# A mass stranding event of sea turtles on the coast of Israel during 2018-19 winter – Final report

Dan Kerem, Itzhak Aizenberg, Eli Biton, Eran Brokovich, Roee Diamant, Ron Goldman, Barak Herut, Noam Leader, Yaniv Levy, Shachaf Lippman, Ilan Nissim, Ofir Talor, Dror Zurel


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*This report was prepared subsequent to a major sea turtle stranding event along the coast of Israel during the 2018-19 winter. The Ministry of Energy, together with the Israel Nature and Parks Authority and the Ministry of Environmental Protection established a multidisciplinary expert team to investigate the possible causes of this event.*


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## Contents

# *Executive Summary*

## Background

During the winter of 2018-19, 250 sea turtles beached on the entire Mediterranean coastline of Israel, evenly spread from the Lebanese to the Gazan border. In January alone there were nearly 100 strandings, an order of magnitude higher than the mean stranding rate for this month in previous years. Beached turtles belonged to the two main Mediterranean species: loggerhead (*Caretta caretta*) and green (*Chelonia mydas*), at roughly the same ratio of their prevalence in Israel (i.e. 4:1, respectively). Of the beached turtles, 48 were beached alive and underwent whole body CT scanning as a guide for attempted treatment. The scan revealed that 24 turtles (50%) suffered from soft tissue trauma (blast-like injuries to tissues lining air spaces of the lungs and middle ears).

The populations of both species in Israel are highly threatened (the green sea turtle is defined as endangered and the loggerhead as vulnerable) and the magnitude of this stranding event was alarming. The fact that this winter was not exceptional climatically, together with the high number of blast-like injured turtles (as a working hypothesis we assumed that 50% of all beached turtles were thus affected), suggested an exceptional anthropogenic involvement. A primary suspect was an airgun-based seismic survey, carried out during January 2019 in deep water off the northern Israeli coast. The Israeli Ministry of Energy (MoE) , Ministry of Environmental Protection (MoEP) and the Israel Nature and Parks Authority (INPA) decided to summon an ad-hoc investigation, headed by the MoE together with multidisciplinary experts from the MoEP, INPA, Israel Oceanographic and Limnological Research Institute (IOLR) and leading academic professionals.

The investigative effort aimed to appraise potential injurious agents that may have caused the observed trauma, focusing on the seismic survey, but considering two other anthropogenic sources, namely: detonations and low/mid frequency military SONAR and one natural source: lightning strikes. In addition to learning lessons from the event and trying to prevent its recurrence, The investigating team wished to identify associated knowledge gaps and ways to fill them and also to recommend additions to existing regulations that may enhance turtle conservation.

## Methodology

The following investigative means were employed:

Literature search into the theory and practice of each potential injurious energy source, as it pertains to causing soft tissue trauma, including any previous cases where a given source has been shown to cause such trauma in turtles.

Using an injurious pressure threshold derived experimentally on turtle cadavers, source levels and radii of injury were computed and their relevance to the investigated event tested, taking into account pertinent aspects of turtle biology in general and in the area of interest in particular.

Assuming the affected turtles behaved as passive floats, a drifting oceanographic model based on currents was deployed to back-track in time all turtles diagnosed with blast-like trauma from their beaching locations. This in an attempt to locate a time and/or area of convergence where an episodic energy input (detonation) may have affected multiple animals (aggregation) or where a long-lasting energy input (seismic survey) may have affected many single animals over time.

A similar exercise was made to forward-track in time a floating object from the locality(ies) of the seismic survey to the point where it hits the shore, to see if the latter matched any of the observed beaching locations.

Maps and numbers of lightning events per day during the period of the event and per month in the winters of 2012-2019 were consulted and extracted, respectively, in an attempt to evaluate the potential role of this natural source in the die-off event.

## Main findings

1. Underwater explosions are the most likely cause of soft tissue trauma in sea turtles and cases in which turtles were thus affected are well known. Even a large charge of 450 kg, given published turtle densities, will only injure one or two animals, unless deployed amidst an aggregation. Except for a few notices to mariners depicting some closed areas, the Israeli Navy was not cooperative in disclosing whether, when and whereabouts detonations were deployed, nor do we have any relevant information from neighboring countries.
2. The Seismic survey conducted offshore Israel was not the cause of the injuries based on the following findings:
    a. Based on a thorough literature search and consultations with international experts, we could not find any direct evidence for seismic surveys causing tissue trauma to any vertebrate, other than to the sound-detecting organs in the inner ear. Presumably, this is because airguns do not create an explosion and a super-sonic blast wave.

b. Theoretically, being very close to a single large operating airgun, a turtle may suffer injury to tissues in contact with air spaces, but according to pressure field modeling, nowhere beneath an airgun array is the injury threshold exceeded.
c. Based on the oceanographic currents model, both back and forward tracking, we found no linking between the locations of the seismic survey offshore Israel and the stranding locations of the affected sea turtles.

3. With no known cases, lightning strikes may theoretically be a source for soft tissue trauma, within a 40 m radius from the point of hitting the water surface. The back-tracking drifting simulation revealed an area (at roughly 32.30° E, between 31.80° & 32.30° N, and roughly 60-80 km north of Bardawil Lake) where all drifting paths converged into a prevailing eastward current. If lightning storms occurred intermittently over time in this area, lightning strikes may explain the number and the observed spatio-temporal stranding distribution pattern of the victims.
4. Theoretically, some active low and mid frequency SONAR sources may cause soft tissue injury at a very close range. We have found no published evidence to that effect. It is not known whether it was employed during the said winter by the Israeli or other Navies. Of the potential sources investigated, it seems to be the least likely cause for the event.
5. The drift model did identify a possible area and time through which many of the back-tracked trajectories pass, i.e. the north-west section of the eddy that circles around roughly 32° N and 34° E (roughly 50 km west of Tel-Aviv), between December 30$^{th}$ and January 1$^{st}$. This finding hints at an aggregation of turtles that may have been impacted by an unidentified discrete high level energy source introduced at that location and time.

## Conclusions, knowledge gaps and recommendations

The main, rather frustrating, conclusion is that apart from abrogating the seismic survey as a cause for the die-off event, we could find no firm evidence for implicating any other potential cause.

Main knowledge gaps pertain to:

1. Unknown Winter distribution of the two turtle species in the easternmost Mediterranean, including their position in the water column and dive profiles. Instrumenting (satellite tags with depth/pressure sensors) free-ranging turtles and trawler-bycatch animals, the latter possibly after a short assessment period, may help

fill this gap such that operators and regulators may be informed about low/high risk areas and periods, including time of day. Data on winter diving patterns may also improve the accounting for availability bias (turtles too deep to be observed) during both manned and unmanned aerial surveys.

2. Unclear blast-related pathology in sea turtles in terms of both comprehensive organ involvement and differential diagnosis. Needed development, with the aid of foreign experts, detailed protocols for medical testing of suspected blast-injured animals and for necropsy of blast-injured victims is highly recommended as one means of filling this gap.
3. The most effective manner to deter sea turtles from a hazardous noise/shock source. Controlled experiments on rehabilitated animals may help fill this gap.

Recommendations for regulators to improve the safety of turtles, re the introduction of potentially harmful energy include:

1. The existing Ministry of Energy's 'Environmental Guidelines for Conducting Offshore Seismic Surveys' which ban surveys in shallow water during the sea turtles spring-summer reproduction season should be reevaluated, considering the possibility of substantial numbers of mature turtles migrating towards and arriving at coastal waters earlier than the established reproductive season.
2. Timely alert of INPA and MoEP about every planned seismic survey.
3. Adding to the Guidelines a requirement to conduct an environmental (marine mammals, sea turtles, fish, cephalopods and other invertebrates) risk assessment as part of a seismic survey plan, a requirement for the use of “turtle guards” on the streamers array, a requirement for the operator to demonstrate that the chosen array emits the minimal energy needed for the particular task and a requirement to use, when possible, seismic sound sources with lower environmental impact, e.g. marine vibroseis.
4. Supplementing/replacing onboard observer-based detection methods with more advanced methods, namely unmanned aerial vehicles (drones) and active acoustics (a novel tracking method of mobile targets through the emission of wideband pulses and evaluation of their reflection patterns from the target).
5. Establishing a dialogue between the Israeli Navy and the INPA in regards to alerting the latter before a planned detonation and/or active SONAR deployment.
6. Every planned civilian introduction of loud noise, such as construction or structure removal, should be reported to the INPA and NoEP well ahead of time and if in sufficiently shallow water, a bottom survey by divers may be considered to

supplement observer-based measures, prior to implementation. Mitigation actions such as a bubble curtain should also be considered.

# 1. *Background*

During the months of December 2018 and January, February and March 2019, 250 turtles (186 loggerhead turtles (*Caretta caretta*), 44 green turtles (*Chelonia mydas*) and 20 unidentified sea turtles, were washed onto the Mediterranean coast of Israel, 48 of which were beached alive. Almost all live-beached turtles, that were brought to the Israel Nature & Park Authority (INPA) Sea Turtle Rescue Center (STRC) for medical treatment, were subjected to CT scanning which revealed that 24 turtles suffered **soft tissue trauma** (blast-like injuries, henceforth **STT**), which was expressed as pulmonary opacity and accumulation of fluids in the middle ears (Figure 1). January 2019 was the most exceptional, with a total of 96 stranding events (roughly 10 times the annual mean stranding rate for this month) and 19 blast-like wounded turtles (3 times the highest previous monthly rate). However, unusually high stranding rates were also evident in the other months.

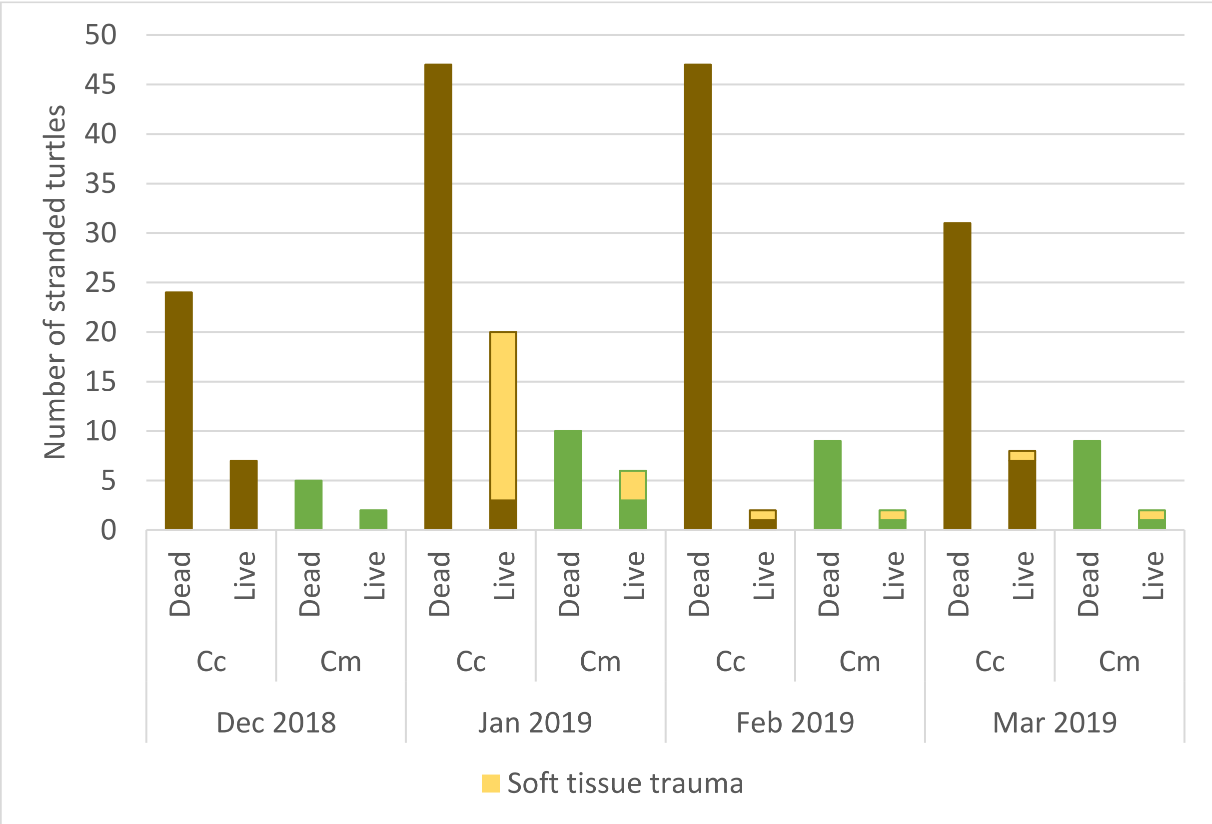



*Figure 1. Breakdown of die-off event by month, species, beaching status (dead or alive) and injury (only in live turtles). Cc- Caretta caretta (brown columns); Cm- Chelonia mydas (green columns). * Sea turtles unidentified to species were excluded.*

The real numbers of blast-injured individuals as inferred from the above table are most probably grossly underestimated since dead turtles, even recently dead, as a practice are not brought in for scanning, but must have contained many similarly injured animals. As detailed below, these are very high numbers compared to mean turtle stranding rates for these months during the last decade (range 8-16), making this event highly unusual (Levy et al., 2019). According to the records of the Israel Marine Mammal Research & Assistance Center, there were no extraordinary stranding of cetaceans during the same period.

During and immediately subsequent to the event, several possible explanations were brought up as for the cause of the stranding. These included military naval activity and an airgun-based seismic survey which was conducted in deep water offshore Israel during January 2019.

The Ministry of Energy, Ministry of Environmental Protection and INPA decided to summon an ad-hoc investigation, headed by the Ministry of Energy together with multidisciplinary experts from the Ministry of Environmental Protection, INPA, Israel Oceanographic and Limnological Research Institute (IOLR) and leading academic professionals (Table 1).

The Terms of References for the investigative panel are listed in *Appendix I*.

This report aims to evaluate possible causes of the stranding event such as seismic surveys, explosives (military, fisheries or other), low and mid-frequency active SONAR and weather conditions.

*Table 1. Investigating team. Names are by alphabetical order.*

| Name | Area of expertise | Affiliation |
|---|---|---|
| Dr. Itzhak Aizenberg | Veterinarian | Sea Turtle Rescue Center |
| Dr. Eli Biton | Oceanography | Israel Oceanographic and Limnological Research |
| Dr. Eran Brokovich | Marine Ecology | Ministry of Energy |
| Dr. Isaac Gertman | Oceanography | Israel Oceanographic and Limnological Research |
| Dr. Roee Diamant | Marine acoustics | University of Haifa |
| Ron Goldman | Oceanography | Israel Oceanographic and Limnological Research |
| Prof. Barak Herut | Marine sciences | Israel Oceanographic and Limnological Research |
| Dr. Dan Kerem | Marine mammal& diving physiology | Freelancer and University of Haifa |
| Dr. Noam Leader | Wildlife Ecology & Conservation | Israel Nature and Parks Authority |
| Dr. Yaniv Levy | Turtle ecology and biology | Israel Nature and Parks Authority, Sea Turtle Rescue Center |
| Shachaf Lippman | Geophysics | Ministry of Energy |

| | | |
|---|---|---|
| Ilan Nissim | Environmental policy | Ministry of Energy |
| Ofir Talor | Project manager | Ministry of Energy |
| Dr. Dror Zurel | Marine Ecology | Ministry of Environmental Protection |

# 2. *Detailed description of the turtle die-off event*

## 2.1. Event background

The large number of stranded turtles in the three months of the 2018-19 winter (Figure 1) greatly surpasses the mean annual stranding rate of turtles (182) during the years 2007-2015. It also represents an alarming nearly eight-fold increase in the number of stranded turtles located yearly in the month of January (Figure 2) and ca. 3-5 fold increase in December, February and March. On the 9th of January alone, the rescue center received nine turtles in a severe condition. This unusually high number of turtles in the course of a single day is the highest that was ever recorded since the establishment of the STRC 20 years ago.

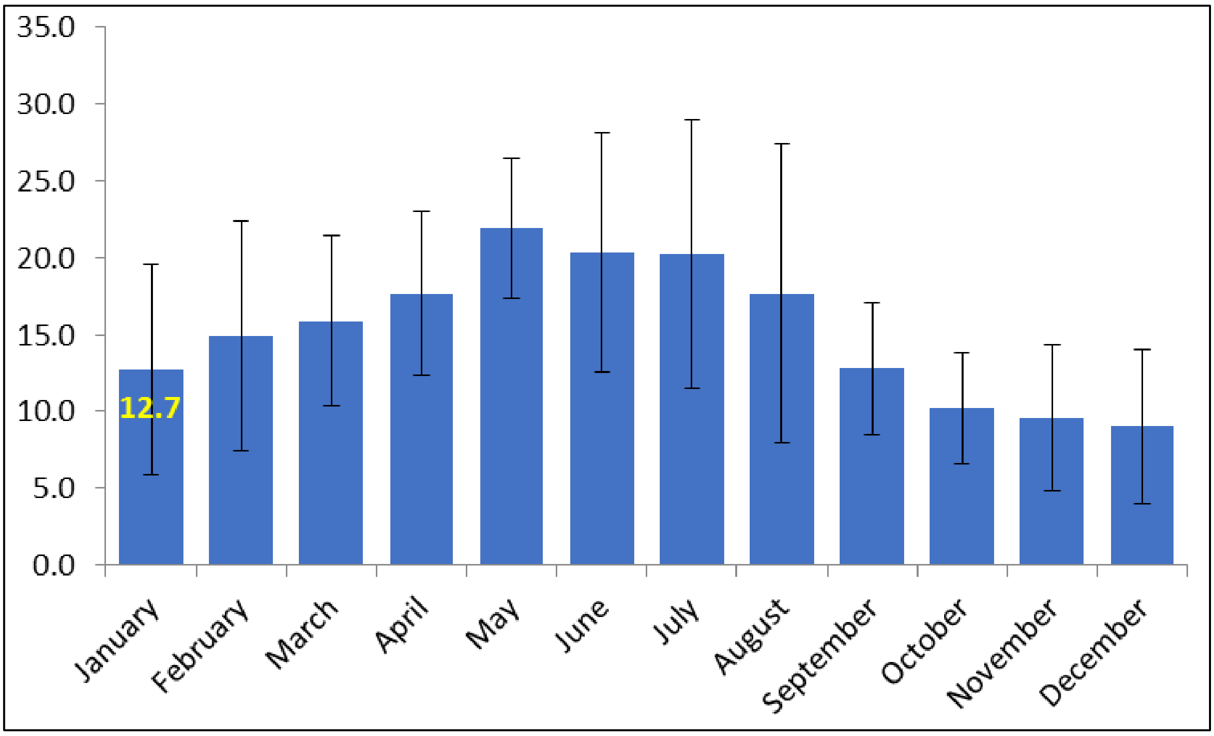



*Figure 2. Monthly mean of stranded sea turtles (both dead and alive) during the years 2007-2015 (n=1,640). Data: STRC. Note: during the extended summer breeding season, search is conducted on a daily basis on all beaches. Searches during other seasons are also done almost daily (supplemented by improved technology for public reporting).*

All documented turtles (alive and dead) were reported by civilians, rangers and beach employees to the local municipal hotline, INPA hotline, through social media or directly to

STRC’s volunteers. The information included location and usually a photograph. The compiled data was stored on the INPA's designated computer network using the "Cybertracker" field data collection system. The geographic distribution of stranded sea turtles along the coastline of Israel was relatively homogenous, from Rosh HaNikra at the northern border of Israel, all the way to Ziqim in the south, bordering with the Gaza Strip (Figure 3).


*Figure 3. Green and loggerhead sea turtle stranding locations during January 2019, along Israel's coastline. Red marks – Loggerhead; Green marks – Green turtle; Light blue – Unidentified turtle*

Medical triage, intensive care treatment, fluid and drug therapy were administrated to all sea turtles hospitalized at the STRC. Radiological examinations (CT and X-Ray) were performed on survivors at the Kol Hai Veterinary Clinic, Rehovot, by Dr. Itzhak Aizenberg. Tissue samples from green turtles were taken and stored in order to establish their origin by means of genetic analysis.

Three turtles had fishing hooks and one had fishing lines in their digestive system. The carapaces of two others were injured by boat propellers, and another was most probably bitten by a shark. During the veterinary diagnosis and treatments, ultrasounds, X-ray and emergency surgery were performed in order to extract the hooks and fishing lines from the digestive system. Furthermore, three of the examined females had developed follicles, indicating their readiness for the reproduction season.

CT scans of live injured sea turtles revealed that 83% (19 of 23 examined) showed symptoms of STT: pulmonary opacity and accumulation of fluids in the middle ear (Figure 4, *Appendix II*). Such symptoms are consistent with shock-wave trauma, suggesting a close-range exposure to an as-yet undetermined strong impulsive sound source, such as underwater explosions.

## 2.2. Detailed pathological report

Full details on date and stranding location, health status upon arrival, appropriate treatment and diagnosed symptoms were recorded for all live turtles examined in the period of December 2018-March 2019 and are presented in Table 2.

The two main findings from CT scans were lesions in the middle ear and in the lungs. These findings, which in all the affected sea turtles did not express an established externally apparent cause, are indicative of shockwave trauma. Almost all such affected turtles presented accumulation of various degrees of fluid in the middle ear cavities. In the milder cases, the fluid was ventral to the columella (see section 4.1 below on turtle ear anatomy and *Appendix III* for expansion) and in severe cases, the fluid filled the entire cavity. Lung radiology showed patchy infiltrations in the pulmonary parenchyma. The extent of the infiltrations ranged from mild to severe. The appearance of those changes resembles pulmonary hemorrhage. In some instances, air escaped out of the lung through ruptured parenchyma and/or airways, forming a gas pocket that had to be aspirated.

In many specimens, both lung and ear pathology showed lateralization, i.e. only one side was affected, or, one side was affected to a higher degree (Lungs: 12 of 25 animals; Ears: 8 of 25 animals). As a rule, in a given individual, the lung and the ear on the same side were affected or more severely affected. Such laterality is a familiar characteristic of blast injury as portrayed in chapter 4.4. Other symptomatology which characterized turtles diagnosed with

STT were apathy, muscle weakness, diminished awareness to the external environment and buoyancy problems (lopsided floating/swimming) – all in the face of a high body score and no apparent external damage. As for the outcome, 5 affected turtles did not survive, only two were released to the wild and the rest are still in rehabilitation, indicating that these turtles had little if any chance of surviving the trauma on their own.

