Vol. 590: 145–154, 2018
https://doi.org/10.3354/meps12478

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published March 12

Seasonal aggregations of sharks near coastal power plants in Israel: an emerging phenomenon

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ABSTRACT: Sharks in the Mediterranean Sea are at extremely high risk, and their populations are rapidly declining. In the Eastern Mediterranean along the Israeli coastline, anecdotal observations have suggested that sharks aggregate at warm water outflows from coastal power plants. Using interviews, we examined fishermen's perceptions in order to (1) verify the presence of shark aggregations at power plant outflows; (2) examine whether there are differences in sighting frequencies among seasons; and (3) examine whether there is a trend of increased sightings of sharks during the past 2 decades (1993–2013) compared to the previous 20 yr period (1973–1993). A total of 128 fishermen were interviewed at 4 power plants and 4 nearby marinas along the shore: Hadera, Tel Aviv, Ashdod and Ashkelon. Results indicate that (1) sharks are observed much more frequently near power plants where there is a continuous warm water outflow (all except Tel Aviv); (2) shark sightings at the outflows peak during the cold season and are negatively correlated with water temperatures; and (3) there has been a general increase in shark sightings between 1993 and 2013 compared to the previous 2 decades. Shark aggregations occur at power plant outflows most likely due to elevated water temperatures. Further research is needed to understand the process underlying the recent increase in shark abundance at power plants, and its ecological implications on these endangered species and the structure of local communities.

KEY WORDS: Local ecological knowledge · Mediterranean Sea · Sharks · Thermoregulatory behaviour

INTRODUCTION

Sharks are marine predators that are important for the integrity of food webs and ecosystem functions (Heithaus et al. 2008). In the past few decades, it has become clear that shark populations are threatened by over-exploitation, and increasing evidence indicates that a number of populations worldwide are drastically declining (Baum et al. 2003, Clarke et al. 2007, Dulvy et al. 2014). This poses a great challenge to marine conservation in general and shark conservation in particular. An additional challenge to shark conservation is that long-term data regarding the state of many shark populations worldwide are largely incomplete (Ferretti et al. 2010). In fact, out of 465 described shark species, the statuses of 209 (45%) were considered by the International Union for Conservation of Nature (IUCN) as Data Deficient, and population trends (increasing, stable or decreasing) for most shark species are still unknown (Dulvy et al. 2014).

Shark populations in the Mediterranean Sea are at extremely high risk, with 21 of 70 species listed as globally Critically Endangered or Endangered on the IUCN Red List (Cavanagh & Gibson 2007). Some pelagic species of sharks have declined in the Medi-

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terranean by up to 95% throughout their range to the point where large coastal predatory sharks almost disappeared completely from the Mediterranean. Worse off are requiem sharks from the genus *Carcharhinus*, which have been depleted to undetectable levels in the Northwest Mediterranean (Ferretti et al. 2008). A recent IUCN assessment found that since the previous report on the detrimental status of sharks in the Mediterranean, no improvements were found while some populations have further worsened (Dulvy et al. 2016).

Obtaining comprehensive data on the dynamics and distribution of marine megafauna often presents substantial and intrinsic challenges. Research methods such as vessel-based surveys depend on weather, logistics and labor pool, and often prove to be costly and time consuming. Furthermore, as most shark species have long generation times (Musick 1999, Serena 2005), studying temporal trends in populations can require decades of ongoing research.

When conventional methods are limited, observations by, and the knowledge base of, local communities offer an alternative for gaining ecological insights and managing natural resources (Johannes 1993, Huntington & Mymrin 1995). Based on this rationale, 'local ecological knowledge' has been collected from fishermen in order to monitor changes in abundance of marine fauna (Poulsen & Valbo-Jørgensen 2000, Maynou et al. 2011, Coll et al. 2014). Experienced fishermen spend numerous days at sea during all seasons, and can therefore prove invaluable when studying occurrence and distribution of fish. In a recent study, Maynou et al. (2011) used fishermen interviews to assess trends in dolphin and shark abundances between 1940 and 2000. Data compiled from the interviews were congruent with actual population trends in the Mediterranean Sea as described by quantitative surveys and reconstructed landing data (Fortibuoni et al. 2010). These results showed that knowledge from local fishermen not only complements scientific sources, but may at times constitute the only information source for population trends of evasive marine species (Maynou et al. 2011).

