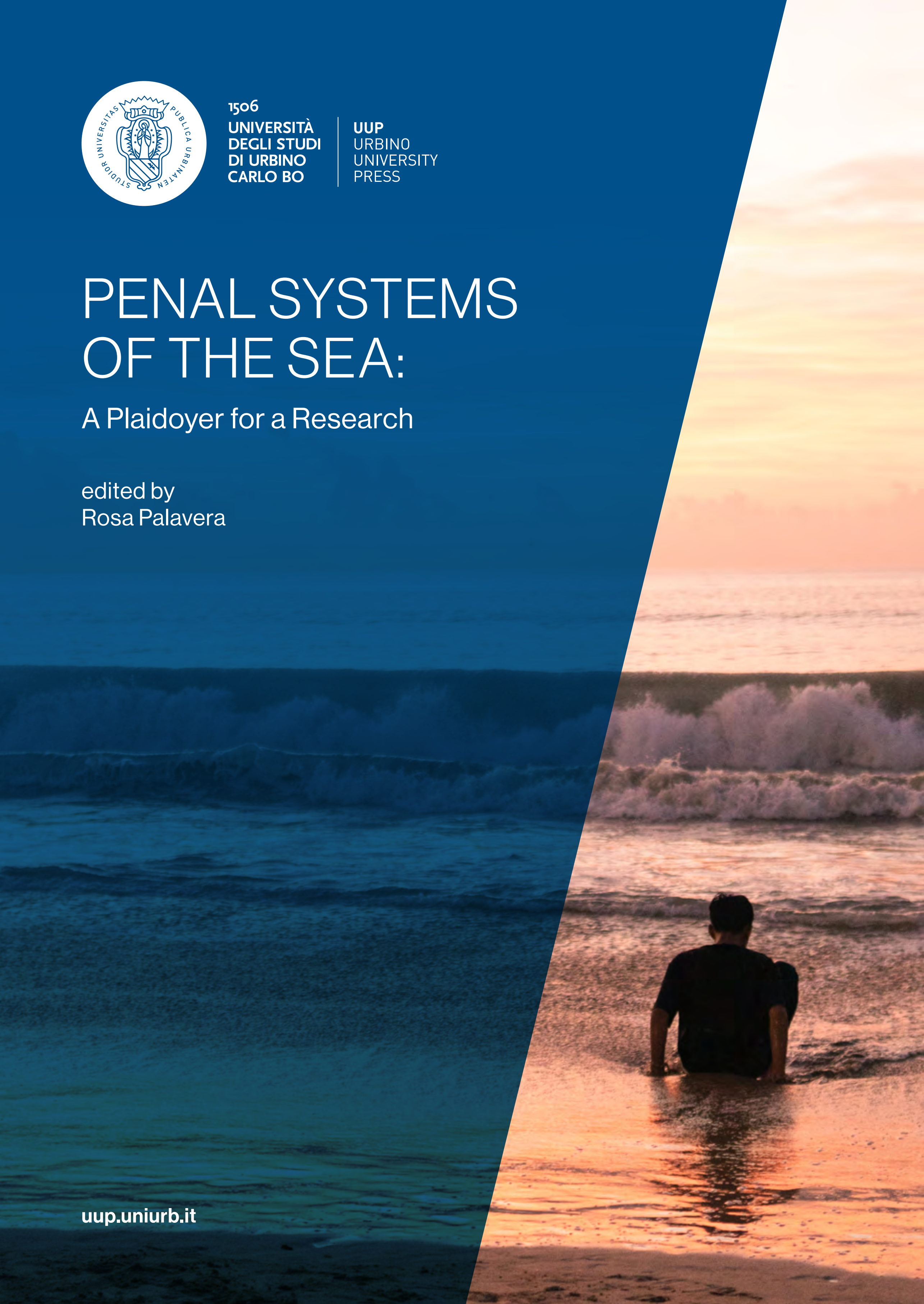

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PENAL SYSTEMS OF THE SEA:

A Plaidoyer for a Research

edited by
Rosa Palavera

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SOMMARIO

LESSONS FROM TSUNAMI

BLACK SWANS AND GREY RHYNOS

The art of reducing the tsunami risk

Alessandro Amato
Istituto Nazionale di Geofisica e Vulcanologia

Rara avis in terris nigroque simillima cygno
Decimo Giulio Giovenale

No amount of observation of white swans can allow the inference that all swans are white, but the observation of a single black swan is sufficient to refute that conclusion
David Hume

1. INTRODUCTION

Tsunami risk is among the most difficult risks to cope with. This is due to several reasons, both inherent to the phenomenon, such as its complexity and unpredictability, and its relative rarity, which means that little attention is paid to it by decision-makers and ordinary people.

Moreover, tsunamis are often seen as black swans, i.e. unexpected mega-events such as the 2004 tsunamis in the Indian Ocean or the 2011 tsunami in Japan, which claimed tens to hundreds thousands of lives and caused incalculable damage. Therefore, the risk posed by "grey rhynos", more frequent, relatively small tsunamis with wave heights of 1-2 meters, is underrated, despite these can be dangerous and potentially deadly, at least locally. While the mega-tsunamis occur rarely in specific locations, typically many centuries, the small tsunamis may happen every few years or tens of years, hitting adjacent locations or even the same ones along some countries' coastal areas. Managing the risk posed by both "grey" and "black" tsunamis is therefore extremely challenging. The affair is complicated by the fact that the two faces of the risk may be present at the same time, as for instance, in case of a large tsunami hitting suddenly a coastal region close to its origin (typically, a large earthquake), and other, more distant regions some hours later and with less violence. Or, the same location might be hit by either large or small inundations in two different events.