*Table 2. Details of the blast-injured sea turtles. Biology: Sp.=species (C.c. =Caretta caretta and C.m.=Chelonia mydas); M=male, F=Female, Juv=juvenile, Sub=sub adult, P.h.=post hatchling. Health state: STT=soft tissue trauma; rehab=currently in rehabilitation.*

| Biology | | | | Health state | | | | | | | Dates | | CT Scan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| urtle name | Sp. | Gender | Plastrom Length | Cause of injury | L. Lung: Inflammation/ bleeding | R. Lung: Inflammation/ bleeding | Fluids in L. inner ear | Fluids in R. inner ear | Turtle state | Outcome | Arrival | Death | |
| **Tamir** | C.c. | M | 53.0 | STT | No | No | Yes | Yes | Very weak but responsive. Slightly thin. Hypothermia | Rehab | 4/1/19 | | Y |
| **Efrati** | C.c. | F | 51.0 | STT | Damaged | Damaged | Yes | Yes | Thin and Exhausted | Death | 7/1/19 | 2/2/19 | Y |
| **Lotem** | C.m. | Juv | 24.5 | STT | No | Severe condition | No | Yes | Exhausted and very weak | Rehab | 8/1/19 | | Y |
| **Shimona** | C.c. | Sub | 47.0 | STT | Severe condition | Severe condition | Yes | Yes | | Rehab | 9/1/19 | | Y |
| **Liron** | C.c. | Sub | 48.7 | STT | Damaged | Damaged | Yes | Yes | | Death | 9/1/19 | 12/1/19 | Y |
| **Mor** | C.c. | F | 51.0 | STT | Moderately damaged | Severely damaged | Yes | Yes | | Rehab | 9/1/19 | | Y |
| **Zvia** | C.c. | F | 51.0 | STT | Bleeding | Bleeding | Yes | Yes | | Death | 9/1/19 | 11/1/19 | Y |
| **Itzik** | C.c. | F | 52.0 | STT | No | Severe condition | Small amount | Small amount | | Rehab | 9/1/19 | | Y |
| **Dud** | C.m. | F | 59.0 | STT | No | Laceration | Yes | Yes | Injuries in both eyes | Death | 9/1/19 | 18/1/19 | Y |
| **Victoria** | C.c. | Sub | 44.0 | STT | Severely damaged | Moderately damaged | Yes | Yes | Very thin and exhausted. Bleeding from both eyes | Rehab | 10/1/19 | | Y |
| **Nus** | C.c. | Sub | 48.0 | STT | Moderately damaged | Severely damaged | Yes | Yes | Very weak, thin with parasites and mucus on the throat | Rehab | 10/1/19 | | Y |
| **Moris** | C.c. | P.h. | 8.0 | STT | No | No | No | Yes | Bitten fins. Lethargic | Rehab | 11/1/19 | | Y |
| **Shahar** | C.m. | Juv | 24.0 | STT | No | No | High amount | Yes | Weak and thin | Released | 14/1/19 | | Y |
| **Danilo** | C.c. | F | 52.0 | STT & marine vessel injury & hooks | Moderately damaged | Severely damaged | Yes | Yes | Thin and active with fractions in carapace | Rehab | 14/1/19 | | Y |
| **Oren** | C.c. | F | | STT | Damaged | Damaged | Yes | Yes | 1 hook on front right limb and on tongue. Broken carapace in the tail area | Rehab | 17/1/19 | | Y |

| Biology | | | | Health state | | | | | | | Dates | | CT Scan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| urtle name | Sp. | Gender | Plastrom Length | Cause of injury | L. Lung: Inflammation/ bleeding | R. Lung: Inflammation/ bleeding | Fluids in L. inner ear | Fluids in R. inner ear | Turtle state | Outcome | Arrival | Death | |
| **Boneh** | C.c. | F | 54.0 | STT | No | Severely damaged | Yes | No | There are developed follicles | Rehab | 17/1/19 | | N |
| **Harela** | C.c. | F/sub | 56.0 | STT & a hook | Moderately damaged | Severely damaged | Yes | High amount | | Rehab | 17/1/19 | | Y |
| **Jacob** | C.c. | F | 54.5 | STT | Severely damaged | Moderately damaged | Yes | Yes | Breathing heavily, lethargic | Rehab | 18/1/19 | | Y |
| **Nuris** | C.c. | F | 51.0 | STT | No | No | Yes | Yes | Weak and very thin, lesions in the eyes | Rehab | 29/1/19 | | Y |
| **Kobi** | C.c. | M | 52.0 | STT | No | Damaged | No | No | Algae on carapace | Rehab | 31/1/19 | | Y |
| **Milka** | C.m. | Sub | | STT | Damaged + sand in lungs and esophagus | Damaged + sand in lungs and esophagus | Yes | Yes | Lethargic, very thin, hardly breaths | Death | 15/2/19 | 1/3/19 | Y |
| **Adama** | C.c. | F | 49.0 | STT and trawler net | No | No | Small amount | Small amount | Chubby and active | Released | 23/2/19 | | Y |
| **Kfir** | C.m. | M | 65.0 | STT | Damaged | Damaged | Yes | Yes | Right eye injury | Rehab | 10/3/19 | | Y |
| **Moshe** | C.c. | F | 53.0 | STT | No | air pocket of 6 litter was aspirated | No | Yes | weak but responsive, old head injury, parasites, floating for a long time, fractures in the beak | Rehab | 11/3/19 | | Y |

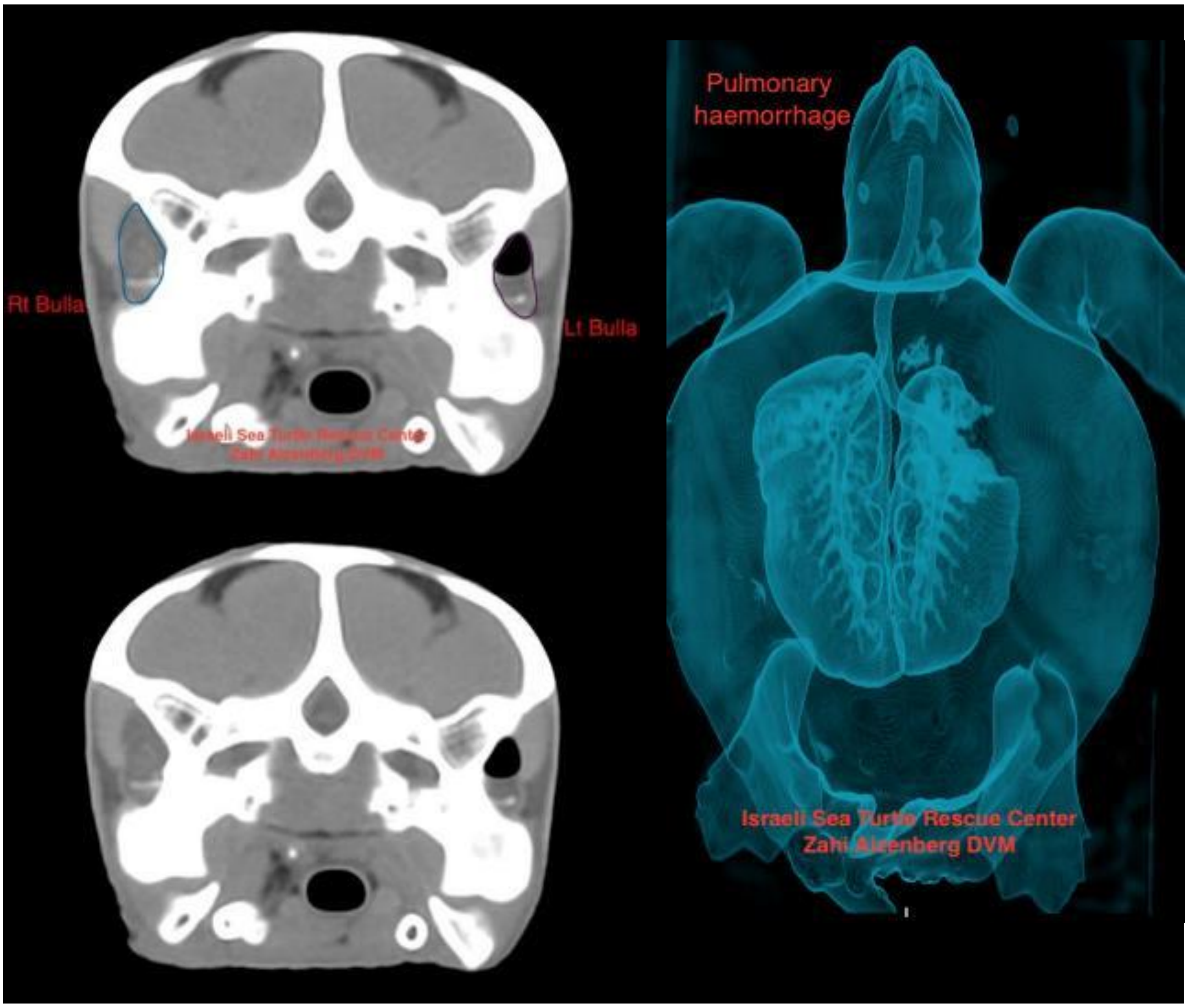
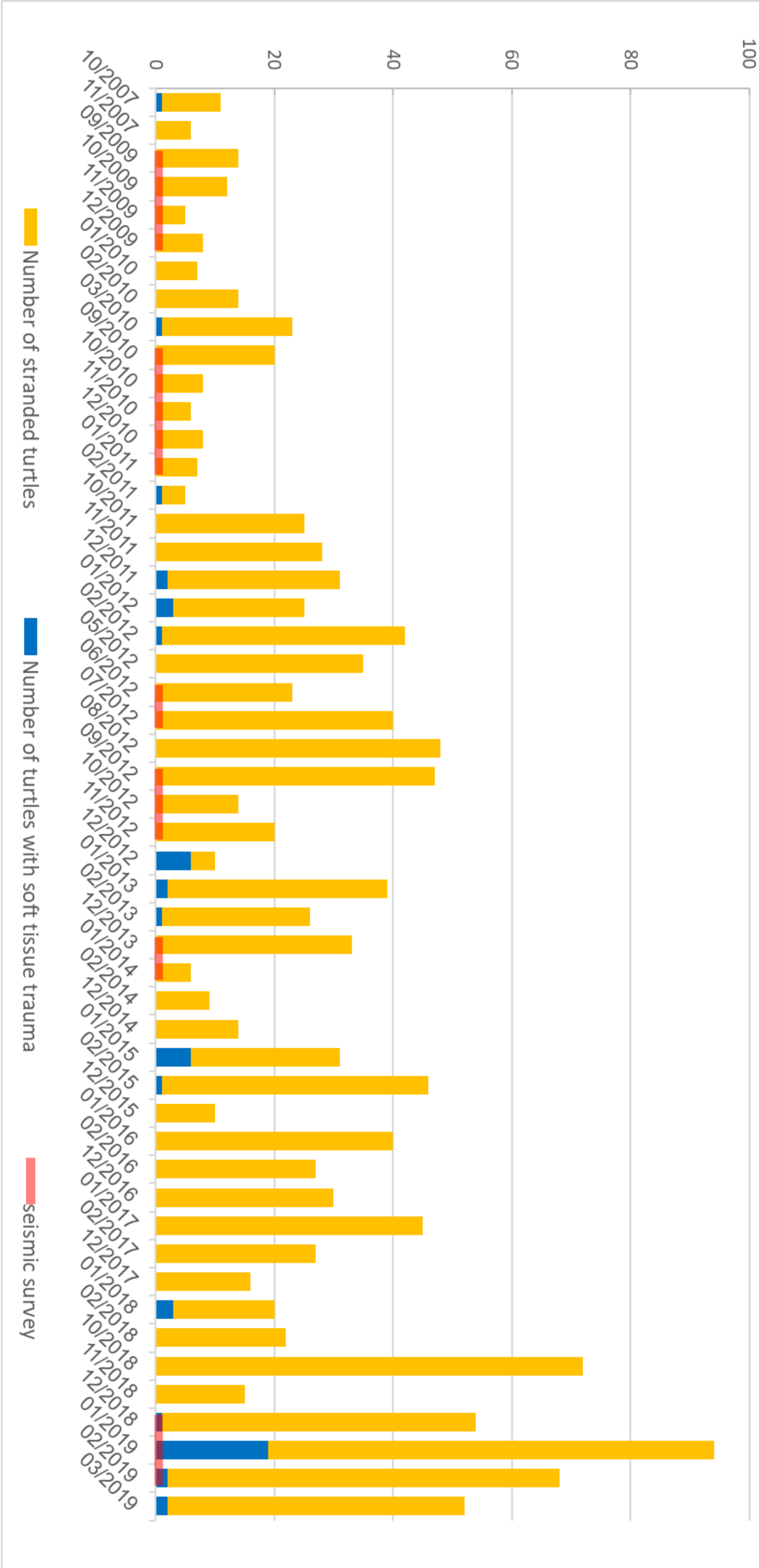



*Figure 4. An example of CT scans showing symptoms of STT: opacity of the lungs and right pnemothorax (right) or a progressive infection and fluids in the inner ears (top left): the right inner ear is filled with fluids, marked in blue, and the left ear is half-way full, marked in purple). Photo Credit: Dr. Itzhak Aizenberg, Kol Hai veterinary clinic, Rehovot.*

## 2.3. Live-stranding events with blast-like injury in previous years

Similar stranding events (>5 injured turtles with identical clinical symptoms of STT; Aizenberg *et al*., 2013), were previously documented by the INPA on a smaller scale in December 2012 (following a seismic survey) and in January 2015 (Figure 5).

*Figure 5. The number of stranded sea turtles (dead and alive) and alive injured sea turtles diagnosed with soft tissue trauma between 2007-2019 (months shown around SST and seismic survey events).*



# 3. *Habitat and migration routes of sea turtles in the eastern Mediterranean*

## 3.1. Turtle dispersion in the Mediterranean

The Eastern Mediterranean Sea encompasses the known habitat of green turtles in the Mediterranean, while loggerhead turtles nest both in the central and eastern basins of the Mediterranean (

Figure 6), green turtles are known to nest only in the eastern (Levantine) basin (

Figure 6). Being mainly neritic-feeders, green turtles exhibit relatively localized shallow (200 m) inshore foraging grounds and a high degree of fidelity over extended time-scales to nesting beaches, foraging grounds and migratory corridors, most of which are localized within the Levantine basin (Broderick *et al*., 2007; Casale *et al*., 2018).

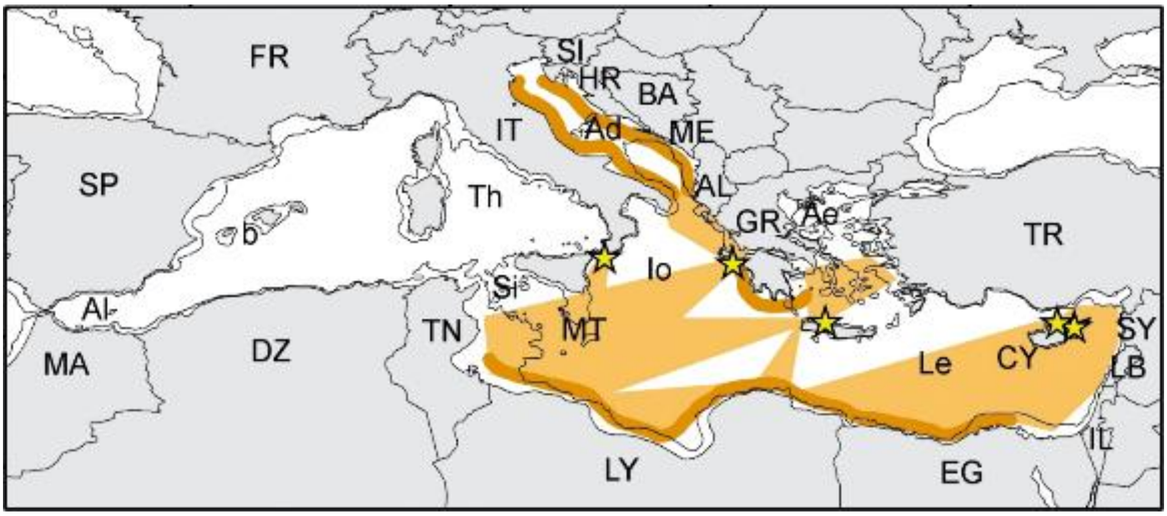



*Figure 6*. Main known migratory corridors for adult loggerhead turtles Caretta caretta (females and males) during reproductive migrations from and to the breeding sites (yellow stars). Light brown areas represent migratory corridors in the open sea while darker strips represent paths along the coasts, typically in shallow waters. From Casale *et al*. (2018).

The available, yet limited data on green turtle yearly distribution patterns within the eastern Mediterranean suggests that turtles spend the winter mainly in coastal feeding areas (Figure 7). Therefore, if shallow water feeding areas attract aggregates of turtles, a localized blast event may be sufficient to explain the numerical impact observed. We do not know of any feeding area capable of attracting sea turtles in pelagic waters, yet the use of deep water might be important as migratory corridors (Stokes *et al*., 2015).

A substantial presence of sea turtles within Israel's EEZ might thus occur, however, it is not expected to be in an aggregated form. Hence, in such a scenario, a moving blast source, capable of producing many underwater shock waves, while covering large areas, or other spatial phenomena as lighting storms, may suffice to explain the large number of stranded sea turtles.

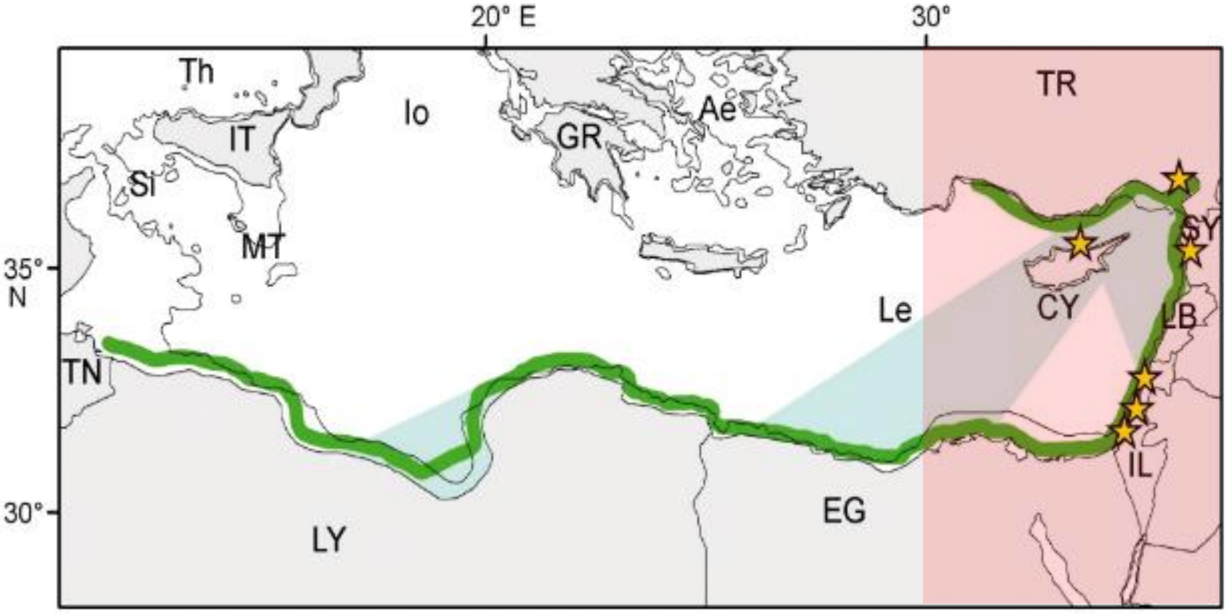



*Figure 6. Main known migratory corridors for adult female Green turtles, Chelonia mydas, during reproductive migrations from the breeding sites (yellow stars). Light green areas represent migratory corridors in the open sea while darker strips represent paths along the coasts, typically in shallow water. From Casale et al. (2018). Area in light red marks suggested impact area.*

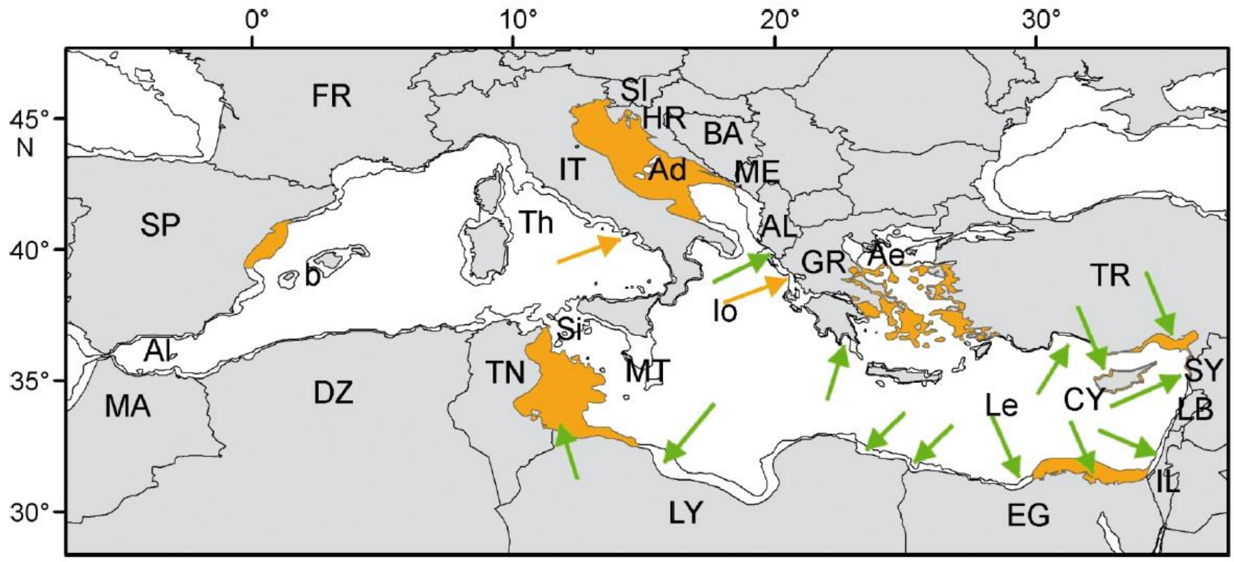



*Figure 7. Neritic foraging and wintering sites for loggerhead turtles Caretta caretta (orange areas and arrows) and green turtles Chelonia mydas (green arrows). Neritic areas correspond to the continental shelves, which are conventionally delimited by the 200 m isobath (solid line). From Casale et al. (2018).*

Loggerhead turtle nesting activities were documented in various Mediterranean countries, but more than 96% of the clutches are laid in Greece, Turkey, Libya and Cyprus. Less significant nesting areas are present in Egypt, Israel, Italy, Lebanon, Syria and Tunisia (Figure 8).The major nesting areas of the green turtle are located in Turkey, Cyprus and Syria, with minor nesting aggregations occurring in Egypt, Lebanon and Israel. Some of these nesting sites host only few scattered nests and others large and dense aggregations of one or both species (Casale *et al*., 2018).