Along the Mediterranean coast of Israel, studies of shark populations do not exist, but sharks are present, and catches in large numbers by fishermen have been documented (e.g. Yurista 2010). Intriguingly, large numbers of requiem and hammerhead sharks (families Carcharhinidae and Sphyrnidae, respectively) have also been anecdotally reported in warm water discharges of coastal power plants along the shore (Fig. 1). During the past several years, this phenomenon has increasingly been reported in the media and on social networks; however, it has yet to be properly documented. Very few cases of similar occurrences are reported from elsewhere. Hoising-

Fig. 1. Sharks aggregating at the Hadera (Israel) power plant near the water discharge (right). Photograph taken from a drone in January 2017. Credit: Kobi Sror

ton & Lowe (2005) describe high abundances of stingrays near warm outflows from power plants, and suggest that the species use the site as an alternative for natural estuaries. A similar situation may also be occurring in Tampa Electric's Big Bend Power Station in Tampa Bay, Florida, USA, where manatees aggregate in the power station's warm water discharge canal between November and February, or when Tampa Bay waters drop below 20°C (Laist & Reynolds 2005). Sharks also gather at the warm water discharge (W. Anastasiou pers. comm.). Curtis et al. (2013) reported a similar phenomenon, where bull sharks *Carcharhinus leucas* were found to use human-altered habitats, including power plant effluents. However, bull sharks regularly migrate between open sea, estuaries and freshwater rivers (e.g. Thorson 1971, Drymon et al. 2014, Matich & Heithaus 2015), a fact that is likely to uniquely affect their habitat preferences. Moreover, such studies on habitat use by bull sharks examined presence/absence data of selected individuals, and did not address aggregations specifically at power plants.

Coastal power plants use seawater in order to cool their turbines; water is then flushed back into the sea at higher temperatures through pipes on the shoreline. The temperature of sea water around the outlets is up to 10°C above ambient temperature, and the warm water plume generally extends about 1 or 2 km away (Fig. 2). Discharge sites are characterized by strong shallow currents, vigorous turbulence and consequentially, high oxygen levels. Although not yet quantified, the conventional wisdom is that fish and algal biomasses appear to be substantially greater at the discharge sites on the Israeli Mediterranean coast (Geffen Glazer et al. 2013).

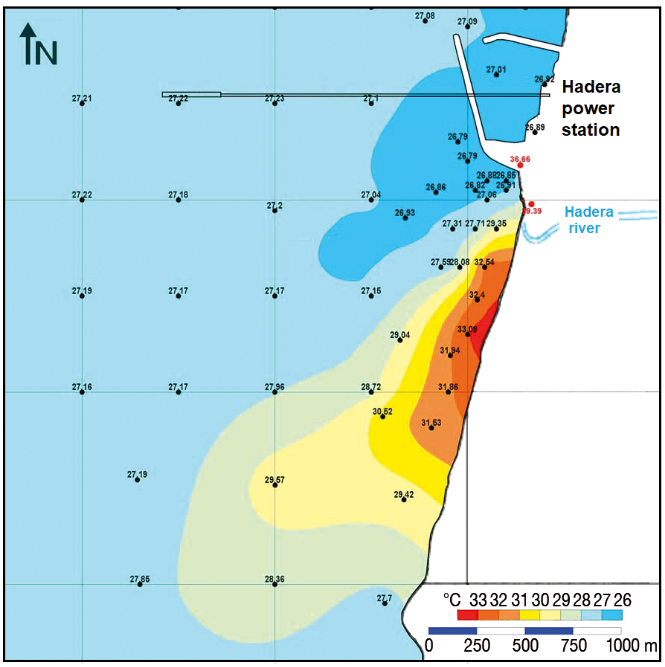

Fig. 2. Example of the warm water plume at the Hadera power plant. Adapted from Geffen Glazer et al. (2013) (measured on the morning of 16 October 2012). Values represent measured temperatures at the respective sampling location, taken at depth of 0.5 m

Observations of 128 fishermen (with combined fishing experience of more than 4000 yr) were documented through interviews to assess the phenomenon in which sharks aggregate at water effluents of power plants as well as to find out whether shark abundances have changed in the past 4 decades along the Israeli coast. The objectives of the interviews were to establish whether (1) sharks are sighted more often in effluents of power plants; (2) a relation exists between sightings and seasonality; and (3) fishermen have observed changes in shark abundance during the past 20 and 40 yr.

MATERIALS AND METHODS

Study sites

The Israel Electric Company operates 5 coastal power plants along the Mediterranean Coast that use seawater for cooling. The 5 plants, from north to south, are located in Haifa, Hadera, Tel Aviv, Ashdod and Ashkelon. For this research, we chose not to include the smallest plant in Haifa, as it is located well within a large commercial port, and is seldom operational. Our study thus considered 4 power plants (Table 1).

