרחשות לעיתים עקב, קרעים ברשתות, או סערות שפוגעות ברשת, או התנהלות לא נכונה. ייתכן שתחנת האכלה לא מתוכננת זאת מאפשרת את שרידותם של כרישים עם פציעות חמורות ואלו בוחרים להעדיף להתקרב למקור החקלאות על פני חיפוש טרף בים.

בחינת מיני דגי הסחוס לחופי הים התיכון של ישראל הראה כי מלבד כריש סנפירתן (*C. plumbeus*) וכריש עפרורי (*C. obscurus*), המין כריש ארך-גף (*C. brevipinna*) הדומה בצורתו החיצונית לשני המינים האחרונים, נוכח אף הוא במים הישראלים ויש לבחון אם גם מין זה מגיע לתחנות הכח. ניתוח המשפחות השונות הראה כי לרשימת המינים בישראל אפשר להוסיף את הטריגון הנמרי שהיגר מים סוף (*Himantura leoparda*) ומין נוסף של כריש קוצן (*Squalus*) שלא הוגדר עדיין אך נמצא גם בעבודה מולקולרית על כרישים במלטה.

עבודה זאת מתעדת להעלות את הידע על פיזור והתנהגות דגי הסחוס בחופי הים התיכון של ישראל ולשמש כמקור מדעי עבור מאמצי השימור המקומיים בניהול האינטרקציות בין דגי הסחוס ובני האדם.

תנועה והרכב מינים של כרישים ובטאים במי הים התיכון בישראל

עדי ברש

בהנחיית: פרופסור דן צ'רנוב

חיבור לשם קבלת התואר "דוקטור לפילוסופיה"
דוקטורט פרסומים

אוניברסיטת חיפה
ביה"ס למדעי הים
החוג לביולוגיה ימית
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