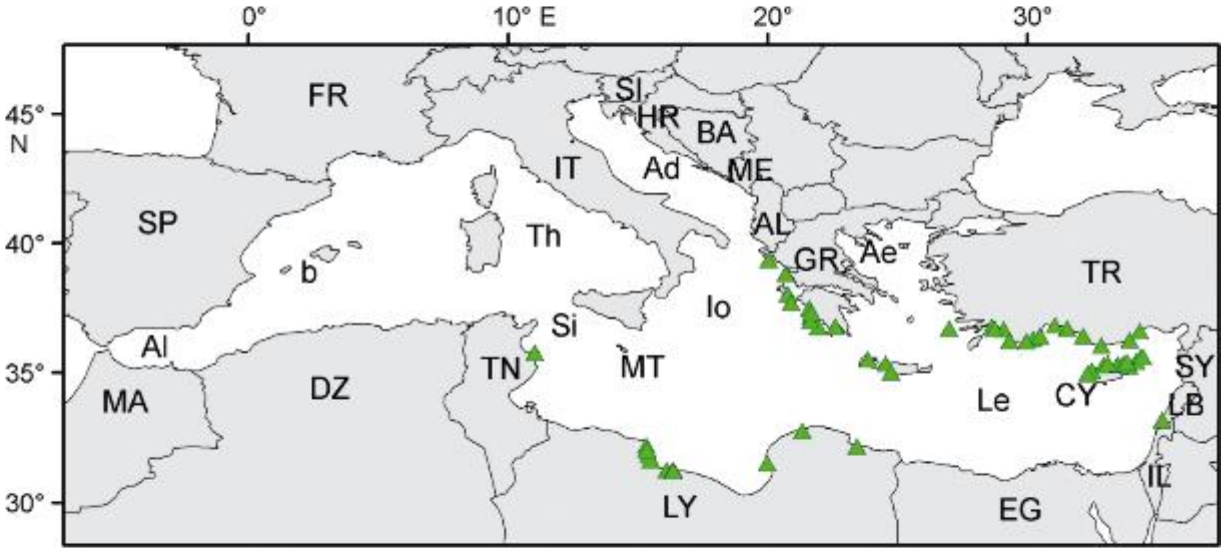



*Figure 8. Major nesting sites (i.e. ≥10 clutches yr−1 and ≥2.5 clutches km−1) of loggerhead turtles Caretta caretta in the Mediterranean. Countries: AL: Albania; DZ: Algeria; BA: Bosnia and Herzegovina; HR: Croatia; CY: Cyprus; EG: Egypt; FR: France; GR: Greece; IL: Israel; IT: Italy; LB: Lebanon; LY: Libya; MT: Malta; ME: Montenegro; MA: Morocco; SI: Slovenia; SP: Spain; SY: Syria; TN: Tunisia; TR: Turkey. Marine areas: Ad: Adriatic Sea; Ae: Aegean Sea; Al: Alboran Sea; Io: Ionian Sea; Le: Levantine* Basin; Si: Sicilian Strait; Th: Tyrrhenian Sea; b: Balearic Islands (Spain)

Data on seasonality and periodicity of breeding behavior of green turtles is provided in Table 3.

*Table 3. Seasonality and periodicity of Mediterranean sea turtles (Caretta caretta and Chelonia mydas) reproduction. Values represent medians or means. The table is based on table 2 in Casale et al., 2018. Sources are quoted therein.*

| Biological periods | *C. caretta* | *C. mydas* |
|---|---|---|
| Remigration interval for females (yr) | 2−3.35 | 3 |
| Remigration interval for males (yr) | 1−1.8 | >1 |
| Renesting interval (d) | 12.7−19.9 | 12.5 |
| Mating period (peak) | Apr−May | - |
| Male breeding migrations (to/from breeding site) | Oct−Apr / May−Jun | - |
| Female breeding migrations (to/from breeding site) | Apr−May / Jul−Aug | – / Jul−Sep |
| Nesting season (peak) | Jun−Jul | Jun−Jul |

(–) No data available.

From a limited source of transmitter-bearing turtles (Kot *et al*., 2018), the INPA investigated the seasonality in the use of deep-water areas. It is apparent that the selected turtles use deep water mainly during July-August (Figure 9).Turtles also used the coastal area more during the summer.

The data is very limited due to low number of turtles, a difference in the number of transmitter-bearing turtles between years and the tendency to put transmitters on females during the egg laying season.

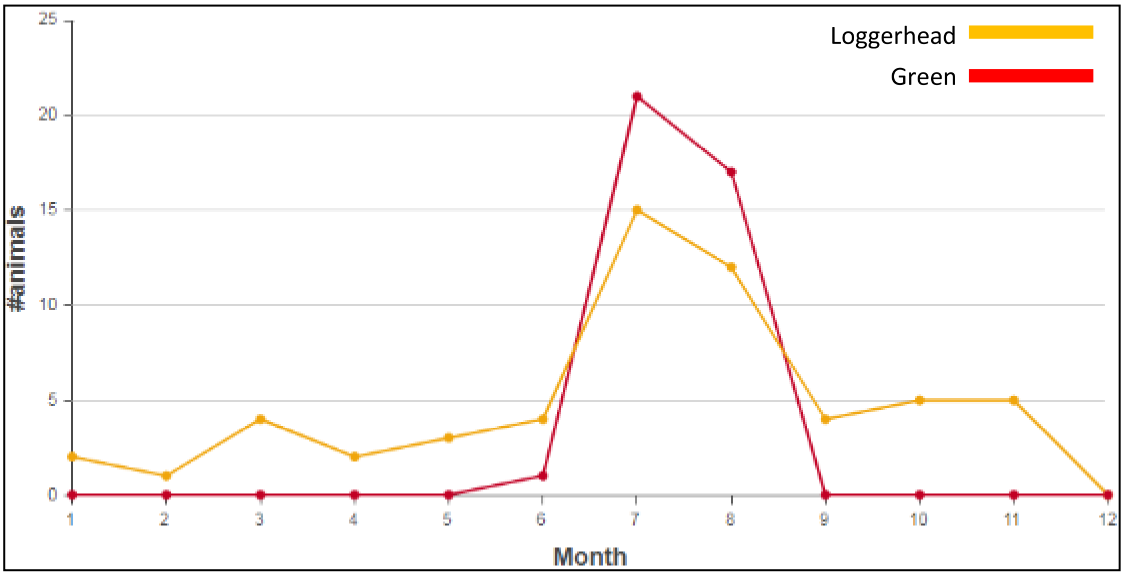



*Figure 9. Number of sea turtles using deep-water routes along the year.*

### 3.2. Turtle density considerations

While directing any investigation of a potential harmful cause, it is useful to question whether the local population density, assuming homogeneous occupation of the space, can account for the number of affected turtles, or whether the latter could only be explained by some form of aggregation. Lacking density estimates from our region, we used the closest ones available, i.e. from the Adriatic Sea, which will most probably be an overestimation of local density. The estimates were derived by aerial surveys conducted in the summers (July-September) of 2010 & 2013 (Fortuna *et al*., 2018). The highest concentration was evident throughout the northern region, both in- and offshore, at depths between 20-100 m, but another 'hotspot' was revealed in the midline of the southern region, at depths exceeding 1000m. The authors reported for the entire Adriatic a density of 0.2 individuals/km$^2$, uncorrected for detectability. A later (unpublished) correction arrived at a value of 0.8 individuals/km$^2$ (D. Holcer, personal communication). This value is used below to evaluate potential causes for the observed injuries.

# 4. *Possible causes of lung and ear trauma in sea turtles*

CT findings of fluid opacity in middle ear cavities and lungs, similar to those found in that event, are familiar for turtles suffering from blunt trauma and/or infection. Furthermore, increased radio-opacity surrounding the bronchi, could be consistent with aspiration pneumonia, as well as with forced submergence in fishery interactions (Craig Harms, personal communication). Yet, considering the large number of affected animals and barring an infectious epidemic (see details in section 2.1), we decided to concentrate, as potential causes, on intense-sound-producing sources, known or suspected to have been operative during the event, i.e. detonations, seismic surveys, active SONAR and lightning strikes.

Due to their intensity (Figure 10), each of the above could theoretically explain the large number of affected animals. Seismic and sonar by being a mobile sound source affecting a large area, detonations by spreading radially over large distances away from the source and lightning strikes by being a spatially distributed source. During the same period of the event and the seismic survey, we came across two Israeli Navy navigation-warning announcements: "Closed area and danger to navigation zone", (ASP NtM 138/2018 and ASP NtM 002/2019) that were issued on the Israeli Administration of Shipping and Ports - Notices to Mariners web-site. These areas are located near Ashdod at the southern edge of the coastline and extend 120 km westward in a diamond-like pattern. There is no further information concerning the cause of closure and the nature of the naval activities. Naturally, we could not find any information regarding neighboring countries military activities.

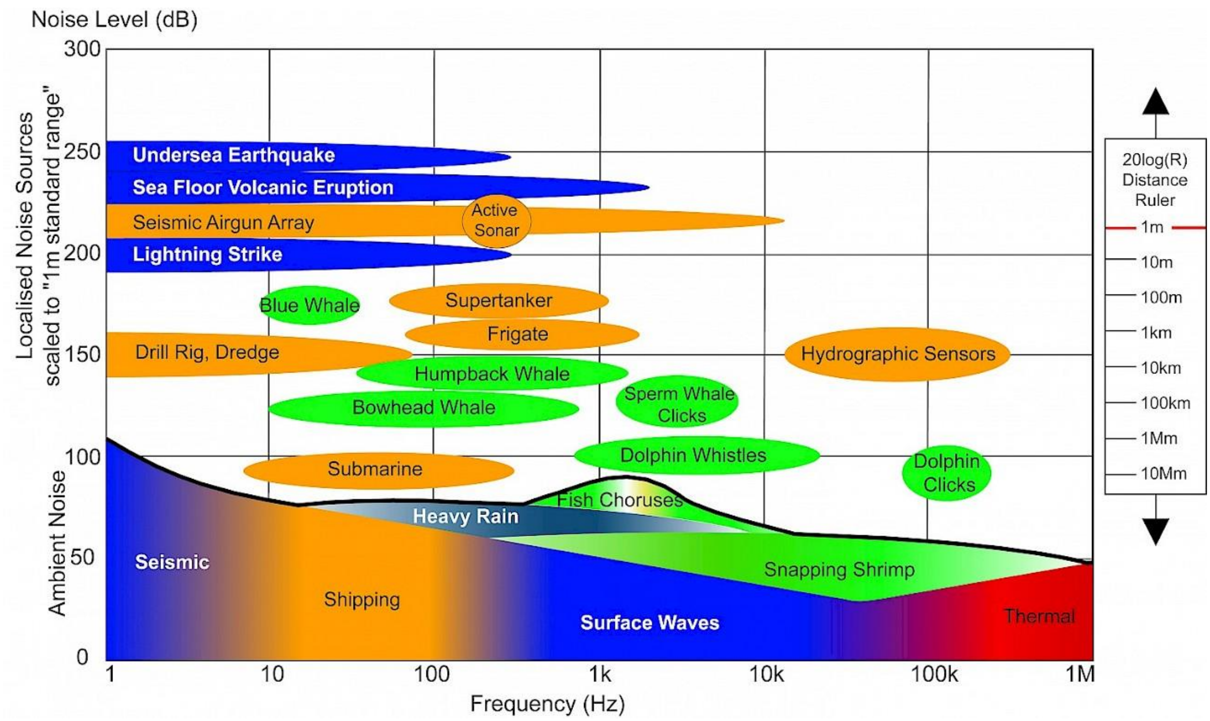



*Figure 10. Levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment. OSPAR 2009. https://www.ospar.org/work-areas/eiha/noise. Absent from the figure are tactic*

*SONARs, with source levels of 215-235 dB and frequencies between 0.1-10 kHz and underwater detonations with values similar to those of earthquakes.*

### 4.1. Background –Units and conversions

While it would have been helpful if the International System of Units (SI) was the only one used in the field of sound (or any other field involving physics), that is not the case and the following text will adhere to the general practice. This section is for the benefit of readers who are not entirely versed with the physics. It is mainly borrowed from the University of Rhode Island's Discovery of Sound in the Sea (DOSITS) site - https://dosits.org/, specifically designed to clarify terms and topics in the field of underwater sound to regulators, policy makers and laymen. Links in the text direct the reader who looks for more details to the relevant sections in the DOSITS' site.

Below are some common units used in the field of underwater sound, what they measure, and the way for their interconversion.

**Frequency**

1 hertz (Hz) = 1 cycle per second

1 kilohertz (kHz) = 1,000 hertz

**Pressure**

1 Pascal (Pa) – SI unit of pressure = 1 $N/m^2$

1 micro Pascal (µPa) = $10^{-6}$ Pa – commonly used when measuring sound pressures.

1 atmosphere (atm) = 1 Bar = 101,325 Pa = $1.0133 \cdot 10^{11}$ µPa – occasionally used when measuring pulsed sound pressures (seismic).

1 $lbs/in^2$ (psi) = 6,892.857 Pa = 6,892,857,000 µPa – commonly used in relation to detonations and their effects on animal tissues.

**Intensity**

Decibel (dB) – a measure of the intensity of a sound; 1/10 of a Bel.

Decibels are a relative unit comparing two pressures:

$$I(dB) = 20\log(\mathbf{P}_{measured}/\mathbf{P}_{reference}) \qquad (1)$$

Therefore, a reference pressure must also be indicated. In underwater acoustics, the reference pressure is 1 µPa, so the true unit of intensity for underwater sound is dB referenced to 1 µPa (dB re 1 µPa). Since the energy (and pressure) decays with distance from the source, one needs to specify at what distance was it measured. For practical reasons, 'source pressure level' is expressed as the value measured at 1 m from the source, hence: 'xxx dB re 1 µPa @ 1 m'.

The logarithmic scaling was resorted to in order to cover the immense pressure range to which the vertebrate ear is sensitive to and which is perceived by the animal, as judged by behavior. For pulsed sound and detonation/ lightning strike the measured pressure used is usually the highest peak (see 'Sound Pressure Level' below)

Converting pressure value measured in micropascals to decibels is done by using the above equation. Converting a pressure measured in other units, e.g. psi, require firstly a conversion to micropascals.

Example:

What is a pressure of 200 psi expressed in dB?

According to the highlighted conversions above:

**200 psi** = 1,378,571,400,000 µPa = 20log(1,378,571,400,000 /1) dB re 1 µPa=**242.8 dB re 1 µPa**.

Due to the logarithmic scale, one cannot use a single conversion factor to switch from pressure to dB or *vice versa*.

**T**he following table converts a practical range of source intensity levels to equivalent pressures:

| **dB re 1 µPa @ 1 m** | **psi** |
|---|---|
| 250 | 458.5 |
| 240 | 145 |
| 230 | 45.9 |
| 220 | 14.5 |
| 210 | 4.6 |

## Sound Pressure Level (SPL)

SPL is a means of characterizing the amplitude of a sound based on pressure measurements that can be done in several different ways.

Root-mean-square pressure (rms pressure) = the square root of the average of the square of the pressure of the sound signal over a given duration:

$$rms\ pressure = \sqrt{(p^2)_{average}} \qquad (2)$$

peak-to-peak = the range of pressure from the most negative pressure to the most positive pressure of the signal.

peak pressure = the range of pressure from zero to the greatest pressure of the signal; also called 0-to-peak pressure

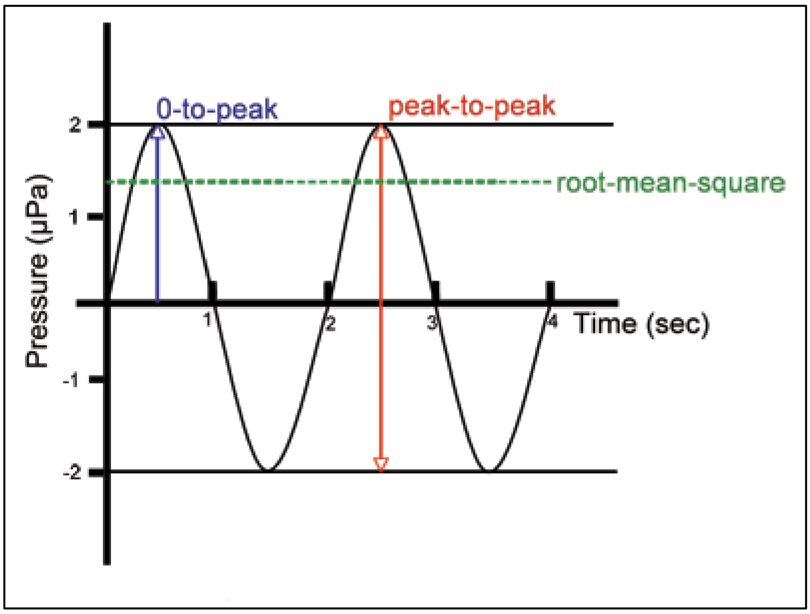



*Figure11. Simple sound wave diagram.*

**Sound Exposure Level (SEL)**

SEL is the decibel level of the time integral (summation) of the squared pressure over the duration of a sound event. It takes into account the received level as well as the duration of an exposure. Units are dB re 1 μ$Pa^2$·sec

Single strike SEL = the duration of the sound event is a single pulse or signal. This term is often used in pile driving

$SEL_{cum}$ = the duration of the sound event is multiple pulses or signals, which should be specified as well as the total duration over which the sound energy has accumulated.

## 4.2. Background – Ears and hearing of sea turtles

### 4.2.1. Anatomy

Sea turtle's ears function as sound detectors and equilibrium organs. The ear lacks an external portion (pinna), nevertheless, the terms *inner ear* and *middle ear* are used as in mammals. As in mammals, the middle ear, an air-filled cavity, is involved in sound transduction while the inner ear functions in sound reception and detection of position and acceleration.

The external tympanum is covered by a tympanic scale (Figure 12). A unique feature of sea turtles' tympanum is a thick layer of underlying fat, coupling the tympanum with the ossicular mechanism (Wever, 1978). This reinforcement may render the tympanum more resistant to rupture.

As in mammals, each middle ear (tympanic) cavity is connected to the mouth cavity via the Eustachian tube, which open close to the jaw joints (Wyneken, 2001). The ossicular mechanism consists of a mushroom-shaped cartilaginous extracolumella that lies beneath the tympanum, connected by ligaments to the columella, the only true ossicle in turtles. The columella is a long, thin, curved bone that traverses the middle ear air cavity before expanding into a cone-shaped cartilaginous footplate (stapes) that, in turn, expands to overlay the oval/vestibular window of the inner ear (Wever, 1978).

*Further anatomical details are provided in* Appendix III.

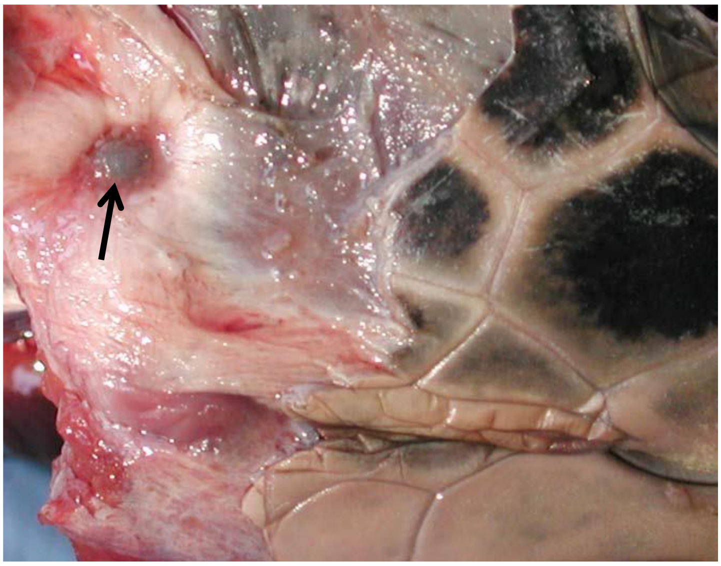


*Figure 12. Right lateral view of the head (turtle faces right). Tympanic scale is deflected to expose the tympanum (arrow). Figure 217 from Wyneken (2001).*

### 4.2.2. Physiology

Sea turtles hear in air (laying females vocalize on the beach) as well as in water. They are low-frequency hearing specialists, with an underwater hearing frequency range of 50-1000/1100 Hz in adults and up to 16 kHz in juveniles (Dow Piniak *et al*., 2012). Underwater hearing thresholds in a single captive loggerhead sea turtle (*Caretta caretta*) were measured by Martin *et al*. (2012), using both behavioral and auditory evoked potential methods. Behavioral sensitivity was highest between 100 and 400 Hz, with thresholds around 100 dB re 1 µPa. AEP measurements on the same individual were up to 8 dB higher. Both techniques demonstrated similar frequency response, with a steep loss of sensitivity above 400 Hz, of about 37 dB per octave. Hearing frequency range diminishes somewhat with age but threshold sensitivity (low to begin with, relative to marine mammals, with a sensitivity ranging between 30-40 dB re 1 μPa) does not change throughout ontogeny, despite residence in acoustically distinct environments (reviewed in Lavender *et al*., 2014).

Naturally occurring sounds at the frequency range of sea turtles (Figure 10) are undoubtedly perceived and it is possible that final orientation toward the beach is partially guided by the sound of breakers. Ironically, evolution made them also perceptive to most forms of anthropogenic noise, including that of airguns, the peak frequency band of which overlaps partially with their highest hearing sensitivity frequency band (BOEM, 2016).

Unlike marine mammals, however, turtles are not considered acoustic animals. To the best of our knowledge, they are not vocal underwater, do not pursue sound-emitting prey and do not have sound-producing natural predators. Their ability to localize sound sources is unknown but is suspected to be crude, both on account of their small head (and/or reliance on bone conduction) which minimizes the difference in sound arrival times to the two ears and the presumption that during evolution, their brain may not have been conditioned to resolve exact locations of sound sources.

## 4.3. Underwater detonations

General

In-water explosions from a freely-suspended charge produce a spherical shock wave that travels at speeds greater than the speed of sound in water. Explosives like TNT and other nitroglycerine-based explosives (‘high explosives’), have a very rapid detonation process (5,000 to 10,000 m/s), produced by a violent chemical reaction, which turns the explosive solid into incandescent gaseous reaction products at extremely high temperatures and pressures. The initial mass of explosive rapidly expands to produce a large bubble of superheated gas, with a volume >5000 times the solid volume. The boundary of the gas bubble creates a pressure disturbance that is transmitted to the surrounding water by the accelerating interface between the explosive gas bubble and the water. Near the source, the pressure rise-time for high explosives is nearly instantaneous, of several microseconds, followed by an exponential decay. The rise time for other explosives may be longer, and the decay of the pulse slower. This rise time affects the frequency content in the signature of the explosion, with longer rise times lacking the higher frequencies (Urick, 1983).

The wave in the vicinity of the explosive does not propagate in an identical manner to small amplitude acoustic waves. The leading edge of the blast front, rising in a very short time, contains much of the high frequency energy. It propagates in a non-linear manner, changing its form during propagation. The leading edge steepens to form a shock, and the tail of the wave becomes extended. It has a relatively fast decay rate at a distance from the source. At large distances from the source, the propagation of the pressure wave usually approximates that of regular sound waves, decaying slower and traveling further. The high frequency energy is absorbed and scattered, and the waveform becomes dominated by low frequency components, and is perceived as a "rumble". A 1 kg charge will have a source pressure level of 274 dB re 1 μPa @ 1 m (see below).