Hadera and Ashkelon are the biggest stations, generating more electricity and discharging the larger volumes of cooling water back to sea. Both stations are being used by nearby desalination plants as dump sites for desalination brines consisting of organic and inorganic particles. In Ashkelon, the outlet was also used for discharging treated industrial waste water until March 2013. The Tel Aviv power plant is substantially smaller, operates intermittently, and its discharge is diluted by the large Yarkon River (Geffen Glazer et al. 2013).

Eight locations were selected for the interviews: piers at the 4 power stations and at 4 nearby marinas, the latter served as controls where no warm water is being discharged. The control locations were in proximity (<6.5 km) to their paired power station and structurally, the land–water interfaces were most similar to the physical configuration of a power plant.

Table 1. Main characteristics of the power plants for the year 2012. Data are from the 2012 Israel Electric Company report (Geffen Glazer et al. 2013)

Name	Area	Resource	Adjacent stream	Cooling water discharge (10^3 m^3 h^{-1})	Desalination brine discharge (10^6 m^3 yr^{-1})	Year operation began
Orot Rabin	Hadera	Coal	Hadera	320	200	1981
Reading	Tel Aviv	Gas	Yarkon	70	–	1938
Eshkol	Ashdod	Gas	–	164	–	1958
Rutenberg	Ashkelon	Coal	–	336	175	1990

Seasonal temperature changes

Ambient water temperatures were measured by the Marine Community Ecology Lab of the Israeli Oceanographic and Limnological Research Institute, as part of a long-term monitoring programme that was initiated in 2010. Temperature data were collected to investigate if a relation exists between the frequency of shark sightings and water temperatures. Temperature data were recorded over 3 yr (2010–2012) at 2 sites near Ha'Bonim, and Palmachim (Fig. 3). Ha'Bonim Beach is located 18.5 km north of Hadera, and Palmachim is located 15 km north of Ashdod and 32.5 km north of Ashkelon.

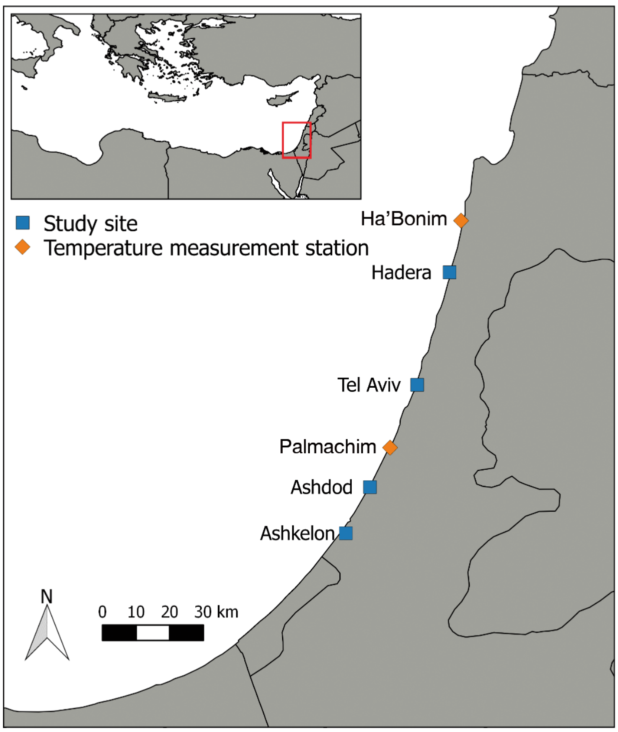

Fig. 3. Study sites along the Israeli Mediterranean coastline. Each site (square) consists of a coastal power plant and a nearby marina. Diamonds represent locations of water temperature measurements

Temperature measurements were taken using HOBO TidbiT v2 temperature data loggers that were positioned 0.5 m below maximum water level during high tide, attached to the bedrock (the loggers remained continuously submerged due to narrow tidal amplitude).

Water temperature at Hadera was sampled during the winter of 2013 on 7 occasions (Fig. 4). Temperatures were measured at a depth of 0.5 m, at the power plant at the base of 2 discharge outlets (shown as red points on land in Fig. 2) and farther away from the outlet (250 m). Temperatures were also measured at a nearby marina (Caesarea marina; control site) at the waterline and 200 m seaward along the pier. Measurements at each point were repeated 3–4 times during the day.