Underwater detonations activated close to the water surface in addition to the over-pressure peak, produce a surface-reflected negative under-pressure or rarefaction wave of similar characteristics but lower amplitude. The initiation of the surface rarefaction interrupts the decay phase of the positive wave at the 'cutoff time' (

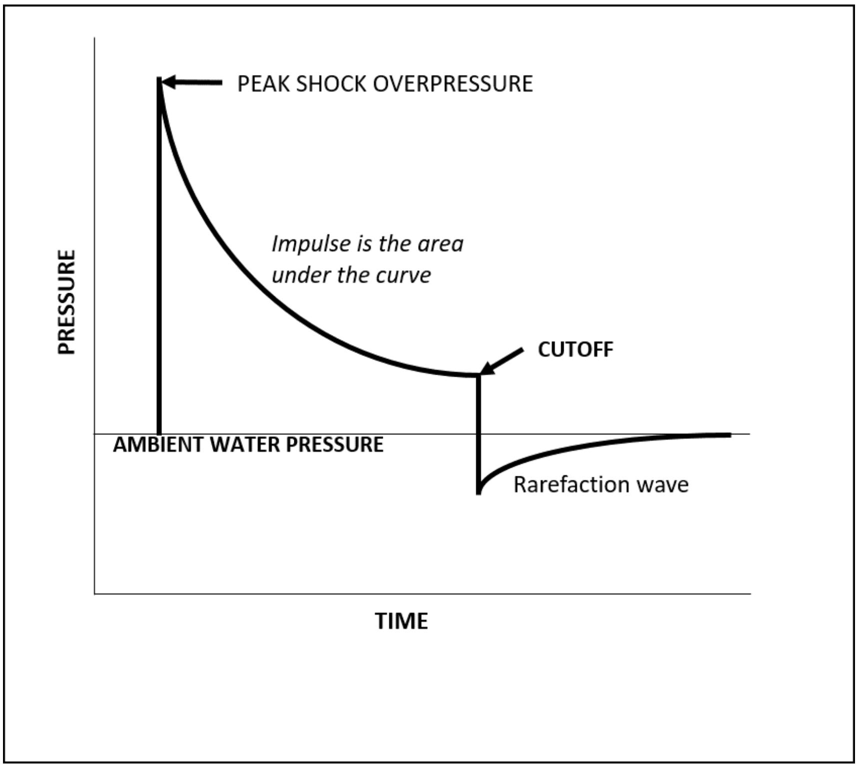



Figure 13).

*Figure 13. A generalized scheme of a shock wave (Following Wang et al., 2014).*

The shock wave at a given received location may be characterized by the peak pressure(s) and/or the impulse, which is the time-averaged pressure over the duration of the wave, multiplied by the duration (area under curve) in units of pressure x time. The peak pressure in μPa of the primary shock wave and its decay with distance (and time) can be calculated as (Urick, 1975; Ward, 2015):

$$P_{peak}(\mu Pa) = 5.24 \cdot 10^{13} \cdot [w^{1/3}/R]^{1.13} \qquad (3)$$

$$P_{peak}(psi) = 8.22 \cdot 10^{3} \cdot [w^{1/3}/R]^{1.13} \qquad (4)$$

With w being the charge weight in kg (TNT- equivalent) and R being distance from the source in m.

For a 1 kg charge, the source pressure at 1 m is 7,598 psi. At 10 m, it decays to 563.2 psi, at 100 m to 41.8 psi and at 1,000 m to 3.1 psi.

For a 100 kg charge, the corresponding pressures are 43,000 psi, 3,190.5 psi, 236.5 psi and 17.5 psi, respectively.

### 4.4. Blast injury

When traveling through an organism situated close to the source, the shock wave produces tissue damage, which in vertebrates mainly affects gas-containing cavities such as the lung, middle ear, sinuses and intestinal gas pockets, (Yelverton *et al*., 1973, Stuhmiller *et al*., 1991) but other organs too (Ketten *et al*., 2005; Sharpnack, 2006). Surmised causative mechanisms for the observed permanent injuries include deformation, differential acceleration, air-space resonance, airspace compression followed by implosion, etc., which are thought to mechanically stress tissue structures beyond their physiological limits of compliance/tensile strength, inducing leak, rupture, spalling, etc. (*references as above*).Internal tissue pressures in fresh cadavers exposed to blasts have been measured (Ketten, 2006; Ketten *et al*., 2005). Yet, due to lack of sufficient funding (D. Ketten, pers. comm.), these were unaccompanied by real-time photographic documentation of tissue dynamic response, which may have validated some of the proposed physical mechanisms, as well as the role, if any, played by the negative pressure in causing the tissue damage.

A shock wave is the agent most consistent with the present pathological findings, at least as inferred from those described in humans (Lance *et al*., 2014), live terrestrial mammals and birds (Yelverton *et al*., 1973) and fresh marine mammal or turtle cadavers (Ketten, 2006; Ketten *et al*., 2005). Blast-injured victims often show lesion laterality, allowing the inference of the victim’s position relative to the detonation source (*references as above*). Viada *et al*. (2008) summarize the few cases in which sea turtles were unintentionally or intentionally (Klima *et al*., 1988) exposed to underwater detonations, with explosives mainly buried underground, in conjunction with removal of offshore structures. Effects varied from non-noticeable, through stunning, cracked shells to death, depending on distance from the explosion source. The charge weight was 92 kg. Although in-water measurements of pressure levels were not recorded, modeled received levels were estimated to be 221, 217,213, and 209 dB for horizontal distances from the detonation site of 229 m, 366 m, 549 m, and 915 m, respectively. Two Kemp's ridleys (6.7 and 0.6 kg) and two loggerheads (4.2 and 5.5 kg) within 229 and 366 m, as well as one loggerhead (6.8 kg) at 915 m were rendered unconscious. Distance of 549 m and of 915 m for a Kemp’s ridley, appeared safe. The stunned turtles recovered when pulled out of the water but may have drowned if left underwater or in a real scenario. In the only reported instance where an autopsy was performed (N=2), examinations revealed ‘extensive internal damages, particularly to the lungs (Viada *et al*., 2008). These were two immature green turtles, killed when 9.1 kg of plastic C-4 explosives were detonated at distances of 30.5-45.7 m from the turtles. In an open water environment, at ranges of 30.5 and 45.7 m, such a charge would be expected to generate nominal peak pressures of 347 and 244 psi, respectively (Viada *et al*., 2008), obviously lethal (see Table 4 below).

In a series of three underwater shock tests, each detonating 544 kg of TNT at mid-depth in water about 37 m deep, three turtles were located after the explosions. One turtle was killed at a distance of 152-213 m; one turtle at 366 m sustained minor injuries and one turtle at 610 m appeared to be uninjured (O'Keeffe and Young, 1984). It would be hard to assess the at-sea immediate and evolving effects of injuries such as those seen radiologically in victims of the winter die-off event in Israel. Fluid in the middle ear is bound to adversely affect hearing, since external pressure fluctuations would hardly move the tympanum (and columella) with incompressible media present on both its sides. If, however, as some authors suggest, hearing underwater in turtles relies wholly or partially on bone conduction (e.g. Lehnard *et al*., 1985), then the effect may be minor. Fluid in the lung, especially if representing hemorrhage, would most certainly impair respiration, buoyancy and swimming, the latter two more so if it is one-sided or unsymmetrical.

As an extension of a controlled laboratory study on fresh marine mammal cadavers (Ketten, 2006), some fresh sea turtles' cadavers were also exposed to varying received explosive pressures (Ketten *et al*., 2005). The experimental setup for the turtle blast injury investigation was the same as described by Yelverton *et al*. (1973) for live terrestrial mammals and birds and by Ketten (2006) for fresh marine mammal cadavers. Weights of explosive charges (TNT equivalents) and/or distances from the explosive to the object were chosen so as to produce received peak pressures at the object’s surface ranging from 10 to 400 psi, in an experimental pond. At the highest pressure (400 psi), flipper fractures, traumatic brain injury and cerebral emboli were found. The lungs were relatively spared, as may be expected from their position within the body cavity, their dorsal aspect being in close contact with the carapace (Figure 14).

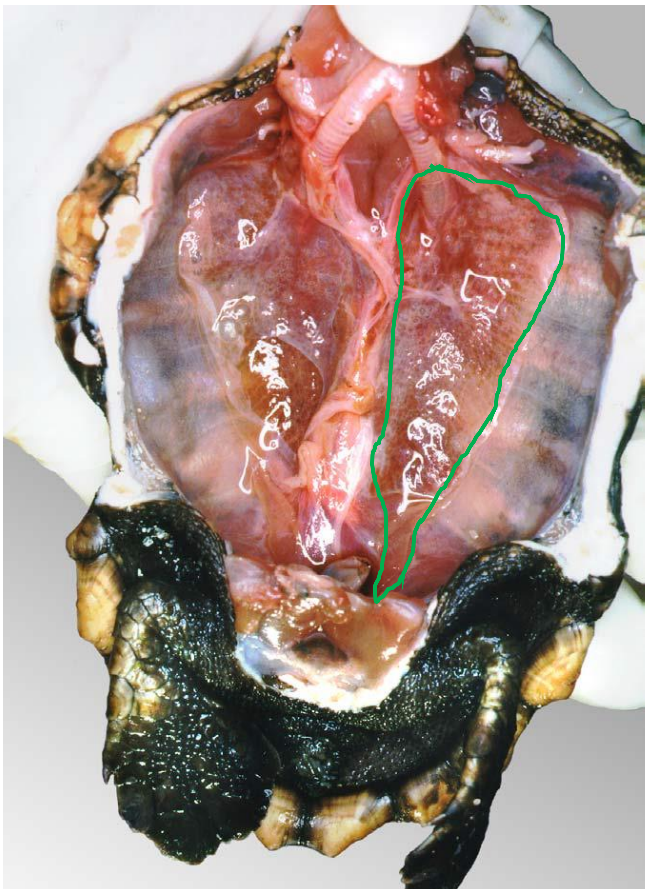


*Figure 14. The (collapsed) lungs are seen in contact with the carapace, extending for most of its length. Figure 78a from Wyneken (2001). The outline of the left lung is marked in green.*

The effect of the carapace in protecting the lungs was evident when a gauge inside the lung recorded a peak pressure of 84 psi, when the outside, free-field, gauge registered 400 psi. On this limited series (N=6), the authors found tissue trauma to occur at received pressures of 200 and 400 psi, but no gross macroscopic evidence at **50 psi, which may be used as the threshold** for injury to turtles.

Young (1991), based on results from terrestrial mammals, predicted the safe distance (1% mortality rate) for a sea turtle from a detonation charge to be:

$$R = 560 \cdot (w)^{1/3} \qquad (5)$$

With R being the distance in feet and w the charge weight in pounds. The safe distance from a 1 kg charge would then be **212** m.

Solving equation (1) for the assumed 50 psi threshold, for a 1 kg charge and a 100 kg charge, the safe distances seems to be **85.5** m and **396.6** m, respectively. The figure 'Charge-Damage Zone Estimates for Received Peak Pressure' from Ketten (2006), depicting distances for porpoises could serve for a rough prediction of safe distances (50 psi threshold), minor/moderately injurious distances (assumed 150 psi) and lethal distances(assumed 400 psi) from charges of various weights for turtles. The mean weight of the scanned adult turtles in the die-off event was 38.5 kg (N=20), which, allowing for carapace and plastron weight, roughly overlaps the porpoise weight range. Predicted values for the 450 kg charge weight fit rather well with observations reported by O'Keeffe and Young (1984)(Table 4).

*Table 4. Predicted safe, injurious and lethal distances (m) by charge weight, (derived from Ketten (2006)).*

| | Distance category (m) | | |
|---|---|---|---|
| Charge weight | Safe (50 psi) | Injurious(150 psi) | Lethal (400 psi) |
| **0.5 Kg** | 63 m | 24 m | 10 m |
| **1 Kg*** | 85.5 m | 32.2 m | 13.5 m |
| **2 Kg** | 100 m | 39 m | 18 m |
| **22.5 kg** | 220 m | 92 m | 42 m |
| **100 kg*** | 396.6 m | 149.4 m | 62.6 m |
| **450 kg** | 680 m | 250 m | 110 m |
| **450 kg; O'Keeffe& Young** | 610 m | 366 m | 152-213 m |

***** Calculated from equation (1)

## Relevance to the 2018-19 winter die-off event

We could not extract any information about such blasting activity from the Israeli Navy or from any other regional source. Table 5 lists the number of charges required to injure 20 animals for the charge weight range in Table 4, given a density of 0.8 ind/km$^2$ (see section 3.2 above). For that, we will use the conservative assumption that being within the radius from the charge out to the safe threshold may result in an injury. It is conservative on two accounts. One, on approaching the safe threshold as we defined it, a turtle may have already moved out of the injurious range. The other, a turtle being within the lethal range and dying would not be counted as having been affected.

*Table 5. The theoretical number of charges, by charge weight, required to injure 20 turtles*

| Weight (kg) | 0.5 | 1 | 2 | 22.5 | 100 | 450 |
|---|---|---|---|---|---|---|
| # charges | 2000 | 1000 | 800 | 167 | 51 | 14 |

It can be seen that even large charge weights of the order of 500 kg by creating injurious zones of only a few km$^2$ are predicted injure one or two animals. Thus, to affect a large number of animals, multiple detonations had to have occurred, or else fewer charges had to be deployed in regions of (temporary) aggregations.

## 4.5. Seismic surveys

### 4.5.1. General

Marine seismic surveys use intense pulses of underwater sound to image the seabed geology, either for scientific purposes or, more often, in search for oil and gas. By far, the most common sound source used for these surveys is the airgun (Duncan, 2016).

<u>Airgun</u>

An airgun is a stainless-steel cylinder filled with high-pressure air, typically at a pressure of about 14 MPa (2000 psi) but sometimes as high as 3000 psi. An acoustic signal is generated when the air is released nearly instantaneously into the surrounding water, producing an air bubble. The air bubble expands rapidly and creates an impulsive signal, but with a much slower rise time to peak pressure than that which occurs with explosions, of the order of milliseconds (Figure 15). In seawater It travels at the speed of sound namely at around 1,500 m/s, with differences relating to the salinity and temperature of the water. Inertia causes the bubble to over-expand, whereupon it compresses, creating a negative pressure phase. It then creates a series of smaller oscillations that follow the primary pulse of its initial formation.

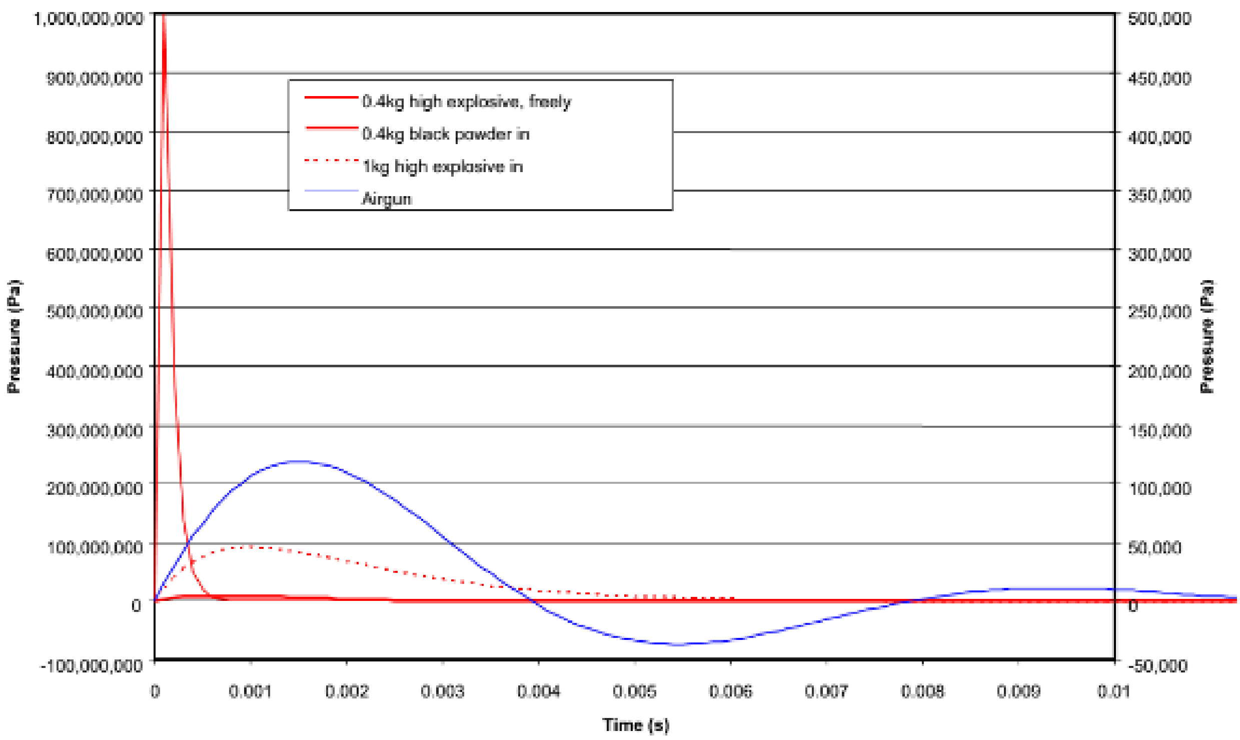



*Figure 15. Idealized underwater blast waveforms. Freely suspended high explosives, (thin red line), high explosives buried in boreholes to fragment rock (dotted red line, typically 5% peak pressure of freely suspended explosive), deflagrating explosives (fast burning black powder in propellants, thick red line, typically 100kPa) and airgun sources (blue, typically 1.4-15 MPa) (figure from Cudahy & Parvin., 2001)*

The sound impulse generated by a single airgun is omnidirectional, with a frequency range of approximately 10 to 2,000 Hz, peak energy at low frequencies, typically 20-50 Hz, and declining energy at frequencies above 200 Hz. Individual airguns are available in a wide range of chamber volumes, from < 5 $in^3$ to more than 2,000 $in^3$, depending on survey requirements. Airguns are usually deployed several meters below the surface of the water and as with a shock wave, when the acoustic pressure wave hits the surface, there is an almost perfect reflection and inversion, resulting in a negative peak of almost equal amplitude. It may be considered as if emanating from an imaginary above-water mirror source, at equal distance from the surface to the real one, therefore termed 'ghost wave' by the industry, and is treated together with the primary wave (Caldwell and Dragoset 2000; Mattsson *et al*. 2012).

Airgun array

During seismic surveys, arrays consisting of many airguns are towed behind vessels. The array is designed to maximize the initial pulse, focusing the acoustic energy downwards and to minimize the effect of bubble oscillations and surface reflections through complex interactions between the different airguns. Guns are 'shot' and recharged continuously, and seismic pulses are usually emitted at intervals ranging between 5 and 30 seconds as the towing vessel moves ahead, and the survey may continue in the same general region for hours, days or longer. The sound from the array is more directional, due to variable phase delays between airguns at different positions within an array. More energy is directed downwards to enter the seabed and the reflected sound is detected by hydrophones towed by the surveying vessel at a large distance behind the airgun array (Caldwell and Dragoset 2000; Mattsson *et al*. 2012). Although the majority of energy is directed downwards, considerable energy is also propagated horizontally as 'sidelobes', mainly in the cross-line direction (perpendicular to the ship's course) and less prominently at the center of the array, in the in-line direction (Duncan, 2017).

For deep penetration seismic surveys, the combined volume of airgun arrays can vary from approximately 45 to 8,460 $in^3$.The source level of an airgun array can vary considerably with its design and the type of the component airguns (Richardson *et al*. 1995; MacGillivray and Chapman 2005; OGP 2011).

### 4.5.2. Seismic surveys offshore Israel

From 2009 until January 2019, 18 deep penetration 3D seismic surveys were conducted in Israel's EEZ (Figure 16).

Table 6 presents the name, dates, combined array volume and gun-loading pressure for each given survey.


*Figure 16. 3D seismic surveys in Israel's EEZ (2009-2019). The survey relevant to the reported die-off is number 18. Within the two triangles, the triangle more to the south west was the first performed and was done on license block number 31. The second, north-eastern triangle was performed in license block number 23.*

*Table 6. 3D Seismic surveys details for offshore Israel 2009-2019. Location and order numbers as in Figure 16.*

| | Survey Name | Start Date | End Date | Start Date | End Date | Start Date | End Date | Number of arrays | Volume (in^3) | Pressure (psi) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | IOL_2009_PGS_M_3D_1 | 15.12.2009 | 25.12.2009 | | | | | 2 | 4135 | 2000 |
| 2 | Noble_2009_PGS_M_3D_2 | 15.09.2009 | 15.12.2009 | | | | | 2 | 4135 | 2000 |
| 3 | PetroMed_2009_WG_M_3D_3 | 5.11.2009 | 3.12.2009 | | | | | 2 | 3147 | 2000 |
| 4 | Noble_2010_PGS_M_3D_1 | 4.09.2010 | 29.10.2010 | | | | | 2 | 4135 | 2000 |
| 5 | Pelagic_2010_PGS_M_3D_2 | 29.10.2010 | 15.11.2010 | 4.12.10 | 25.12.10 | 7.01.2011 | 28.11.2011 | 2 | 4135 | 2000 |
| 6 | Ratzio_2010_PGS_M_3D_3 | 16.11.2010 | 26.11.2010 | | | | | 2 | 4135 | 2000 |
| 7 | Avner_2010_PGS_M_3D_4 | 27.11.2010 | 3.12.2010 | | | | | 2 | 4135 | 2000 |
| 8 | Adira _2010_WG_M_3D_5 | 27.11.2010 | 22.12.2010 | | | | | 2 | 3147 | 2000 |
| 9 | Adira _2010_WG_M_3D_6 | 27.11.2010 | 22.12.2010 | | | | | 2 | 3147 | 2000 |
| 10 | Modiin_2010_PGS_M_3D_7 | 25.12.2010 | 6.01.2011 | | | | | 2 | 4135 | 2000 |
| 11 | Ginko_2010_WG_M_3D_8 | 29.12.2010 | 31.12.2010 | | | | | 2 | 3147 | 2000 |
| 12 | Adira _2011_AR_M_3D_1 | 18.06.2011 | 30.07.2011 | | | | | 5 | 850 | 2000 |
| 13 | Lapidoth_2012_PGS_M_3D_1 | 16.06.2012 | 5.07.2012 | | | | | 2 | 4130 | 2000 |
| 14 | Colridge_2012_PGS_M_3D_2 | 5.07.2012 | 27.07.2012 | | | | | 2 | 4135 | 2000 |
| 15 | Ginko_2012_AR_M_3D_3 | 14.09.2012 | 30.11.2012 | | | | | 5 | 900 | 2000 |
| 16 | Noble_2013_Dolphin_M_3D_1 | 15.11.2013 | 9.12.2013 | | | | | 2 | 4100 | 2000 |
| 17 | Isramco_2013_PGS_M_3D_2 | 24.12.2013 | 18.01.2014 | | | | | 2 | 4130 | 2000 |
| 18 | Energean_2018_PGS_M_3D_1 | 29.12.2018 | 1.02.2019 | | | | | 2 | 3260 | 2000 |

## 4.6. Can seismic airguns physically injure sea turtles?

### 4.6.1. Literature search:

All but one of the sources retrieved by a literature search which discuss the issue, discount the possibility of seismic sounds producing injury akin to blast injury to marine mammals or sea turtles. However, this is mainly based on lack of evidence of related mortality and/or specific examinations of sporadic mortality (page 18 in Gordon *et al*., 2003; NMFS, 2018; Nelms *et al*., 2016 and Popper *et al*., 2014; Page 4-133 in BOEM, 2016).