Interviews with fishermen

Interviews were carried out during 2013, to gather ecological knowledge from local fishermen, using a specifically designed interview questionnaire adapted

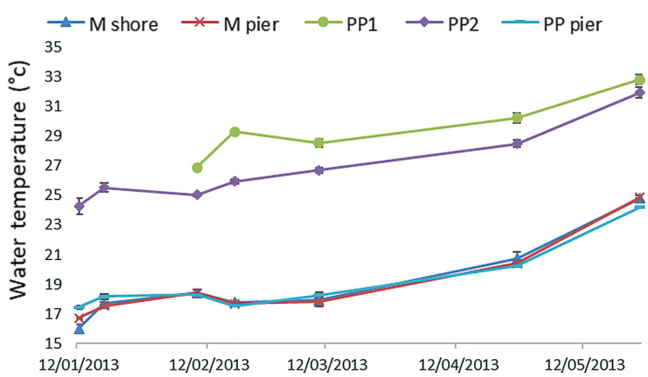

Fig. 4. Mean temperatures at the Hadera power plant south outlet (PP1), north outlet (PP2), 250 m away from the water outflow on the wave breaker (PP pier) and at a nearby marina on the waterline and 200 m seaward along the wave breaker (M shore and M pier, respectively). Error bars represent ± SE. Dates given as dd/mm/yyyy

from existing protocols in Maynou et al. (2011). Considering the imperfections in relying on memory, rather than providing specific dates and sightings, fishermen were asked to refer to long time periods (20 yr) and rank sighting frequencies into qualitative comparative categories (such as 'same', 'twice as much' etc.). Maynou et al. (2011) employed this approach in order to address possible variation in memory performance and reliability of the interviewed fishermen. All 128 fishermen interviewed in our study were recreational shore anglers with a minimum experience of 15 yr, and at least 30 yr of age at the time of the interview. Each interview was comprised of 5 parts:

(1) Personal information: years of fishing experience, fishing habits in terms of seasonal preferences (months) and average duration (hours) of a fishing day.

(2) Shark sightings: estimation of number of sighting occasions (never, once or twice, a few [3–5] times, many [≥6] times) and months in which sightings occurred.

(3) Shark description: interviewed fishermen who had seen sharks were asked to describe the animals' size and general appearance. Apart from the hammerhead family, correctly identifying most local shark species is virtually impossible from shore, a difficulty enhanced by the powerful currents and turbulence near the water outflows. Therefore, a distinction was made only between 'hammerhead sharks' and 'other sharks'.

(4) Fish abundance trends: based on their own perceptions, fishermen were asked to compare among current (2013) bony fish abundance, abundance 20 yr earlier (1993) and 40 yr earlier (1973). Possible answers for each time period comparison were 'much less' (one-third), 'less' (half), 'same', 'more' (twice as much) and 'much more' (at least 3 times as much).

(5) Shark abundance trends: fishermen who had seen sharks on at least 3 occasions at any of the 8 sites were asked similar trend questions (as for fish abundance) about sharks. Finally, in cases where an increase in shark abundance was reported only within the last 20 yr (1993 vs. 2013), interviewees were asked to assess how many years it has been increasing.

Only interviewed fishermen over 50 yr of age and with at least 35 yr of experience were asked to respond to the 40 yr trend questions.

Statistical analyses

Data are described as mean ± SEM. For the statistical analyses, we applied nonparametric tests throughout, using JMP (SAS Institute). All tests were 2-tailed tests. A Mann-Whitney test (ranked sums) was used with normal approximation. All correlations were performed using the Spearman rank correlation. For the binomial test, we used InStat (GraphPad Software).

RESULTS

A total of 128 fishermen with 15–64 yr of experience (mean 35 ± 1.1, median 32.5 yr) were interviewed at all 8 sampling sites (Table 2).

Power plants and marinas

Results show that 65.7% of fishermen fishing at power plants sighted sharks, in comparison to 3.3% of fishermen fishing at the marinas. None of the fish-

Table 2. Summary of personal information of all interviewees at each of the 8 locations; n = number of interviewees. Age, experience and time appear as mean values per site. Seasonal fishing preferences are shown as the percentage of fishermen who stated that they fish during the season in question

Area	Type	n	Fisher age	Years fishing	Days wk^{-1}	Hours d^{-1}	Winter (%)	Spring (%)	Summer (%)	Fall (%)
Hadera	Power plant	16	53.33	30.44	1.91	4.75	94	81	75	81
	Marina	14	52.00	31.64	2.46	3.89	93	100	100	100
Tel Aviv	Power plant	18	60.35	40.22	2.25	4.28	100	100	100	100
	Marina	16	59.00	36.88	1.89	3.64	88	100	100	100
Ashdod	Power plant	17	59.65	39.24	2.90	5.32	94	94	88	94
	Marina	15	57.27	29.93	2.57	4.70	80	87	87	100
Ashkelon	Power plant	16	54.50	34.44	2.25	5.50	100	81	75	81
	Marina	16	62.25	35.88	3.28	4.75	100	94	100	94