Popper *et al*., (2014) is the only publication that lists exposure guidelines and thresholds for lethal or potentially lethal (as well as less serious) damage to fish and turtles exposed to seismic airguns, (see Table 8in *Appendix VI*). The author's rationale for the coupling of fish and sea turtles is that the hearing range for the latter approximates more that of fish than the hearing range of most marine mammals, and that the functioning of the inner ear of sea turtles (basilar papilla and saccula) is dissimilar to that of mammals (cochlea). This rationale however is biased towards hearing and ignores the presence in turtles of lungs and ossicle-containing middle ears, the organs (external to the inner ear) most affected by shock waves and potentially by intense sound. Popper *et al*. (2014) used experimental data from fish exposed to intense pile-driving noise to project and develop criteria for death or mortal injury of sea turtles (and fish) exposed to airguns. Lacking experimental or even anecdotal support, the report assigns thresholds to sea turtles, which are identical to those for fish that do not hear well. They do acknowledge, however, that it is likely that these would be conservative for sea turtles, because preliminary data suggest that sea turtles are highly resistant to high intensity explosives, making it likely that they would also be resistant to damage from seismic airguns. Furthermore, the authors state that because of their rigid external anatomy, it is possible that sea turtles are highly protected from impulsive sound effects, at least with regard to pile driving and seismic airguns.

Seismic surveys and stranding

There seems to be no published evidence that seismic surveys have been directly linked with turtle stranding. As for marine mammals, there have been several reports that circumstantially tie stranding to surveys (see review by Castellote & Llorens, 2016), but not a single peer-reviewed publication that convincingly demonstrates a cause and effect relationship.

### 4.6.2. Theoretical considerations

Even though the only convincing evidence to date for seismic-induced mortality is to larval krill (McCauley *et al*., 2017), it has been repeatedly implied, both in the literature (e.g. Popper *et al*., 2014) and in verbal and electronic discussions with various experts, that blunt tissue trauma resembling blast injury could afflict a turtle close enough to a seismic source. We therefore set out to further explore this possibility.

As there are no empirical or experimentally-based thresholds for physical tissue injury caused by seismic sources, we have reverted to thresholds determined for blast injury. It is not known whether and how each of the shock wave parameters, i.e. received peak pressure (positive and negative), pressure rise time, waveform and duration (impulse) and travel speed through tissue contribute to the resulting injury. Yelverton *et al*. (1973) point out that the impulse better predicts outcome than peak pressure or energy: '*Three sheep at a 1-foot depth and at a slant range of 26 feet from a 1-pound charge sustained the same amount of G.I.* [Gastro Intestinal] *tract damage as did three sheep at a10-foot depth and at a slant range of 48 feet from a 1-pound charge. The peak pressure was 478 psi at the 1-foot deep animals, and the energy was 2.32 in•lb/in². The peak pressure at the 10-foot deep animals was 269 psi, and the energy was 0.97 in•lb/in². The impulses were 42 psi•msec at the 1-foot deep animals and 45 psi•msec at the 10-foot deep ones. The impulses were nearly the same, yet the peak pressure and energy varied by a factor of about 2*'.

We will take the conservative assumption that peak pressures alone are responsible and that the **50-psi** received peak pressure threshold experimentally derived for blasted fresh sea turtle cadavers (Ketten *et al*., 2005) can also be used to estimate safe distances from an airgun array.

Measuring pressures in the immediate vicinity of an airgun, l*et al*one beneath an array, is a difficult task, so the pressure field needs to be modeled, even though calibration against an actual measurement is required to approximate exact values for each given gun or array. The models tend to neglect quite a few geometric and physical intricacies, relying on the fact that the size of the individual guns and the produced bubbles are small relatively to the acoustic wavelengths over the frequency range at which most of the energy is emitted. In theory, the highest peak pressure to which an animal could be exposed, will be at the port of the largest gun in the array.

The equation relating received peak pressure to gun characteristics (Duncan & Gavrilov, 2019) is:

$$p_R(t') = r(t)\left(p(t) + \frac{\rho u(t)^2}{2}\right)/R \quad (6)$$

R – distance from gun to hydrophone

r – bubble radius (proportional to gun size)

p – difference between bubble and hydrostatic pressures

ρ – density of the medium

u - bubble wall velocity

All but R being functions of time – t.

$t' - t - R/c$, the time taken for the acoustic signal to travel from the airgun to the hydrophone, c being sound velocity

At the instant in which the bubble is generated and before it starts expanding, the velocity is zero and received pressure at the port will be roughly the gun loading pressure (usually 13.8 MPa = 2,000 psi) times 0.1m, the bubble radius emitted by a large (chamber volume = 5,000 $in^3$) gun, or **200** psi. This simple picture is an overestimation, modified in practice by the finite time it takes for the ports to open, frictional losses as the air exits through the ports, etc. The modeled source pressure of a single gun with half this chamber volume is 0.35 Mpa @ 1m, or **50** psi (Duncan & Gavrilov, 2019).

Modeling and expressing the source pressure of an array as a peak pressure at 1m away is a virtual exercise, as the array is a distributed rather than a point source. Nevertheless, the practice in the industry is to measure received pressures far away and then use the model and the configuration of the specific array to project pressures into the near field, including the 'equivalent point source' at 1 m below the array (the direction of interest and the one experiencing the highest energy output). The 'equivalent point source' refers to an ideal point source that would produce the same acoustic field as the array at ranges much larger than its own dimensions. Applying such modeling, received pressures in the near field as well as the source pressure itself are overestimated by as much as 20 dB (Popper *et al*., 2014).

The risk assessment provided by the operators of the December 2018 - January 2019 survey off the coast of Israel was not meant to cover possible physical injury and rather modeled sound exposure level (SEL) values, cumulative SEL, hearing-range-weighted SEL, soft-start SELs, as regards potential hearing damage. The assessment was based on the PGS

Nucleus model, a very well established and tested array model, highly used in the industry. We should clarify at this point that the operators proved that they strictly adhered to all the guidelines set forward by the ministry of Energy regarding soft-start procedures, marine observers etc.

Acknowledging the fact that a turtle, let alone a host of turtles, should be extremely unlucky to be situated at the port of a firing airgun, we tried to estimate pressures further removed from the array. As stated above, the equivalent point source calculations treat the array as if all the guns were located at a single point. The spatial separation of the guns means that close to the array there is no point, even directly under the middle of it, at which the signals from all guns arrive simultaneously and calculated values in the near-field are over estimated. Not being given the degree of overestimation and the projected pressure values in the near-field, we applied numerical modeling results by Duncan (2016) who estimated near-field pressures below a 49.2 l (3,000 in$^3$) airgun array, towed 6m below the surface, accounting for the physical separation of individual guns. The array used off Israel during Dec 2018 – Jan 2019 was 3,260 in$^3$, deployed at 7 m depth, therefore the results are roughly applicable. Consulting Fig. 5 from that publication, uncorrected peak pressure below the array is maximal at 4m, which after correction for over-estimation gives a value of 222 db @1µPa or **18.3** psi. At the transition from the near-field to the far-field, estimated to occur at 14.5 m, the pressure would be **36.4** psi (the overestimation correction curve being steeper than the peak pressure curve) and at 20m below the array, **29** psi – **all being below the trauma threshold of 50 psi.**

Multiple exposures

When considering impulsive sound exposure effects on hearing, repeated exposures (e.g. consecutive hammer strikes during pile-driving) are accounted for in cumulative exposure values. For blast-generated tissue trauma, only single shocks are considered. If we, however, assume that the seismic pressure wave can potentially cause a blast-like trauma, one may argue for repeated airgun shots summing up to elevate a subclinical effect into the pathologic range. With the following values reported for the Israeli seismic survey:

Survey ship operating speed – 4.5 knots = 2.3 m/s

Length of array – 14 m

Inter-shot interval – 8.1 s

Turtle max swimming speed – 0.4 m/s (Houghton *et al*., 2002; Wilson *et al*., 2017)

The worst case would be for a turtle swimming horizontally under the array, at the riskiest depth, in the same direction as the ship. If it experiences an impulse when under the leading edge of the array, 8.1 seconds later the array has advanced 2.3 x 8.1 = 18.6 m and the turtle 0.4 x 8.1 = 3.2 m, which puts it 1.4 m behind the trailing edge, still in position to experience the almost full effect of a second impulse. When the third impulse is delivered, the turtle would be 16.8 m behind the trailing edge, probably out of trauma range. The turtle will be better off swimming in any other direction or maintaining position, whereupon it may escape a second exposure or be exposed to a lesser impact.

#### 4.6.3. Behavior relevant to the probability of a turtle being at a very close range to an airgun array.

Sea turtle's hearing range overlaps frequency bands in which a high percentage of the transmitted airgun energy is contained and even with its relatively low sensitivity, noise should potentially be heard from far enough to take an avoiding action. Theoretically, in an infinitely large ocean, with a hearing sensitivity threshold of 100 dB re 1 µPa, a source SPL of 256 dB re 1 µPa (as reported for the array employed off Israel) and a spherical-spread transmission loss of 6 dB per each doubling of the distance from the source, sound will be detectable $2^{25}$m away! Practically, McCauley *et al*. (2000) estimated that a typical airgun array operating in 100–120 m water depth could affect behavior at a distance of about 2 km and cause avoidance at around 1 km for sea turtles.

Experiments on enclosed captive animals show that sea turtles have a strong initial avoidance response to airgun arrays at a strength of 175 dB re 1 µPa rms or greater (O'Hara & Wilcox, 1990; Lenhardt, 1994; McCauley *et al*., 2000). Enclosed turtles also responded progressively less to successive airgun shots which may either indicate habituation or reduced hearing sensitivity (TTS). One turtle did experience a TTS of 15 dB, recovering two weeks later (Lenhardt, 1994). DeRuiter & Doukara (2010) found that 51% of turtles dived at or before their closest point of approach to an operating airgun array **but** point out that it was uncertain whether this is a response to a visual or to acoustic outputs.

#### 4.6.4. Utilization of the water column

Like most breath-holding vertebrates, except for periods of migration/travel, turtles move through the space predominantly vertically. Females tagged with time/temperature/light/depth recorders during the inter-nesting periods show that at shallow shelf locations, the bottom would be the preferred stratum, both for foraging and for conserving energy by resting (Houghton *et al*., 2002), the water surface would then be used for inter-dive ventilation and occasionally for basking (Wilson *et al*., 2017). Resting in mid water has also been recorded, with turtles achieving neutral buoyancy at given depths by adjusting pre-dive lung volume (Minamikawa *et al*., 2000). Near-shore, between site, traveling involves very shallow and short-duration diving with frequent surface ventilation (Houghton *et al*., 2002).

#### 4.6.5. Potential vulnerability of turtles to a mobile impulsive sound source

1. Source localization may be problematic (see section on hearing).
2. Sight could help but is useless at night.
3. Being a slow swimmer, it may opt to dive rather than horizontally clear the course of the ship's approach, which may prove disadvantageous or even more risky.
4. Finally, its detectability to onboard observers is very low due to its very low above-water relief and its prolonged diving times relative to surface intervals (dependent on temperature, very pronounced in winter). Its detectability by passive acoustic monitoring is practically nil.

#### 4.6.6. Relevance to the 2018-19 winter event.

A point to consider in this regard is the presence of turtles during winter in deep water. Evidence suggests that when surface temperatures fall below $15^0$C, turtles adopt a strategy of hypoactivity, spending most of the time on the bottom (several hours at a time), only moving up to breath (Houghton *et al*., 2002). Such a behavior is not relevant to the 2018-19 winter survey site, which was in over a 1000 m ultra-deep water. However, Hochscheid *et al*. (2007) have shown that winter dormancy is optional and that turtles in winter may be active at temperatures lower than $15^0$C, spend time in deep water, while performing long (up to several hours) dives to >20 m and rest and/or forage in mid-water.

Considering turtle density, the combined transect length, including soft-start of the aforementioned survey was 950 km. Assuming an exaggerated injurious strip of 100m width along the ship's course, we arrive at an area of 95 $km^2$, which, going by the Adriatic density value of 0.8 ind/$km^2$, would include 75 animals.

### 4.7. Active sonar

#### 4.7.1. General

Active sonars are roughly divided into three categories according to their dominant frequency of operation; low frequency (LFAS) ≤1 kHz, mid frequency (MFAS) 1 kHz -10 kHz and high frequency (HFAS) ≥10 kHz. Low, and less so mid, frequency sonars are the most relevant in regard to potentially injurious effects, based on their energy outputs. Sonar is not as pulsed as airgun or pile driving sound. It usually operates with duty cycles (transmission time % of total time) of 10 -20% and individual signal (ping)durations up to 10s, which may be considerably prolonged by multipath propagation, often substantial for many of these systems. Navies use mainly LFAS, designed for long-range detection of submarines, consisting of multi-element vertical line arrays. The U.S. Navy SURTASS-LFAS system deploys 18 transmitters, operating between 100 and 500 Hz. Projected signals include combinations of frequency-modulated and tonal pulses, with intervals between transmissions varying between 6 and 15 minutes. Individual transmitters produce sound with a source level of approximately 215 dB re 1µPa @ 1 meter. The combined system has an effective source level of 230- 240 dB re 1µPa (**46-145** psi) @ 1 meter (Friedman, 2006), potentially injurious at close range, going by the 50 psi injury threshold.

#### 4.7.2. Injurious effects of sonar

Injuries associated with sonar are almost exclusively known from deep-diving cetaceans, mostly beaked whales (Ziphiidae). Autopsied individuals from a post-sonar deployment in the Bahamas showed rather mild unilateral blood deposits within the inner ear and hemorrhaging in the fluid of the auditory canal and the subarachnoid space over the temporal (hearing) lobe. Necropsies of individuals in the Canary Islands, showed, in addition to similar hemorrhage sites, widely disseminated intravascular bubbles in blood vessels and tissues (see review in Ketten, 2014). There is no data on sonar effects on turtles. Popper *et al*. (2014) conclude that risk of mortality and potential mortal injuries is low even at close distances to the source (see Table 8 in *Appendix VI*). Safe exposure limits for marine mammals are provided by NATO (2018) (Table 9in *Appendix VI*).

#### 4.7.3. Relevance to the 2018-19 winter die-off event

The Israeli Navy deploys LFAS, mostly during trilateral maneuvers with the Hellenic and US Navies, termed ‘Noble Dina’. The latest one, Nobel Dina-2019 was April 2019, but such deployment during January 2019 is unknown.

### 4.8. Lightning strikes

Lightning striking the water surface creates a shock wave and can potentially cause blast injury at close quarters. Hill (1985) proposed that a blow-off process at the foot of a cloud-to-water lightning channel, imparts a shock pressure to the water surface. It was estimated that a shock of approximately 100 atm can develop within a few tens of microseconds. Such a shock would be similar to the explosion of a fraction of a pound of TNT at 1 yard. The intensity of the blow-off source was estimated by Hill to be 260.5 dB.

Hill then, with some assumptions, progresses to calculate the transmission loss of the sound component at the distance that Arnold *et al*. (1984) estimated from where the lightning struck the sea surface in the Gulf of Mexico to the point of reception, arriving at values that were in agreement with the actual hydrophone-measured value reported by the authors.

Using again the **50 psi** threshold and solving equation (1) for 0.1 kg charge (our interpretation for Hill's (1985) 'a fraction of a pound'), we get a safe distance of **39.6** m.

Relevance to the 2018-19 winter die-off event

Density-wise (0.8 individuals/km$^2$), with a presumed injurious radius of 40 m, a minimum of 5,000 lightning strikes are needed to account for 20 injured turtles. As can be seen in a more detailed analysis in section 5.5 below, that striking rate can be a daily ration. The strongest objection for lightning being the major cause is the fact that the striking rate during the winter of 2018-19 was not exceptional to a degree that would explain zero or single injury events during previous winters.

# 5. *Detailed analysis of the turtle die-off event*

In this part, we focused our attention on the turtles that were diagnosed with soft tissue trauma (STT) to the lungs and\or inner ear.

## 5.1. Presentation of the stranding along the coastline

*Sea turtles were washed to shore all along the coast of Israel, from the border with Gaza in the south up to Rosh Hanikra in the north (Israel-Lebanon Border) (*

Figure 3). Live turtles that were diagnosed with STT followed the same spatial and temporal distribution along the shore (Figure 17) north up to Atlit (south of Haifa). These turtles locations (Table 7) were used as starting points for the backwards simulation in the oceanographic model described later in subchapter 5.4.Most of the adult turtles were females (13 females, 3 males and the rest were juveniles of undetermined sex) (Table 2).

*Table 7. Dates of turtles collected from shore with their locations. App=approximate location; Acc=Accurate location.*

| Name | Dates | | Location | | |
|---|---|---|---|---|---|
| | Arrival | Death | ITM-LONG | ITM-LAT | location accuracy |
| **Tamir** | 4/1/19 | | 193108.093 | 727191.819 | App |
| **Efrati** | 7/1/19 | 2/2/19 | 189947 | 711744 | App |
| **Lotem** | 8/1/19 | | 193411.5131 | 728793.3 | Acc |
| **Shimona** | 9/1/19 | | 178118.1223 | 664982.406 | Acc |
| **Liron** | 9/1/19 | 12/1/19 | 176120.8066 | 660644.646 | Acc |
| **Mor** | 9/1/19 | | 189430 | 708857 | App |
| **Zvia** | 9/1/19 | 11/1/19 | 191551.7354 | 706771.291 | App |
| **Itzik** | 9/1/19 | | 192819.6046 | 725348.217 | App |
| **Dud** | 9/1/19 | 18/1/19 | 183813.0461 | 684174.525 | Acc |
| **Victoria** | 10/1/19 | | 190004.3891 | 711104.352 | Acc |
| **Nus** | 10/1/19 | | 193493.2408 | 729229.92 | Acc |
| **Moris** | 11/1/19 | | 192559 | 723304 | App |
| **Shahar** | 14/1/19 | | 172384.1527 | 649641.744 | Acc |
| **Danilo** | 14/1/19 | | 173846 | 653474 | App |
| **Oren** | 17/1/19 | | 193522.9011 | 729956.348 | Acc |
| **Boneh** | 17/1/19 | | 193411 | 728793 | App |
| **Harela** | 17/1/19 | | 184436.10 | 686919.20 | Acc |
| **Jacob** | 18/1/19 | | 164292 | 632263 | App |
| **Nuris** | 29/1/19 | | 174955.5305 | 656940.26 | Acc |
| **Kobi** | 31/1/19 | | 164858 | 637437 | App |
| **Milka** | 15/2/19 | 1/3/19 | 165773 | 635425 | App |
| **Adama** | 23/2/19 | | 160125.4589 | 634291.415 | Acc |
| **Kfir** | 10/3/19 | | 181264.2798 | 688734.601 | Acc |
| **Moshe** | 11/3/19 | | 180841 | 673814 | App |

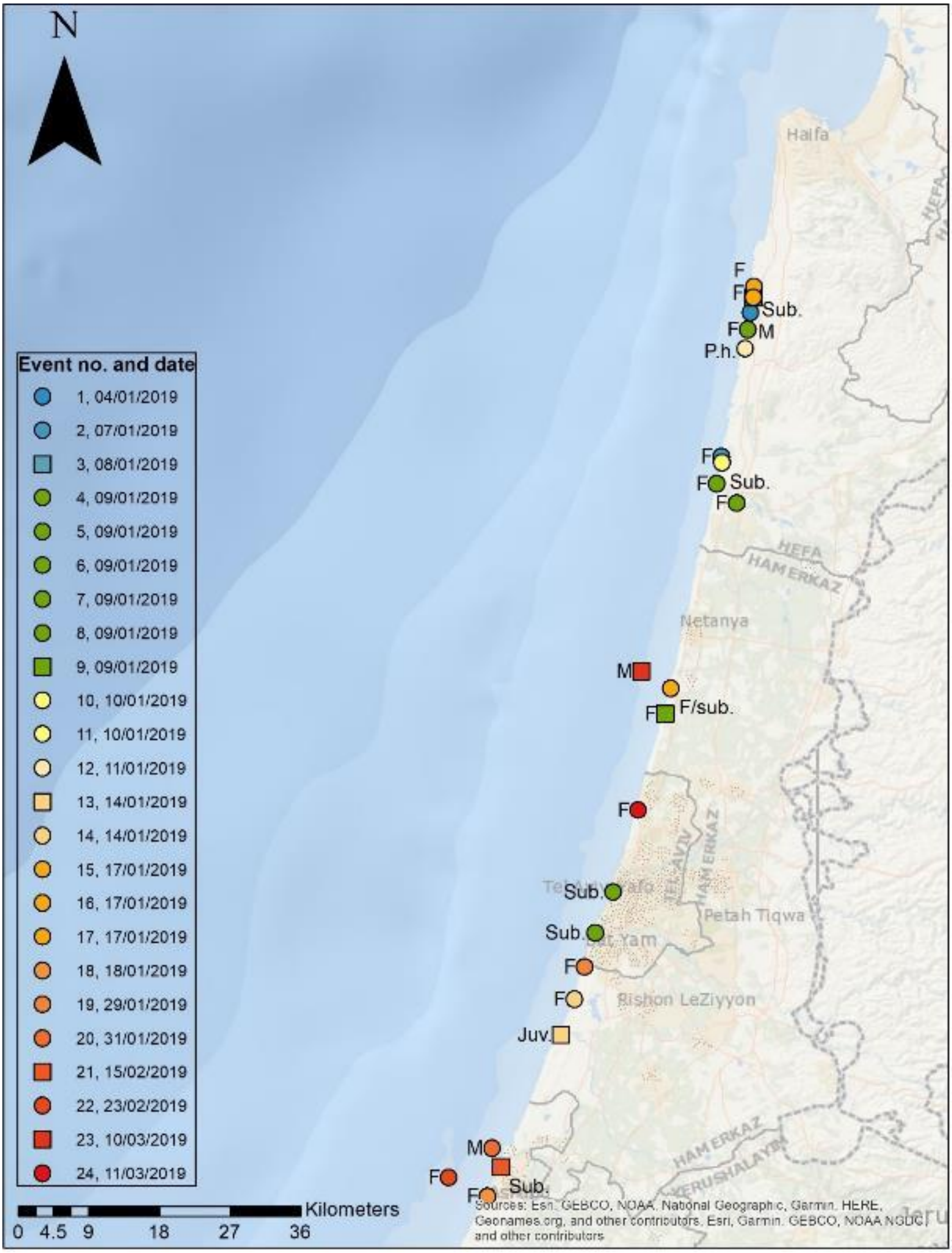



*Figure 17. Spatial and temporal distribution of stranded sea turtles diagnosed with STT. Circles are C. caretta and squares are C. mydas. F=female; M=male; sub.=sub adult; P.h.=post hatchling.*

## 5.2. Turtle stranding vs. Sea & weather conditions & seismic survey timing

All stranding times in the 2018-19 winter were examined against maximum daily wave height as measured by IOLR in the Ashqelon monitoring station, wind speed as measured by the Israeli Meteorological Service station in Ashqelon, and the seismic survey times which was conducted in the Israeli EZZ as reported from the survey logs.

There is circumstantial relationship between the seismic survey times and the stranding times (שגיאה! ארגומנט בורר לא ידוע.). It seems that the first survey preceded the peak of stranded sea turtles, and the spike of stranded turtles suffering from blast-like injuries. Additional circumstantial relationship exists between some stranding peaks and peaks in weather conditions (wind speed and wave height). Increased wind speed and higher wave height could explain why so many individuals were discovered on land.

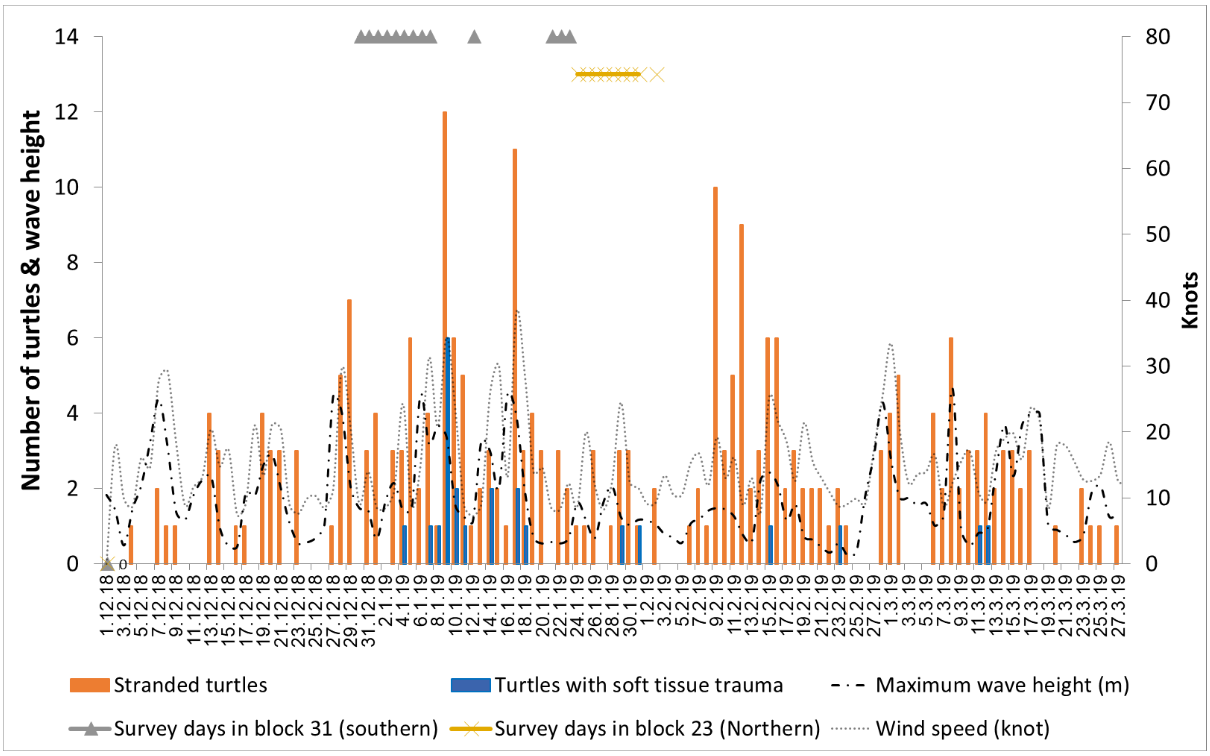



*Figure 18.* Stranding events during 2018-19 winter along the Israeli coastline versus weather conditions, waves, currents and survey timing.

### 5.3. Simulation of drifting turtles from the 2019 survey location

Although it seems that the airguns used in the December-January seismic survey are not the likely cause of the observed STT injuries, it was decided, nonetheless, to simulate drift paths of injured turtles from the survey location and to examine if the survey location could have been a source location for the stranded sea turtles. The simulation was based on the assumption that subsequently to an impact, a turtle is catatonic and assumed to be a passive floating object, lacking the capability for self-propulsion.

Forward trajectories from the entire area of the seismic survey were carried out with trajectories starting at the start, middle and end of the seismic survey period (29-12-2018, 02-01-2019, 06-01-2019) most relevant to the stranding events. The oceanic model that was used is described in the next section (5.4).

The simulation indicates that the main flow is to the north-northeast, parallel to shore (Figures 20-22), and thus affected and drifted sea turtles would most likely never reach the coast of Israel. Although the wind impact is not taken into account in the model, the strong southerlies and westerlies winds which prevailed during the stranding event firstly propel the turtles north (with the currents) and only later east, and the stranding would have occurred on beaches in Lebanon.

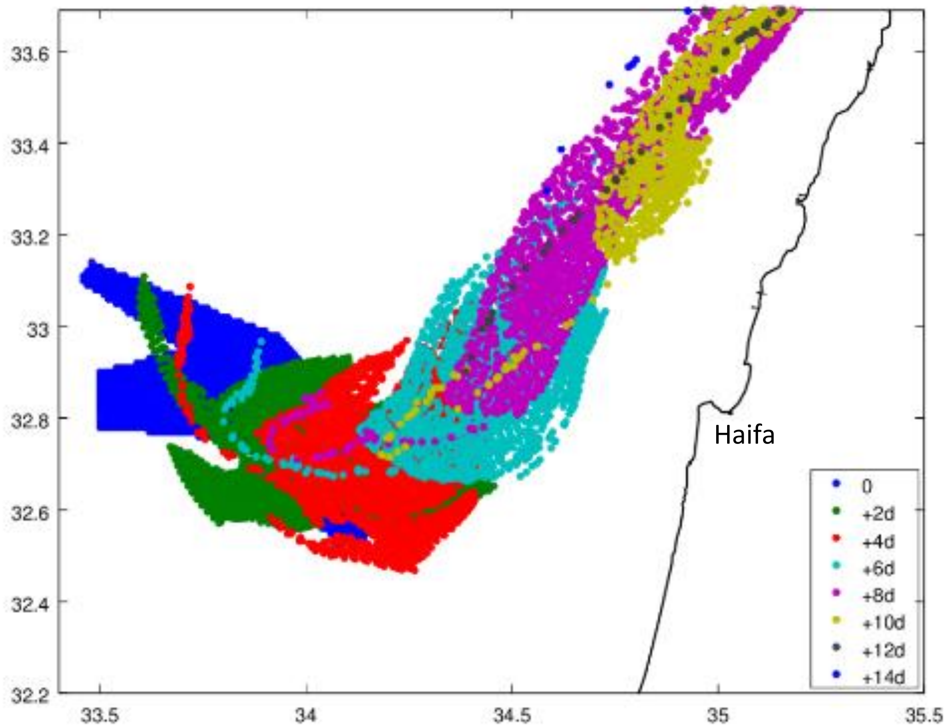



*Figure 19. Simulation of drifted turtles from the whole survey area day by day, starting from 29/12/2018*

*Figure 20. Simulation of drifted turtles from the whole survey area day by day, starting from 02/01/2019.Each degree longitude is about 90 km and each Latitude is about 110 km.*

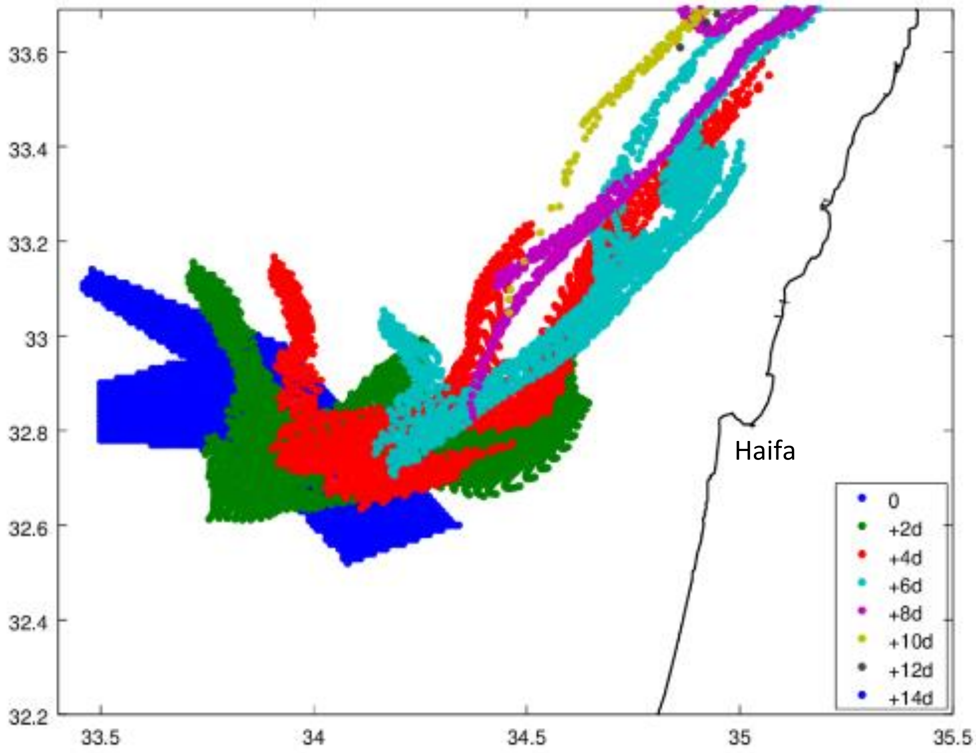
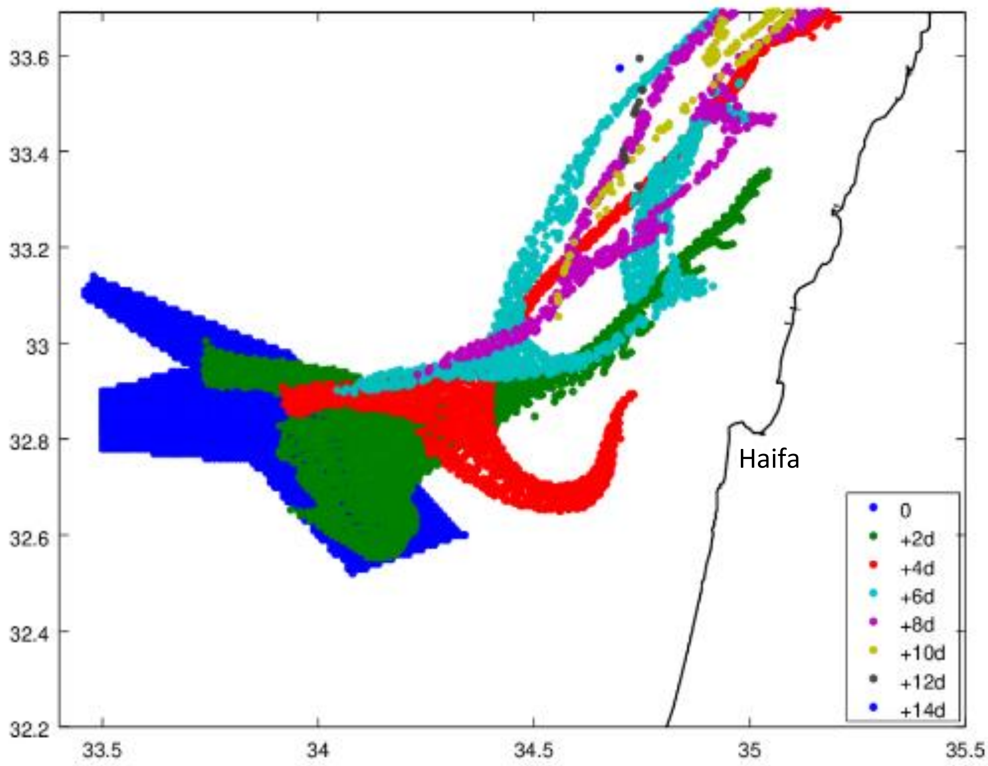



*Figure 21. Simulation of drifted turtles from the whole survey area day by day, starting from 06/01/2019. Each degree longitude is about 90 km and each Latitude is about 110 km.*




## 5.4. Reverse simulation of individual turtles from their stranding points

In order to get a better understanding of the turtles' path until stranding, regardless of the actual injury agent, a simulation was conducted backward in time from the stranding sites on shore to the sea (Figure 22, more examples are in *Appendix IV*). The simulation addressed those turtles presenting with STT. Again, the assumption was that the injured turtles are drifting passively.

Drift back trajectories simulations of wounded turtles along the coast were integrated numerically backward in time from an approximate location of their beaching. The flow fields that were used to create the trajectories were sea currents at 5m depth taken from daily hindcasts[1] of the Southeastern Levantine Israeli prediction system (SELIPS) (Goldman *et al*, 2015). SELIPS is an operational forecasting system based on POM, with horizontal resolution of about 1 km. The output was given as 3-hour averages of the velocity components. SELIPS is one way nested in ALERMO ocean forecast system (Korres *et al*., 2002) and forced with the SKIRON atmospheric forecasts (Kallos *et al.*, 1997; Kostopoulos *et al*., 2016). The lateral boundaries of the model are at 31.5E and 33.7N. Because the model does not take into account wave induced currents, and since the model imposes boundary conditions of zero velocity at the coast, the starting point of the backward trajectories was taken a few kilometers offshore from the actual beach location. The uncertainty of the beaching time was represented by running 3 simulations for each turtle going backwards in time from 00:00 GMT and 12:00 GMT of the beaching date, as well as from 12:00 GMT of the day before beaching.

Our modeling setup uses a simplified drifting model that accounts for the surface currents only (upper 5 m). The model simulates the drifting of injured turtles and assumes that they remain at the surface layer, thus neglecting buoyancy variations. Moreover, the spatial resolution of the circulation model is relatively coarse (1 km) and probably not sufficient to simulate drifting close to the coastal region. Nevertheless, we believe that the model resolution is sufficient to resolve drifting at the open sea. In this simulation, the wind impact, which is not taken into account, would cause the simulated trajectories to be biased toward the east and north because of neglecting the strong southerlies and westerlies winds which prevailed during the beaching event. A more sophisticated drifting model and a finer circulation model resolution will probably improve our results, yet their development was out of scope of the present report.

[1]A statistical calculation determining probable past conditions.

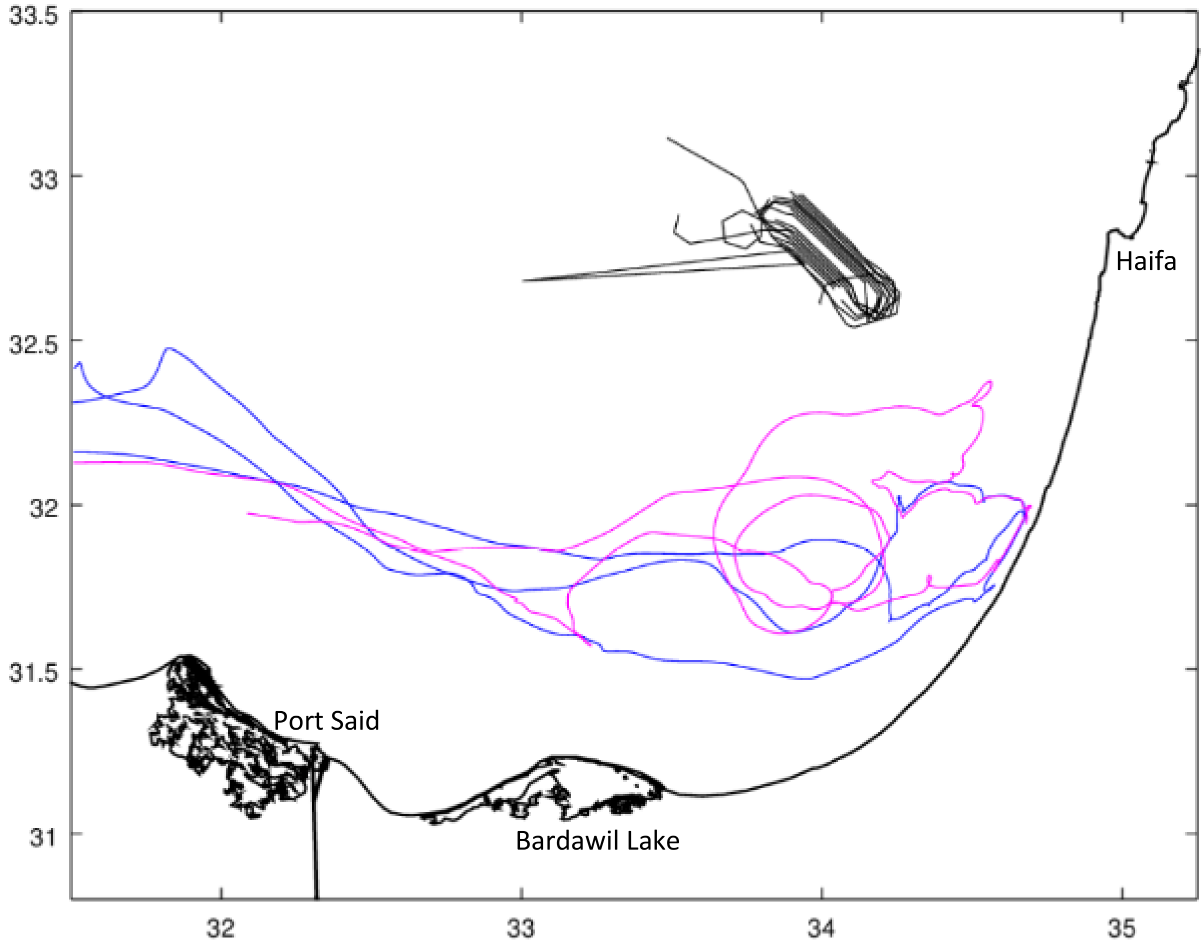



*Figure 22. Drifting path from the coast of two turtles that were stranded wuth STT in 14/01/2019.The survey lines are marked in black. Each degree longitude is about 90 km and each degree latitude is about 110 km.*

Two general hypotheses maybe tested by the simulation. The first involves injury from a single source, in a specific place and time, on a turtle aggregation (e.g. detonation of a large charge). The second hypothesis involves scattered sources, temporal and spatial, affecting single individuals (e.g. lightning strikes).

In order to examine both hypotheses, the locations of all turtles were tracked each day backwards in time aiming to find an aggregation through a spatio-temporal convergence of individual turtle paths – thus supporting the first hypothesis, or to support the second one if such aggregation will not be found.

A possible area and time through which most trajectories (except STT stranding on the 4$^{th}$, 18$^{th}$, 29$^{th}$ and 31$^{st}$) pass is the north-west area of the eddy that circles around roughly 32$^{0}$N and 34$^{0}$E, between December 30$^{th}$ and January 1$^{st}$ (Figure 23, Figure 1). The Lagrangian motion in the eddy system is chaotic, i.e., small changes in the time and place within the eddy or at the entry to the eddy relate to larger changes on time and place of departure from it. Therefore if a single event is the cause of all turtle injuries, there is a great uncertainty about its time and position within the eddy or somewhere upstream of it. Figures for other days appear in

*Appendix V*.

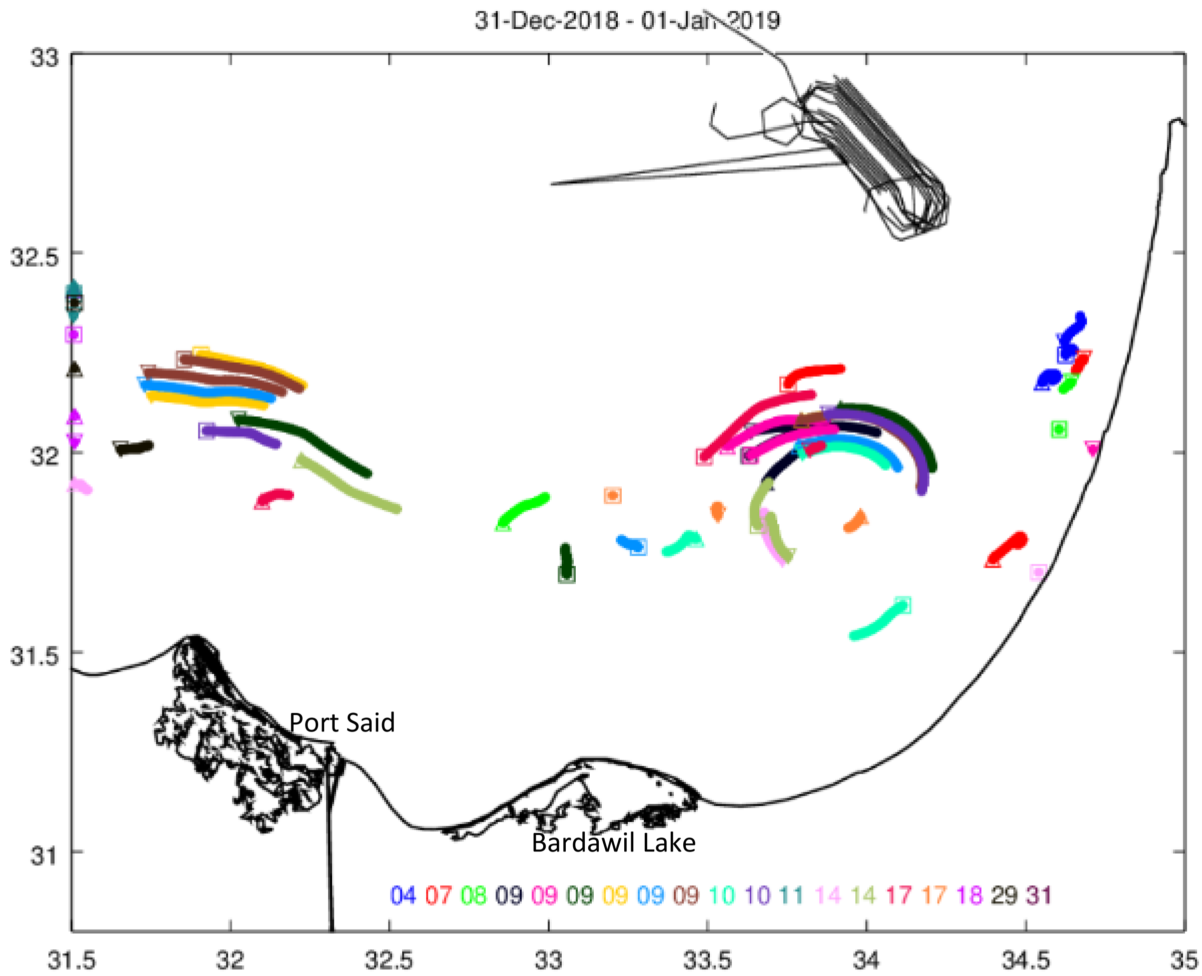



*Figure 23. Backward simuation of turtles from their stranding location on the shore. This figure depicts turtles in the 24 hours between 31/12/18-01/01/19. Each color represents one turtle. For each turtle we defined 3 starting hours for the model, hence the 3 different paths marked as rectangle and two forms of triangles. Colored numbers on the bottom depict each turtle and its stranding day on January 2019. The survey lines are marked in black to the north of the turtles' trajectories. Each degree longitude is about 90 km and each Latitude is about 110 km.*

## 5.5 Analysis of turtle stranding along the Israeli coastline versus lightning strikes

Lightning strikes are an attractive prime candidate to be a spatio-temporally scattered injury source. To test the hypothesis that the sea turtles may have been hit by lightning, we gathered lightning data from the relevant dates of winter 2018-19 as well as data from previous years, trying to correlate lightning events to STT in sea turtle from winters 2014-15 and 2012-13.