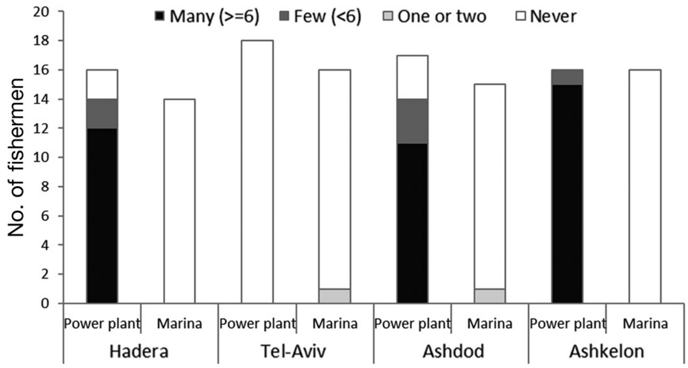

Fig. 5. Frequency of shark sightings at each of the study sites, according to fishermen interviewed at the respective locations

ermen in the marinas reported having seen sharks more than twice (Fig. 5), whereas all fishermen who sighted sharks at the power plants reported seeing them more than twice. None of the fishermen observed sharks at the Tel Aviv power plant. Shark sightings were more frequent at the power plants both as a whole (all 4 sites), and within each area (Fisher's exact test, $p < 0.0001$), with the exception of Tel Aviv, where no difference was found ($p = 0.47$). The data suggest that sharks were not sighted at the Tel Aviv power plant because it is intermittently operational and is much smaller than the other power plants in this study (Table 1).

We performed a binomial test to examine the likelihood of sighting a shark at the 4 power plants. At the Hadera, Ashdod and Ashkelon power plants, the likelihood of observing sharks was greater than not observing them (binomial test, $p = 0.004$, $p = 0.0127$, $p < 0.0001$, respectively), while at the marinas and Tel Aviv power plant, it was more likely to have never seen sharks (Hadera: $p < 0.0001$, Tel Aviv: $p = 0.0005$, Ashdod: $p = 0.001$, Ashkelon: $p < 0.0001$, Tel Aviv power plant: $p < 0.0001$).

Seasonal changes in sightings

Forty-four fishermen specified in which months sharks were observed at the power plants (Fig. 6). Tel Aviv power plant is not part of the analysis, since no sharks were seen there.

A clear negative correlation was found between water temperature and the reported changes in sightings in Hadera (Spearman rank correlation, $\rho = -0.961$, df = 11, $p < 0.0001$), Ashdod ($\rho = -0.822$, df = 11, $p = 0.001$) and Ashkelon ($\rho = -0.935$, df = 11, $p < 0.0001$), showing a peak in shark sightings during mid-winter.

Temporal population trends

Each possible answer for the population trend received a rank, ranging from 2 to −2 as follows: 2: much more; 1: more; 0: same; −1: less; −2: much less. The mean was calculated for each time period with regard to bony fish and shark abundances (Fig. 7). Only 14 data points were available for the entirety of the period between 1973 and 2013, showing no significant change in shark sightings between 1973 and 1993 (Wilcoxon signed-ranks test, $z = 2.5$, df = 13, $p = 0.844$). Reports for the period between 1993 and 2013 indicated an increase in shark sightings ($z = 275.5$, df = 45, $p < 0.0001$), which were significantly higher than in the preceding couple of decades (Mann-Whitney test, $z = -2.219$, $p = 0.026$). Abundance of bony fishes was reported to have declined in both time periods (1973 vs. 1993 Wilcoxon signed-ranks test, $z = -588$, df = 54, $p < 0.0001$, and 1993 vs. 2013 $z = -3730$, df = 126, $p < 0.0001$). The decline was significantly greater between 1993 and 2013 (Mann-Whitney test, $z = 4.45$, $p < 0.0001$).

To avoid dependency issues, we analysed the data once more using only data points with answers received for both time periods. The test rejected the null hypothesis that the median difference between pairs of observations is 0 for trends in both bony fishes (Wilcoxon paired test, $z = 141$, df = 54, $p < 0.0001$) and sharks ($z = -15.5$, df = 13, $p = 0.039$). Out of 34 fishermen who reported an increase in shark sightings during the past 20 yr, 15 mentioned that sharks were sighted only for the last 1–10 yr, with a mean of 6.33 ± 0.8 yr.