Lightning data were collected for the area between 31.18° South, 34.3° North, 34.99° East and 29.8° West. We used the lightning data depository WWLLN (http://wwlln.net/) with the help of Prof. Colin Price from The Porter School of the Environment and Earth Sciences, Tel Aviv University. The WWLLN is a global lightning detection network around the Earth (Virts *et al*., 2013). The electromagnetic radiations emitted by lightning strikes at very low frequency (VLF) and called 'sferics' are detected by the sensors of the WWLLN. These clouds to ground (CG) strikes are then localized by using the time of group arrival (TOGA) technique (Kasereka *et al*. 2018). Within this subset of lightning strikes, the network only detects lightning with high peak currents (large signals) since at least four stations need to detect the same lightning to locate it. Therefore, the system detects only about 10% of the total lightning coming to the oceans and about 30% in areas with good sensor coverage (C. Price, personal com.).Thus, the presented strikes are a gross underestimation of the actual lightning strikes. The location accuracy is better than 10 km.

Looking at the per day lightning strikes and stranding rates of turtles with STT during the 2018/19 winter event (Figure 24), we can see that significant peaks of lightning strikes preceded the STT spike by a few days.

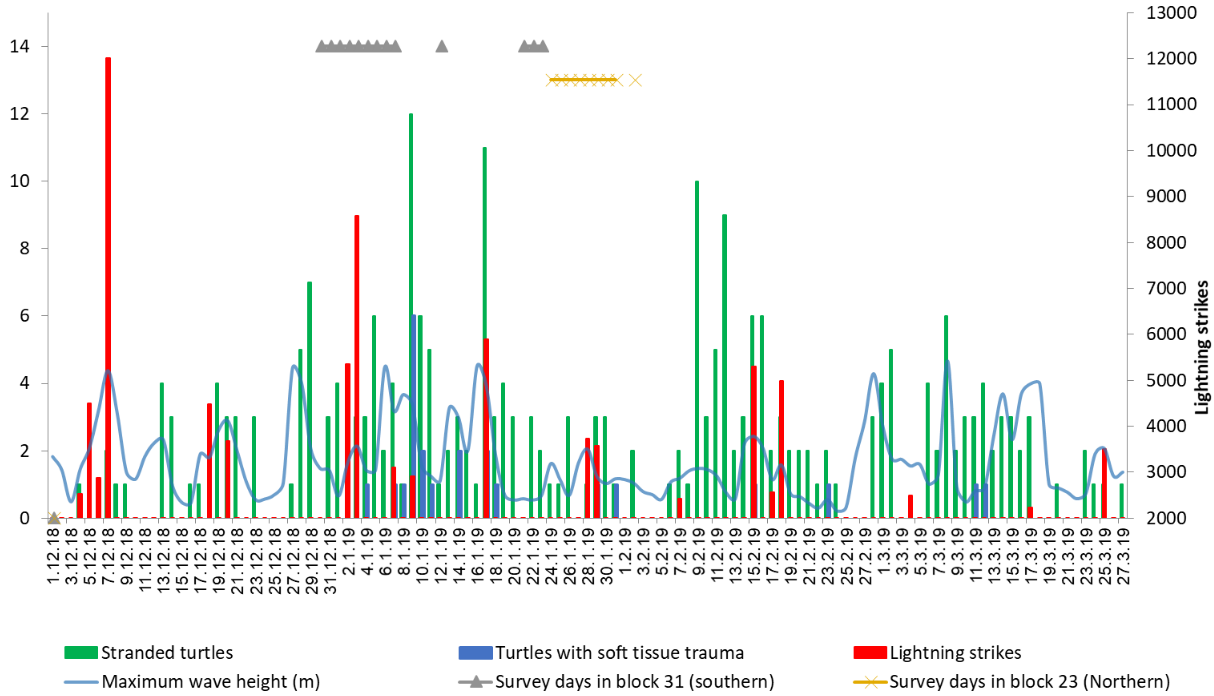



*Figure 24. Number of lightning strikes in comparison with numbers of sea turtles and injured sea turtles.*

The lightning database reveals exceptional winters in 2015-16 and 2018-19. However, not in 2012-13, when a few blast-injured sea turtles were stranded (Figure 25). In 2018-19 most strikes were during November, but substantial amounts were also measured during the following months (Figure 25).

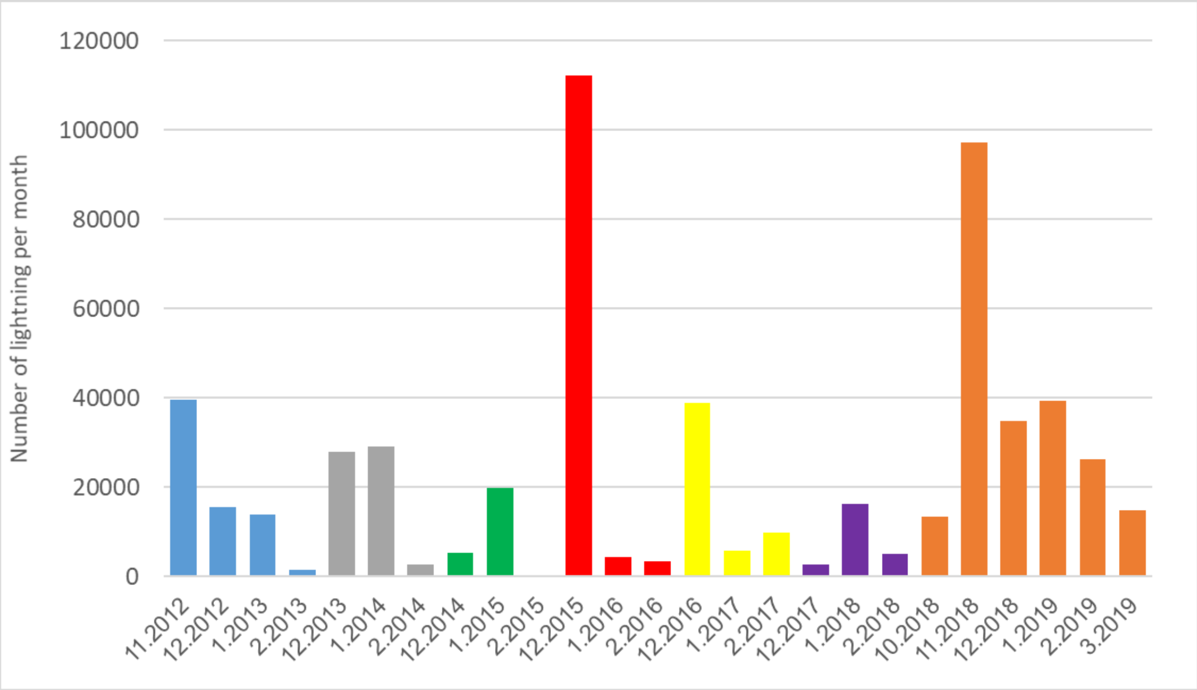



*Figure 25. Total number of lightning strikes per winter months (Dec-Feb in most years and in more details during 2018-19 winter. Missing months may also include lightning strikes).*

In order for lightning strikes to be a factor in the explanation of the die-off event, a significant amount of strikes should hit an area with significant numbers of sea turtles, either during a single extensive storm affecting a wide area, or else, as multiple more modest discrete storms over a time range prior to the event but at a given more restricted location through which turtles pass (corridor). We examined the per day spatial distribution of lightning strikes during December 2018 and January 2019 and cross-examined days with more than 5000 strikes (Figure 24) with possible turtles locations as predicted by the oceanographic simulation model (

*Appendix V*). We searched for evidence of such an exceptional storm hitting a large number of turtles in areas depicted by the oceanographic model to the south and west of the examined area.

During early December and a few weeks prior to the first stranding of the season, there was a significant lightning storm over the whole area of interest (Figure 26). Although this event occurred a month prior to the stranding peak of the blast-injured turtles, we cannot rule it out completely as a source for the injuries. Unfortunately, the backwards simulations of the STT stranded turtles cannot show us their locations that far back in time, as the turtles exit the designated area by two weeks of backward simulation, that being the delimitation of the model (Figure 28).

On January 2nd there was another significant storm with over 8500 strikes (Figure 27). Most of these strikes were northward of the stranding locations and do not fit well with the oceanographic model.

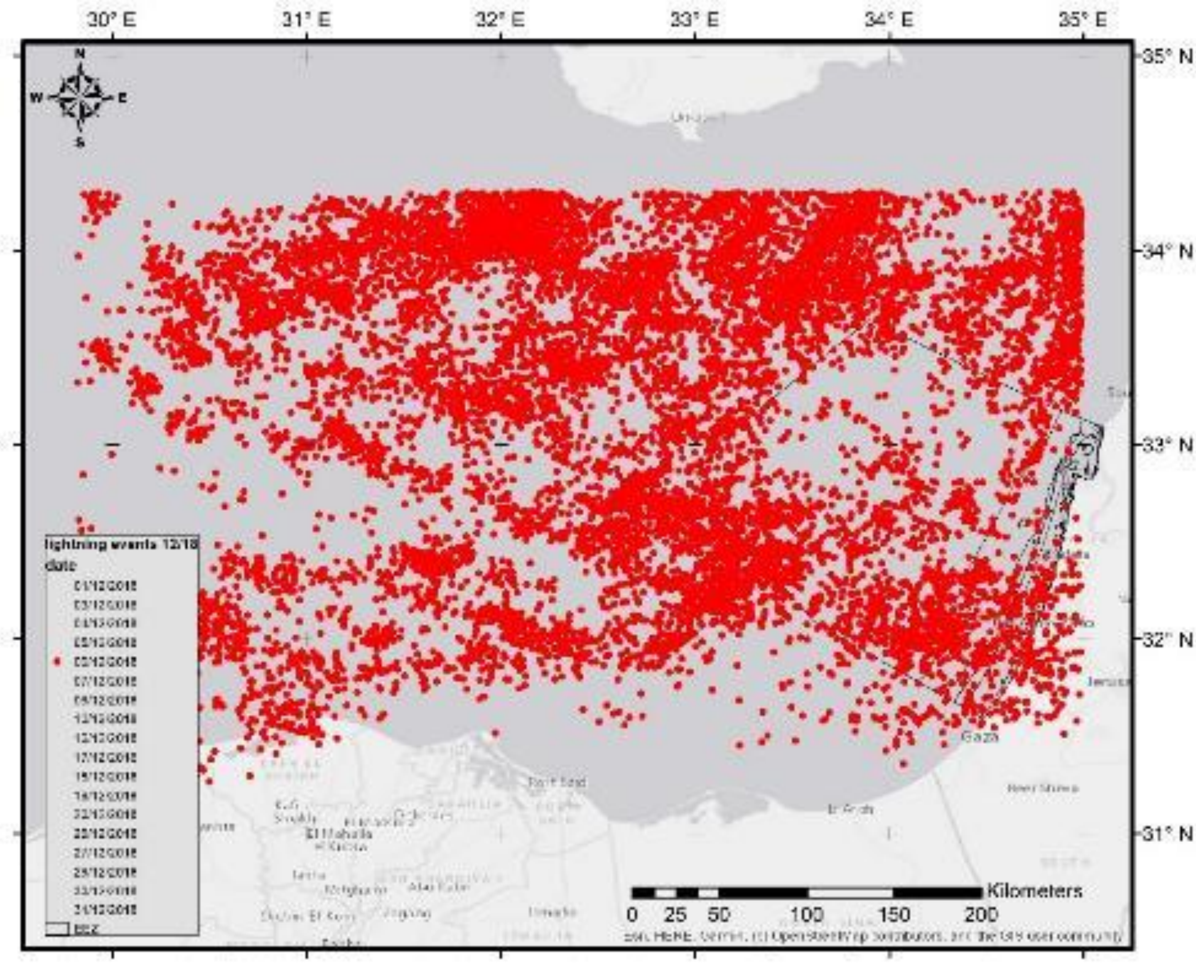



*Figure 26. Lightning strikes on December 6th 2018. over 12,000 strikes were recorded by the WWLNN in the designated area.*

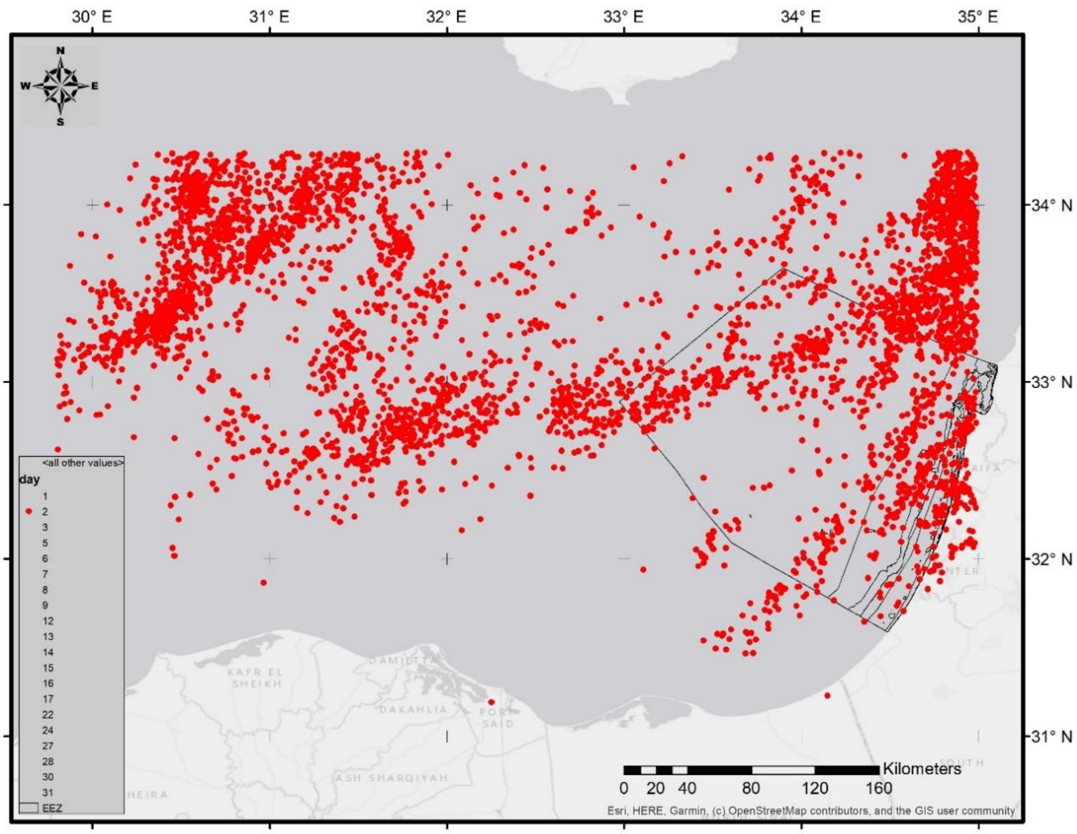



*Figure 27. Lightning strikes on January 2nd 2019. Over 8500 strikes were recorded by the WWLNN in the designated area.*

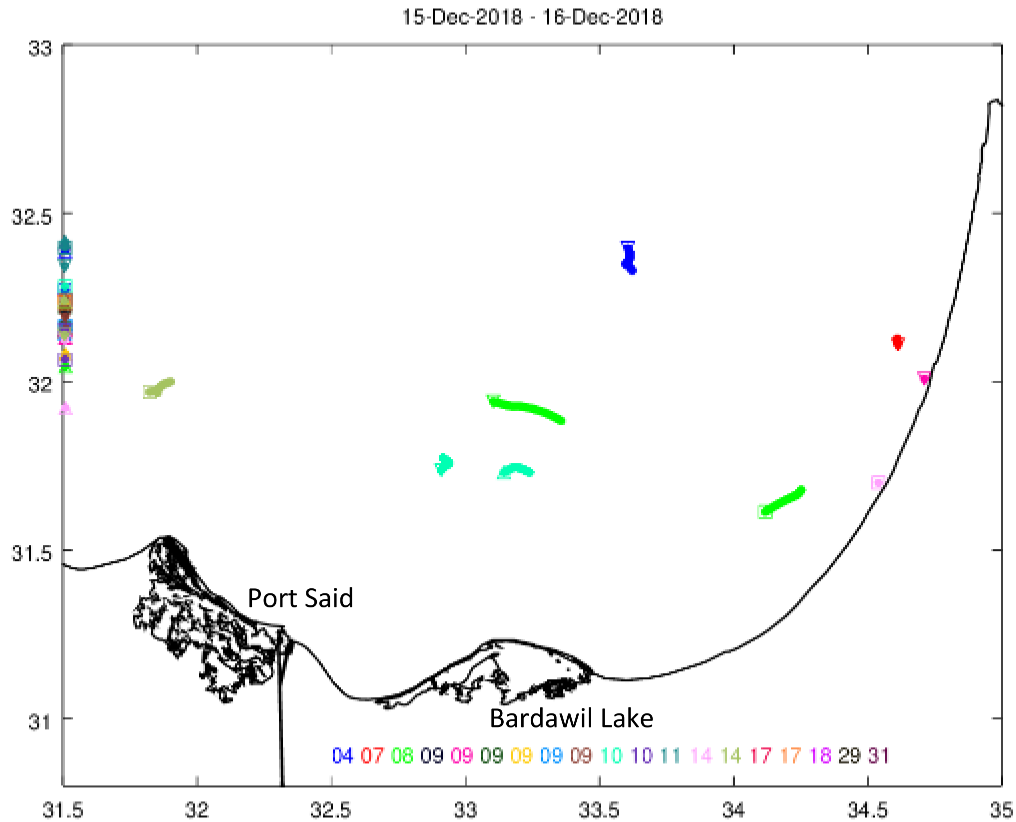



*Figure 28. Results of the backward simulation of the oceanographic model from 15-16th of December 2018. At this date, most of the sea turtles did not enter the model area yet. Each longitude degree is about 90 km and each Latitude is about 110 km.*

Concerning the scenario of multiple discrete strikes/storms hitting a corridor through which turtles traveled over a period of time prior to the stranding event, a glance at Figure 30 (which is also the first figure of *Appendix IV*) reveals an area (at roughly 32.3$^0$ E, between 31.8$^0$& 32.3$^0$ N) where all drifting paths converge into a prevailing eastward current. The south-north extent may even be more restricted if the reverse simulation could be refined. Such a current, by reducing the energy demands of swimming to the coast of Israel, could indeed serve as a preferred corridor for turtles traveling in that direction. If lightning storms (or for that matter other potential injurious sources such as explosives) occurred prior to the stranding (with a time delay for the animals to drift to the final stranding points), this could help explain how discrete events over time but in the same location could cause the distribution of stranding over a larger area.

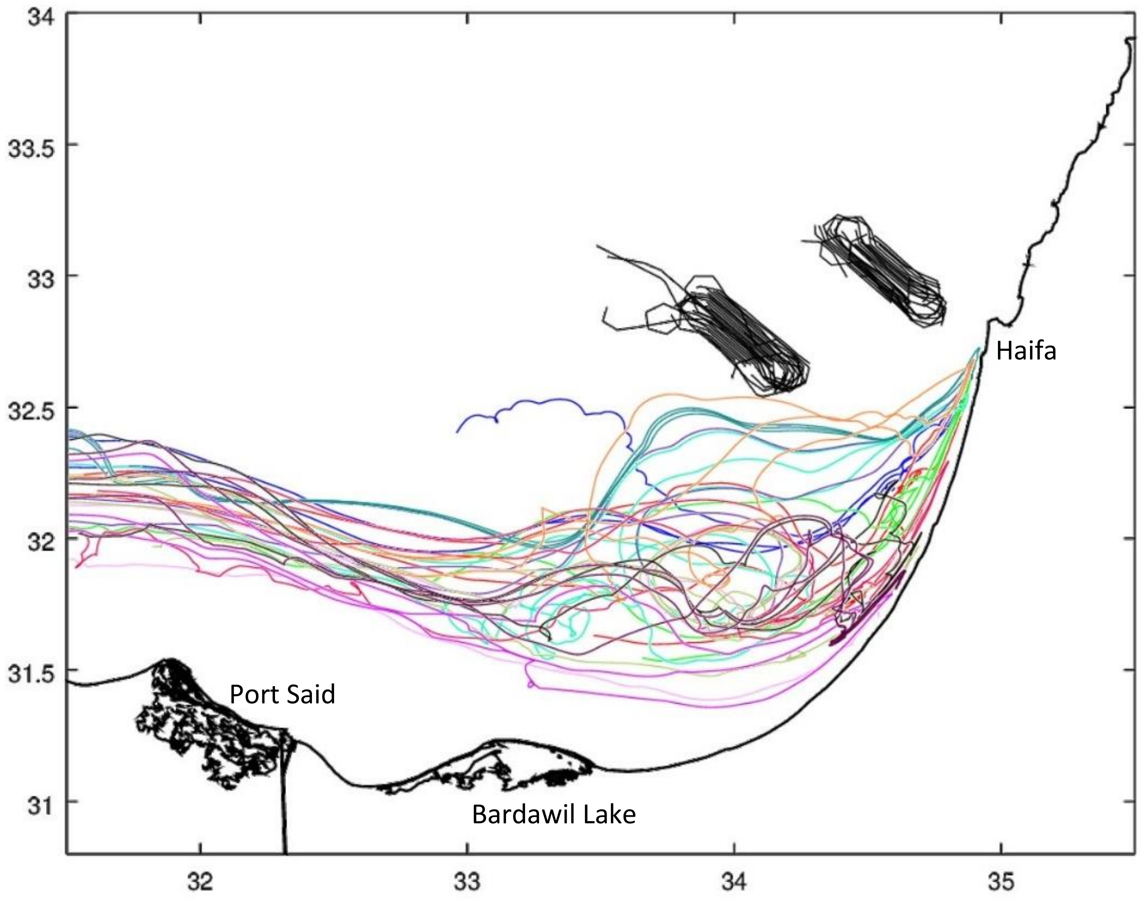



*Figure 29*. Backward flowing paths of 19 turtles that were stranded with STT on January 2019. Three possible paths per turtle are shown, with dependence of stranding time. The seismic survey lines are marked in black. *Each longitude degree is about 90 km and each Latitude is about 110 km.*

# 6. *Multi-year analysis of sea turtle stranding events with regard to seismic surveys and lightning strikes*

When studying the temporal relation between STT events and seismic surveys during the last 7 years (Figure 30), it becomes apparent that while both the 2018-19 and the 2012 seismic surveys respectively coincide with and precede STT events, the injury event of 2015 is not associated with surveys, and the 2013-14 survey is not associated with any diagnosed STT stranding event (though it could have been undetected.) Therefore a straightforward temporal relationship between the two cannot be established.