Because experience (age and years of experience being a fisherman) might affect the reported results,

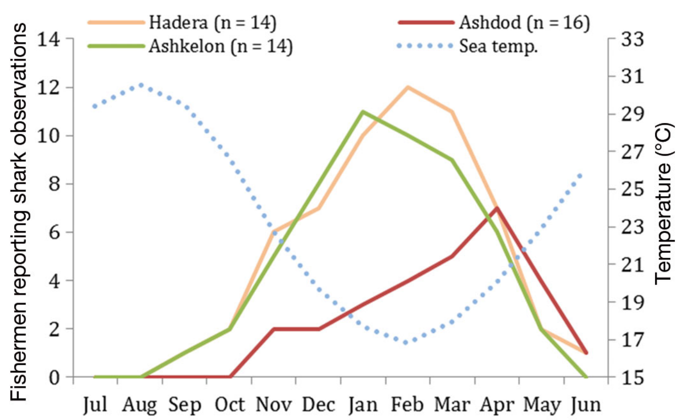

Fig. 6. Seasonal changes in number of fishermen observing sharks, and coastal sea water temperature average. Indication of each month was marked as a binary response (yes/no) and does not represent the actual number of sharks

we decided to test for this in our data effect. A cut-off value of 35 yr of experience was set to distinguish between more experienced fishermen (≥35 yr) and less experienced fishermen (<35 yr), and the results were compared between groups, in order to examine whether experience has an effect on the answers given. This value was derived by its proximity to the mean and median of years of experience of all interviewed fishermen (35 and 32.5 yr, respectively). Questions about trends during the first period (1973–1993) were only answered by experienced fishermen. Therefore, information for population trends was compared only for the second period (1993–2013). Population trends between 1993 and 2013 did not differ significantly between experienced and less experienced fishermen (Fig. 8) for either sharks (Wilcoxon signed-ranks test, $z = -1.5$, df = 4, p = 0.812) or bony fishes ($z = -1$, df = 4, p = 0.875). Similarly, the proportion of fishermen sighting sharks at power plants and marinas did not change as a function of experience ($z = -1$, df = 4, p = 0.750), nor did sightings per fisherman ($z = -1.5$, df = 4, p = 0.750), for both experience groups.

There was no correlation between years of experience and answers given for the 20 yr shark trends (Spearman rank correlation, $\rho = 0.028$, df = 45, p = 0.853). A significant positive correlation was found between years of experience and the 20 yr fish trends ($\rho = 0.225$, df = 126, p = 0.011), as less experienced fishermen reported a more moderate decline. Sample size was reduced as 1 interviewee was not confident enough to provide an assessment of abundance trends.

Species identification

Fishermen reported seeing both 'hammerhead sharks' and 'other sharks' at all 3 active power plants. Reported maximum length was 2.8 ± 0.2 m (n = 24) for hammerhead sharks, and 2.4 ± 0.2 m (n = 45) for other sharks. Body sizes as reported by interviewees are in agreement with body sizes of adult sharks as they appear in the literature for both hammerhead sharks *Sphyrna lewini* (usually 3.6 m) and requiem sharks *Carcharhinus plumbeus* and *C. obscurus* (usually 1.5–3.5 m) (Serena 2005). Species identification of requiem sharks at the power plants has also been confirmed using molecular methods (Barash 2014).

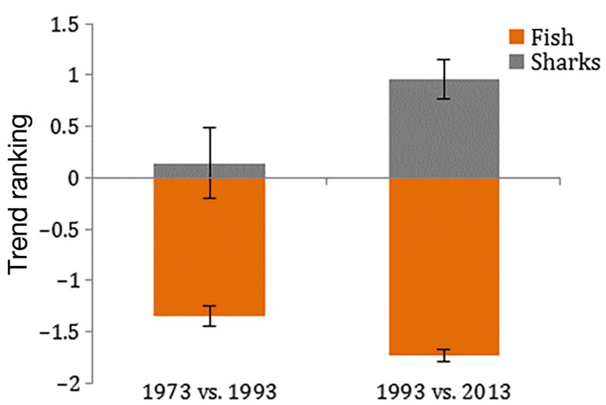

Fig. 7. Population trends of bony fishes and sharks for 2 time periods. Mean values are plotted, error bars represent ± SE

DISCUSSION

Dramatic changes in abundance, migration patterns and distribution of apex predators can all lead to major alterations of local ecological assemblages and food webs (Baum & Worm 2009). Results presented in this study clearly show that sharks are indeed far more frequent at the outflows of large and continuously operational power plants compared to nearby marinas on the Israeli Mediterranean shore or a small plant that operates only intermittently. Moreover, this unique phenomenon of sharks near warm water effluents appears to be increasingly prevalent, especially during the past decade—a surprising fact considering the collapse of many shark populations worldwide, particularly in the Mediterranean (Cavanagh & Gibson 2007). Our findings also contrast those of a study using a similar questionnaire methodology in the Mediterranean which indicated declining shark populations since the middle of the previous century based on the perceptions of fishermen (Maynou et al. 2011), and also a study which used fishermen questionnaires in the Persian Gulf and showed a decline in shark catches, abundances and body sizes over the last 2 decades (Jabado et al. 2015).

Our results suggest that along the Israeli shore, sharks are drawn to power plants but almost exclusively during the winter months, suggesting the behaviour is related to water temperature, either independently, or by interacting with natural variation in distributions (e.g. seasonal migrations). A growing body of literature has revealed behavioural thermoregulation in sharks. For example, Hight & Lowe (2007) described the aggregations of leopard sharks *Triakis semifasciata* in nearshore shallow areas, where they can sustain higher core temperatures. The authors found that all sharks that resided in the shallow warm waters during daytime were females, and this thermoregulatory behaviour has been suggested to assist in physiological functions such as

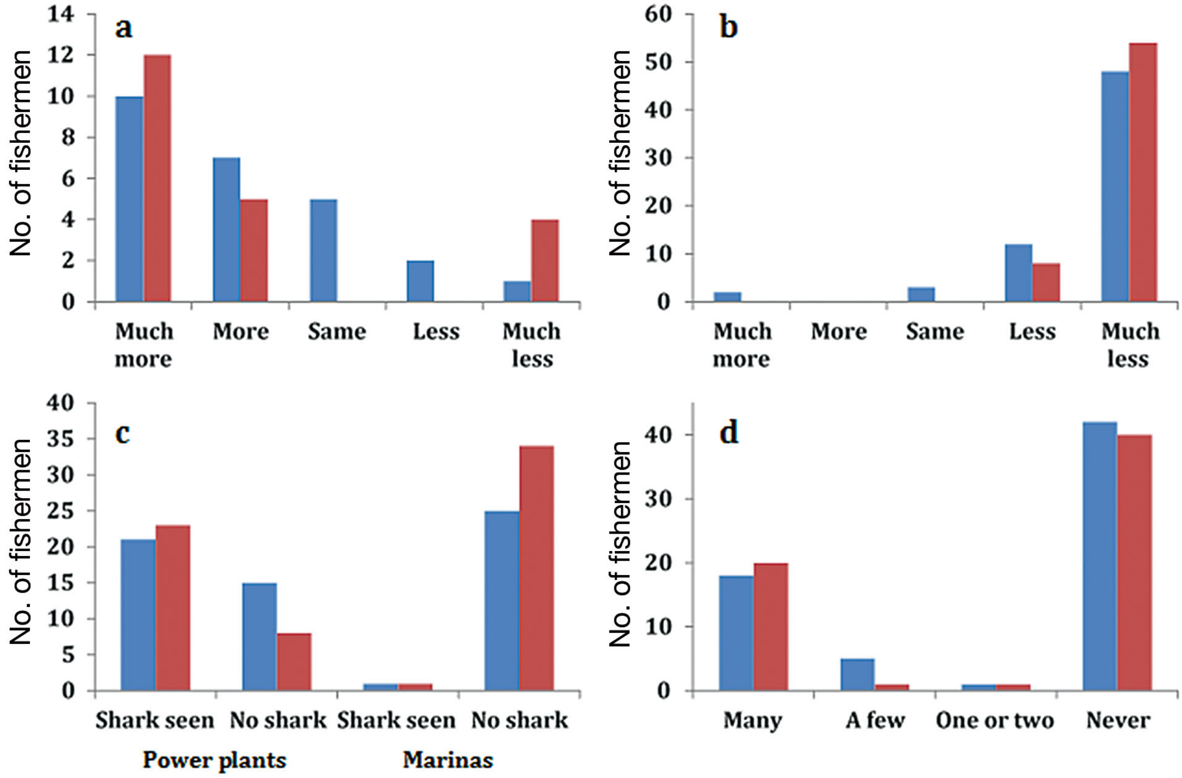

Fig. 8. Comparison of answers between experienced fishermen (≥35 yr of experience, in red) and less experienced fishermen (blue) in regards to population trends of (a) sharks and (b) fish in 1993 vs. 2013, (c) shark sightings at power plants or marinas and (d) numbers of shark sightings per fisherman