Concerning lightning strikes, no clear correlation between the total monthly number of strikes and STT events is evident (Figure 30). However, as postulated above (section 5.5), the location of lightning strikes may play a more important role than their sheer amount and a spatial correlation between a lightning storm and turtle route or aggregation may be a factor of importance.

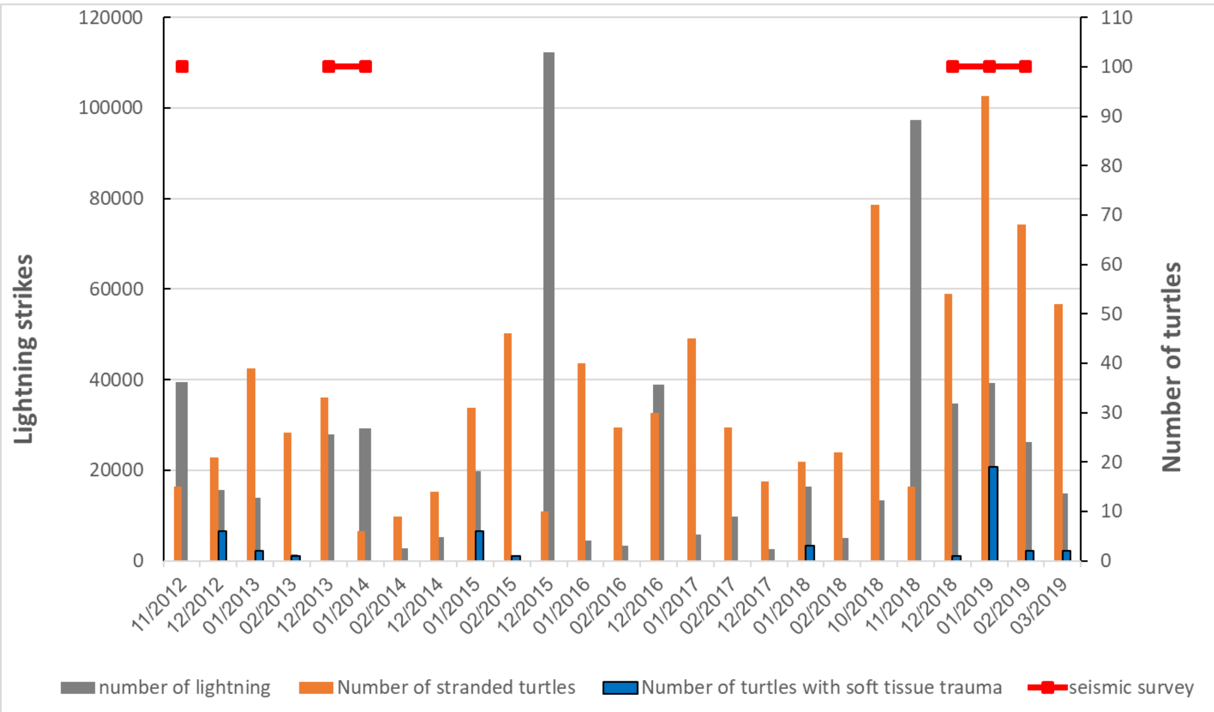



*Figure 30.The per month number of live injured sea turtles diagnosed with STT between 2012-2019 with the number of lightning strikes in the south-eastern Mediterranean (lightning number was taken from Figure 25.*

# 7. *Discussion & Conclusions*

## 7.1. Summary of the likelihood of the potential candidates being the cause of the 2018-19 winter turtle stranding event

The bottom line is that after a thorough consideration, we cannot tie the turtle mortality event in a definitive manner to any of the considered potential causes. As an overall consideration:

- The climatic conditions of the 2018-19 winter were not unusual.
- While we do not have enough information on winter distribution of turtles in the region (very few instrumented animals), we also have no reason to suspect an atypical distribution in this particular winter. What we have learned the hard way is, that the substantial number of mature animals of both species present offshore in Israel during this particular winter, possibly in aggregations, may very well be the norm at that time of the year.
- From the two points noted above, it follows that conditions exist at any given winter for such an event to occur, following an as yet undefined energy input. One should however keep in mind that the same harmful agent (lightning storm excluded) occurring during other seasons may leave turtles dying at sea without bringing (all of) them to our attention.
- Could more than one cause be responsible? While it is possible that several coinciding causes were involved, the similarity of the pathology and parsimony would favor a single cause.

Regarding the list of potential causes that we investigated, they sorted below in an ascending order of likelihood:

1. From our analysis, the concurrent seismic surveys seem to be the least likely cause. The temporal association between the 2018-19 STT event and the lesser 2012 event with seismic surveys was suggestive, but this association did not necessarily prevail in other years. Seismic surveys were generally shown to be incapable of causing blast-like injuries and even if one or two individuals were unfortunate enough to find themselves at very close proximity to a single large operating gun and be afflicted with STT, the oceanographic simulation predicts that they would not have reached the Israeli shore.
2. Low frequency active SONAR would also seem unlikely considering the number of affected animals and the fact that blast-like pathology was never observed in lethal cases of marine mammals. Civilian mid and high frequency active SONAR

could theoretically resonate and injure gas filled cavities in turtles, a possibility worthy of systematic research.

3. Lightning storms – Although the winter of 2018-19 was not exceptional in lightning strike intensity, and although STT stranding events were even more loosely associated with severe storms, there may have been a unique spatial merger of turtles' presence, less imposing lightning storms and currents regime that was responsible for both the injury and stranding pattern, as detailed at the end of section 5.5. Subsequently to this analysis, we consider lightning as a contender for being the cause of the event, which should be given serious consideration when attempting to determine causality in future turtle STT events.
4. Blast – is the most likely explanation for the observed pathology. The lack of information on concurrent military or fishery activity involving detonations precludes the establishment of a definitive cause and effect relationship. Unlike seismic airguns and SONAR which are moving sources that could cover and impact large areas and unlike lightning storms that may consist of thousands of strikes, detonations are fixed single point sources. As to the question of single or multiple blast sources being responsible, the oceanographic model results were rather equivocal in this respect. As shown at the end of section 4.4, even a very large charge would not account for the numbers affected in the stranding event, barring aggregation.

### 7.2. Recommendations for immediate changes in seismic surveys policy

1. Timely alert of INPA and MoEP about every planned seismic survey.
2. An addition of a requirement in the Israel 'Environmental Guidelines for Conducting Offshore Seismic Surveys' to conduct an environmental (marine mammals, sea turtles, fish, cephalopods and other invertebrates) risk assessment as part of a seismic survey plan. The risk assessment should take into account all levels of disturbance, lethal (take) and otherwise, and their possible effects on all the above-mentioned groups.
3. An addition of a requirement in the Guidelines for the use of "turtle guards" on the streamers array.
4. An addition in the Guidelines of a requirement for the operator to demonstrate that the chosen array emits the minimal energy needed for the particular task.
5. An addition in the Guidelines of a requirement to use, when possible, seismic sound sources with lower environmental impact, e.g. marine vibroseis (Duncan *et al*., 2017).

### 7.3. Existing means and R&D for early detection of turtles during seismic surveys

We have already emphasized the lesser likelihood of sea turtles (in particular versus marine mammals) to be detected during surveys, using conventional observing methods (see section 4.6.5). Currently, there are rather inexpensive advanced methods that could supplement/replace the latter. One methodology is based on unmanned aerial vehicles (drones), as reviewed by Rees *et al*. (2018) and the other is a novel tracking method of mobile targets by active acoustics (Diamant *et al*., 2019). The method relies on the emission of wideband pulses the reflection patterns of which are evaluated and reshaped in a time-distance matrix. As opposed to conventional approaches that track targets through template matching or by using tracking filters, it avoids making assumptions about the target's reflection patterns or motion type and instead performs probabilistic tracking using a constraint Viterbi algorithm, by which detection is made based on a maximum likelihood criterion.

### 7.4. Recommendations for a new R&D aimed at reducing the existing information gaps on Israel's maritime space

1. A major regional knowledge gap exists in regards to the winter distribution of the two turtle species. Instrumenting (satellite tags) seriously incapacitated turtles, such as those that were washed ashore in this event, would miss the winter season by the length of the rehabilitation period. Waiting for a sufficient number of rehabilitated turtles that wash in fall may take a long time and also, it is not certain whether they truly represent the free-ranging healthy populations. It is recommended that tagging would be extended to free-ranging turtles and to trawler-bycatch animals, the latter possibly after a short assessment period at the Center.

   Fine scale water-column-use information would also be useful. A depth measurement capability in the existing or in a separate tag would allow a better understanding of where in the water column turtles are found, and improve the accounting for availability bias from aircraft surveys (both manned and unmanned).

   **It is only by filling this gap that operators and regulators may be informed about low/high risk areas and periods (including time of day), if they exist at all.**

2. The blast-related pathology in sea turtles, here and worldwide, is not well established in terms of both a comprehensive organ involvement and differential diagnosis. Controlled experiments on cadavers are expensive. For the time being, it is recommended that detailed protocols for medical testing of suspected blast-injured animals and necropsy of

blast-injured victims be performed with the aid of foreign experts, to be implemented in future cases involving single or multiple animals.

3. Establishing the most effective manner to deter sea turtles from a hazardous noise/shock source. ‘Soft Starting’ assumes that some sub-maximal level of the operational output will deter/chase off turtles from the source. There is some indirect evidence to support this assumption, but it may be that other outputs (e.g. consecutive shots at much shorter intervals, pulses with a narrow frequency band, continuous noise) may be more efficient and could be tested in an experimental setup similar to that of McCauley *et al*. (2000).

### 7.5. Recommendations for the reduction of harm to sea turtles

1. As a general guideline and as a lesson learned from this and past events, near-shore human interventions known to harm turtles, or may potentially do so, should be avoided or minimized. The Ministry of Energy's guidelines for seismic surveys ban surveys in shallow water during the sea turtles reproduction season. We recommend to consider further mitigation measures during the winter. Although the oceanographic simulations favor an injury source removed from the coast, we cannot discard the possibility of substantial numbers of mature turtles arriving at coastal waters earlier than the expected reproductive season.
2. Particular effort should be made to establish a dialogue between the IDF and the INPA in regards to alerting the latter before a planned detonation and/or active SONAR deployment. That can serve as a first step, to establish or disprove a cause and effect relationship between turtle injury rate and such military activity.
3. Every planned civilian introduction of loud noise should be reported to the INPA and MoEP well ahead of time. Furthermore:
   a. Planned construction or structure removal – if in sufficiently shallow water, a bottom survey by divers may be considered to supplement observer-based measures, prior to implementation. Also, a variety of mitigation actions should be considered (e.g. bubble curtain).
   b. Seismic – Unfortunately, with existing knowhow, we cannot recommend specific improvements of the risk assessment, although a pressure map of the array’s near-field at the proposed deployment site would be useful. In addition, measuring pressures in the near-field (both below and on the sides) during the actual operation, to verify the assessment, would be most welcome. Currently, the best way to reduce harm would be through better detection during operation, as specified above and halting firing when turtles are detected within the exclusion zone.

4. The aforementioned early detection of turtles and other megafauna by drones and active acoustics could and should be deployed whenever potentially harmful noise is introduced into the marine environment.
5. Marine mammals, more than sea turtles, are adversely affected by (single and/or continuous) impulsive noise. Updated safe exposure thresholds as listed in *Appendix VI*, should strictly be adhered to when such noise is introduced into the marine environment.

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## *Appendix I*

### *Terms of reference for the investigating team*

**Subject: Terms of Reference (TOR) for investigative expert panel on the increase in the number of injured sea turtles in January 2019.**

Further to the meeting held on February 17, 2019, it was agreed that a professional team of experts would be established to examine the sea turtle mass stranding event of January 2019. The team will examine the possible causes of turtle injuries, including the circumstantial connection between the seismic surveys and the impact to the turtles and other reasons. The team will comprise representatives of the Ministries of Energy and Environmental Protection, INPA, IOLR, Haifa University and other professionals as needed.

Topics for examination by the professional team:

1. Preparation of a review of the relevant literature:
   - 1.1 Sources of energy and their intensity in seismic surveys. Spread of energy waves of seismic surveys in water (sound waves and shock waves), intensities, and affected space.
   - 1.2 Shockwave and hearing injuries in turtles and their possible causes.
   - 1.3 The habitat and migration routes of sea turtles in the eastern Mediterranean Sea.
2. Detailed analysis of the January 2019 sea turtle stranding event (analyses for December 2018 - February 2019):
   - 2.1 Presentation of the stranding along the coastline through time, cross-section of ages and sex.
   - 2.2 Analysis of turtle stranding along the coastline of Israel versus weather conditions, waves, currents, survey timing.
   - 2.3 Presentation of the pathological findings of the injured sea turtles.
3. Macro-analysis of sea turtle stranding during seismic surveys carried out in Israel's maritime area during the last decade and in its vicinity (Egypt, Lebanon, Cyprus), weather conditions, naval announcements to the mariners (closed areas) and other possible causes.
4. OCEANOGRAPHIC MODELS
   - 4.1. Reverse calculation of individual turtle stranding points (location and time) and correlation to different source areas (seismic surveys or other areas such as closed military zones or fishing activities in southern Israel).
   - 4.2. Forward calculations from the survey points, according to the relevant dates and sea conditions and the assessment of drifting of immobilized injured sea turtles without an

ability to swim (if there were turtles in the area where the survey was conducted where they could reach – To be decided according to the findings of section 1.1).

5. To examine existing means and R&D for early detection of turtles during seismic surveys.
6. Formulation of recommendations on new R&D aimed at reducing the existing information gaps on Israel's maritime space.
7. Mapping in time and space of naval firing ranges or other activity in which explosives are used in the maritime area to examine their potential of being an additional source of damage to the turtles.

In accordance with the findings of the investigation, appropriate recommendations to reduce the harm to sea turtles are to be submitted..

# Appendix II

*Pathological findings, X-ray and CT scans of injured sea turtles – in a separate document*

# Appendix III

## *Turtle ear anatomy - Expansion*

The external tympanum, an extension of facial tissue, is covered by a tympanic scale that stretches across a notch which is analogous to the auditory canal (Wyneken, 2001). Computerized tomography revealed single lobes of fatty tissue connected to the tympanum (Ketten, 2008). Together with the sub-tympanal fat, they may function as a low-impedance 'internal pinna' preferentially channeling sound to the ear during underwater hearing.

Small fibrous strands, also unique to turtles, connect the stapes and oval window to the inner ear's saccule, possibly transmitting vibrational energy to the saccule (Wever 1978). The otic capsule of the inner ear is surrounded by a fluid-filled cavity, the perocapsular recess, separated from the perilymphatic duct by the pericapsular membrane. The movement and pressure relief of inner ear fluids are achieved through a reentrant fluid circuit that extends from the inner surface of the oval window, throughout the capsule, out via an opening in the capsule, the foramen, and into the recess and outer surface of the window. This circuit and the volume of fluid it contains may act as a low-pass filter, limiting high-frequency hearing, since the amount of sound pressure needed to move the columella increases with increasing frequency (Wever 1978).

Figure A3-1 shows a ventral view from a coronal section of the skull at the plain of the middle and inner ears, which are seen on both sides of the brain cavity. The columella is clearly seen in the exposed left middle ear.

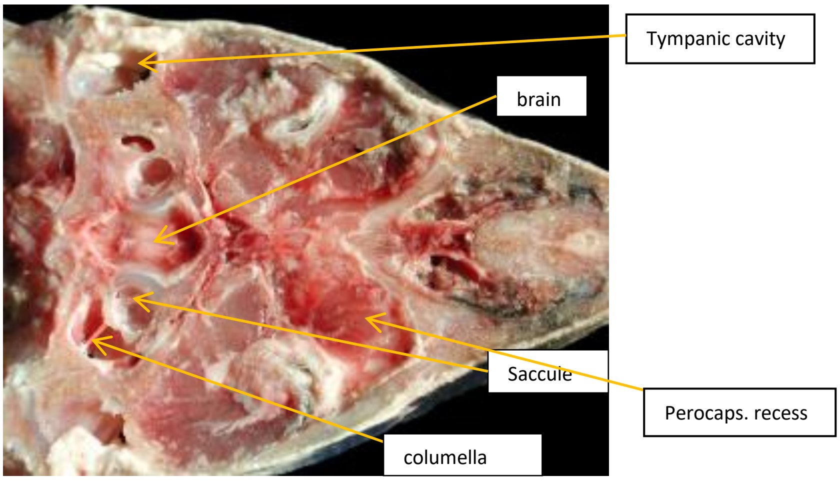


*Figure A3- 1. Coronal section at ear level, showing the positions of the middle and inner ears. Figure 218 from Wyneken (2001).*

The turtle's saccule and 'lagena', a small outgrowth of the saccule, form the cochlear duct. The auditory end-organ is the basilar papilla, the hair-cell-carrying basilar membrane of which is tonotopically arranged, with cells detecting low frequencies located toward the apical (laginal) end and cells detecting high frequencies located toward the basal (saccular) end. Its length is 1-2 mm as compared to 30 mm in the mammalian cochlea. Calcium activated potassium channels transduce cilia deformation to voltage which in turn induces action potentials in the innervating neurons (Crawford and Fettiplace, 1980; Jones *et al*., 1988).

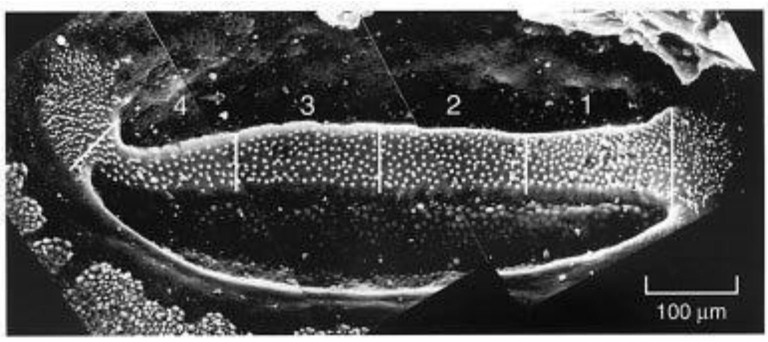


*Figure A3- 2. Scanning electron micrograph of the fresh water turtle (Trachemys scripta elegans, carapace length 10-12.5 cm) basilar papilla oriented with the saccular high-frequency end to the left. Figure 4a of Jones et al. (1998)*

## *Appendix IV*

### *Results of the backward simulations – in a separate document*

In order to achieve a better understanding of the turtles' path prior to stranding, a backward in time simulation was conducted from the stranding sites on shore to the sea (simulations for the entire available model area appear in Appendix IV, and day by day simulations appear in Appendix V). The simulation was based on the assumption that following an impact, the turtle is a passive floating object, lacking the capability for self-propulsion.

Drift back trajectories simulations of wounded turtles along the coast were integrated numerically backward in time from an approximate location of their beaching. The flow fields that were used to create the trajectories were sea currents at 5 m depth taken from daily hindcast of the Southeastern Levantine Israeli prediction system (SELIPS) (Goldman *et al*, 2015). SELIPS is an operational forecasting system based on POM, with horizontal resolution of about 1 km. The output was given as 3-hour averages of the velocity components. SELIPS is one way nested in ALERMO ocean forecast system (Kerres *et al*, 2002) and forced with the SKIRON atmospheric forecasts (Kallos *et al*, 1997; Kostopoulos *et al*, 2016). The lateral boundaries of the model are at 31.5E and 33.7N. Because the model does not take into account wave induced currents, and since the model imposes boundary conditions of zero velocity at the coast, the starting point of the backward trajectories was taken a few kilometers offshore from the actual beach location. The uncertainty of the beaching time was represented by running 3 simulations for each turtle going backwards in time from 00:00 GMT and 12:00 GMT of the beaching date, as well as from 12:00 GMT of the day before beaching.

## *Appendix V*

*Results of the day-by-day backward simulations – in a separate document*

## *Appendix VI*

### *Tables listing safe thresholds for underwater sound exposure: Sea turtles and marine mammals*

(See section 4.1 for definitions of sound levels)

*Table 8. Criteria for safe levels of various anthropogenic sounds for sea turtles*

| | Mortality & potential mortal injury | Impairment | | | Behavior disturbance |
|---|---|---|---|---|---|
| | | Recoverable injury | TTS | Masking | |
| **Explosions** | 229 - 234 dB peak | (N) High<br>(I) High<br>(F) Low | (N) High<br>(I) High<br>(F) Low | NA | (N) High<br>(I) High<br>(F) Low |
| **Seismic air-guns** | 210 dB $SEL_{cum}$ or >207 dB peak | (N) High<br>(I) Low<br>(F) Low | (N) High<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low |
| **Low-frequency SONAR** | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low |
| **Pile-driving** | 210 dB $SEL_{cum}$ or >207 dB peak | (N) High<br>(I) Low<br>(F) Low | (N) High<br>(I) Low<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low |
| Notes: peak and rms sound pressure levels dB re 1 µPa; SEL dB re 1 $µPa^2$·sec. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F). Source: Popper *et al.* (2014). | | | | | |

*Table 9. Criteria for safe levels of active SONAR operations for marine mammals. The below listed values, whichever are achieved first, should not be exceeded within a 24h period.*

| Coherent Sources | | |
|---|---|---|
| **Category** | Received pressure level (dB re 1 µPa) | Received Exposure level (dB re 1 µPa2·sec |
| **LF cetaceans** | 224 | 195 |
| **MF cetaceans** | 170 | NA |
| **Pinnipedes in water** | 212 | 183 |
| **Impulsive sources** | | |
| **LF cetaceans** | 224 | 183 |
| **MF cetaceans** | 224 | 183 |
| **Pinnipedes in water** | 212 | 171 |
| LF – Low-frequency hearing (7 Hz – 22 kHz); MF – Mid-frequency hearing (150 Hz – 160 kHz); NA – None available. Source: NATO (2018). | | |

*Table 10. TTS- and PTS-onset received level thresholds for marine mammals exposed to impulsive noise*

| Marine mammal hearing group | TTS onset: SEL (weighted) | TTS onset: Peak SPL (unweighted) | PTS onset: SEL (weighted) | PTS onset: Peak SPL (unweighted) |
|---|---|---|---|---|
| **LF cetaceans** | 168 | 213 | 183 | 219 |
| **MF cetaceans** | 170 | 224 | 185 | 230 |
| **Pinnipedes in water** | 170 | 212 | 185 | 218 |
| Peak SPL thresholds in dB re 1 μPa and SEL thresholds in dB re 1 μPa2·sec. Weighted refers to giving more weight to frequency bands for which the animal is more sensitive to, using its audiogram. Source: Southall et al. (2019). | | | | |