metabolism and reproduction. Speed et al. (2012) used acoustic tracking of blacktip reef sharks *Carcharhinus melanopterus* to suggest that water temperatures drive movement patterns of tracked individuals. Female sharks select nearshore habitats, where water is warmer, during gestation periods (Hight & Lowe 2007) or for parturition (Curtis et al. 2011). We found no evidence for use as parturition or nursing grounds since pups have never been reported at the site. However, sharks may be using the warm water effluents at coastal power plants to augment gestation, and may proceed to bear their offspring elsewhere. This explanation receives some support by reports of coastal sharks appearing in shallow coastal waters for several months every year near other countries in the basin such as Turkey (Filiz & Gulsahin 2016) and Tunisia (Saïdi et al. 2007). Despite the supposed benefits of the power plants' discharge to gestating sharks, this interaction with anthropogenically modified coastal habitats might also prove to have a deleterious effect for sharks. For example, Walker (2000) suggested that sharks at a Florida power plant might be trapped in the warm water, unable to leave once the ambient temperature substantially decreases.

If warmer waters are indeed beneficial to sharks, then behavioural thermoregulation might explain why sharks aggregate near warm water outlets as temperatures drop in the winter. To further investigate this connection, additional research is needed to elucidate the distribution of aggregating individuals prior to their arrival at the power plants, and after they leave as the cold season ends. Another potential driver for the aggregations of sharks at the power plants might be higher prey abundance near the warm outflow relative to the surrounding areas during winter. While warm water effluents at power plants are commonly considered by fishermen to have higher prey abundance, this assumption has yet to be investigated.

The other disparity between our findings and the current status of shark populations in the Mediterranean is the increase in shark sightings at the Israeli Mediterranean coastline during the last 20 yr, which we find to be reliable. We do not know if the increase represents a change in the overall size of the populations in the region, or an alteration in the behaviour of the sharks, i.e. offshore populations coming closer to shore. Since stock recovery of large coastal sharks such as *C. plumbeus* is considered to take several decades even under strict management (Morgan et al. 2009), we suggest the increase in sighting frequencies reflects only the increase in abundance at the power plants as coastal power plants grew in size and outflow volume. When first constructed, the old plants may have been too small to have a substantial effect on nearshore water temperatures and thus had little effect on shark behaviour, but with the increase in volume of hot water outflow, shark aggregations started to form and increased the sightings near them over years. These aggregations have made the sharks more approachable and thus more vulnerable to illegal fishing. This finding has significant implications for the protection and conservation of these local populations, and should require a management plan targeted at shallow areas near power plants over winter.

Although one cannot assume that an increase in shark sightings at power plant outflows indicates an actual increase in population size, the possibility that shark populations along the Israeli coast are indeed increasing should be further examined. Such a hypothetical increase may be a result of (1) lack of commercial shark fisheries in Israel, and their protected legal status, both of which presumably provide improved protection along the Israeli shore relative to most other areas in the Mediterranean where sharks are commonly overexploited; (2) the Israeli coastline at the eastern-most part of the Mediterranean is generally characterized by the highest sea surface temperatures in the Mediterranean, which possibly provide favourable conditions for coastal sharks during the cold season; (3) biological invasions from the neighbouring Red Sea through the Suez Canal (Safriel 2013), possibly enhancing local shark populations (Barash 2014).

Future research should address the processes underlying the recent increase in shark abundances at power plant outflows, and their possible regional increase nearshore, along with their ecological implications. The main aspects to be investigated should include the estimation of the fraction of the total population that aggregates at the power plants; the impact of the plants' outflow on annual movements and migration; and monitoring shark abundances near the power plants to see if the increasing trend continues over time. Also needed is an investigation of the movement patterns which precede and follow the aggregations at the warm effluents during winter. It is clear that better understanding the dynamics of shark populations along the shore, of the mechanisms underlying their behaviour and of the ecological impacts of these populations is much needed in order to develop conservation strategies for these important top predators.

Acknowledgements. Thanks to Arbel Levy for co-initiating the study, and to Francesc Maynou and project EVOMED ('The 20th Century evolution of Mediterranean exploited demersal resources under increasing fishing disturbance and environmental change'), whose data we used to construct our interview questionnaires. We thank Alfred (Avi) Baranes and Alan R. Templeton for fruitful discussions, and we also thank the reviewers for excellent feedback.

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Editorial responsibility: Elliott Hazen, Pacific Grove, California, USA

Submitted: May 8, 2017; Accepted: January 8, 2018
Proofs received from author(s): February 22, 2018