For giant tsunamis like the two mentioned above, the consequences are not limited to the devastating effects of the floods occurring in the hours following the extraordinary inundations, but also to numerous cascading events whose effects last for months and years.

Just think of the consequences on the economies of the affected countries, the disaster at the Fukushima nuclear power plant, the long-term psychological and medical effects on affected people even years after the events. In the past, similar giant events are known to have hit the coastal regions of many countries bordering all the world oceans but the increased amount of people living in the coastal regions and cities, as well as the presence of important infrastructures (such as nuclear power plants, chemical plants, commercial and touristic harbors, etc.) have strongly amplified the coastal risks. These include the coastal erosion, the storm surges, the sea level rise, and the tsunami risk which is probably the most difficult to face. Since the largest tsunamis are triggered by major earthquakes (as in the two cases mentioned above), in the vicinity of the causative fault the impact of these events adds up to that generated by the shaking of the earthquakes. For such big events, the affected areas can be huge, i.e., extending several hundreds kilometers along the coasts and with inundation reaching some kilometers inland.

For the reasons mentioned above, the tsunami risk management is particularly complex, and not free from possible judicial consequences. Trials following the Maule, Chile tsunami of 2010 (Valbonesi 2023) and the Japan tsunami of 2011 are relevant examples of this possibility. In the past decade, prosecutions have been narrowly avoided for some Mediterranean events following “false alarms”, as occurred after an earthquake in Greece that triggered an evacuation in Corsica in 2015, or after the recent case of the devastating earthquake that occurred in Turkey on February 6, 2023 (magnitude 7.8), that luckily did not generate a big tsunami.

2. WHAT IS A TSUNAMI?

Tsunamis are series of waves propagating in a water body (generally oceans, seas, more rarely lakes), generated by the displacement of a large volume of water, typically earthquakes that deform the sea bottom. Other phenomena like volcanic eruptions or landslides occurring at sea or on the coast can also generate tsunamis. More rarely, meteorite impacts are also potential tsunami sources. About 80% of documented tsunamis worldwide were generated by earthquakes (NOAA). In this contribution, we mostly refer to seismically induced tsunamis, not only for their larger incidence but also because all the tsunami warning centers (TWS) operating worldwide are focused on these events, the only ones that are to some extent "predictable". Nonetheless, we will see that there is an ongoing effort by the scientific community to improve the forecasting capability for other specific cases like active volcanic islands, motivated by recent events in different oceanic basins.

Differently from wind waves, which move only the shallowest part of the water column, tsunami waves affect the whole water column, bringing a huge amount of energy. In open ocean, tsunamis have small wave heights and very long wave lengths, being hardly distinguished by mariners and people on ships. They travel at very high speed where the water is 4-5 km deep as in open ocean, around 700-800 km/h, almost the speed of an airliner. Therefore, it takes some hours to cross large basins like for instance the Mediterranean and even the Indian Ocean, whereas it takes more than 20 hours to cross the whole Pacific Ocean, as for instance from Japan to Chile or viceversa. The long wave length in open ocean gets shorter and slower as the tsunami gets closer to the coast, and at the same times the waves increase their height. This is why they are so dangerous when they reach the coast, being able to penetrate for kilometers inland when the coast is flat, like on broad coastal plains or in presence of riverbeds.

The term *tsunami* comes from a Japanese word, made of two parts: *tsu* (harbor) and *nami* (wave), meaning therefore "harbor wave", to indicate that these waves become relevant (and destructive) when they reach the harbors, without being noticed in open sea. The appearance of a tsunami wave, even a big one, is more similar to a rapid tidal wave than to the "water wall" which are more typical of big wind waves in case of coastal storm surges.

Different from the moon tides, which have a period of approximately 12 hours, tsunami waves have typically periods of several minutes to tens of minutes. The rapid floods filmed during the 2004 tsunami in Indonesia and even more those occurred during the 2011 one in Japan, with the sea level quickly rising over the retaining walls of the harbor, and carrying boats, cars, trees, and a whole suite of debris, are still in the collective imagination of many of us.

2. TSUNAMIS IN THE MEDITERRANEAN?

The Mediterranean Basin has a rich history of earthquakes and volcanic eruptions, which is familiar to everyone: I do not think there is anyone in Italy, Greece or Turkey who is not aware of the high seismicity of the region where they live. The same probably applies to volcanic eruptions. Who in Italy has not heard of the eruption of Pompeii in 79 AD, or the recent ones in Stromboli and Etna? The discourse is quite different for tsunamis (or "maremoti" in Italian). Most Italians do not know the historical precedents in Italy and in other Mediterranean countries, and for this reason they do not consider the phenomenon as a real risk. Recent surveys carried out in all the Italian coastal areas have demonstrated the low level of risk perception in almost all the regions overlooking the sea (Cerase et al. 2019; Cugliari et al. 2022), despite the long record of historical tsunamis available for the Mediterranean basin (Maramai et al. 2014). Moreover, recent studies have assessed the tsunami hazard for the whole Euro-Mediterranean region, taking into account both historical and geological data, showing that it is pretty high for many areas (Basili et al. 2021). The most prone areas to potential tsunamigenic earthquakes are the Greek islands in the Aegean Sea, the Marmara Sea, the Hellenic arc, the Ionian islands, southern Italy from Sicily to Calabria and Apulia, the north-western African margin of Morocco and Algeria, the Eastern Mediterranean. However, since tsunamis are able to travel very efficiently over long distances, all the areas in the Mediterranean can be considered at risk, including those that are far from important active faults at sea. Looking at the catalogue of documented tsunamis one can also finds other areas where "minor" events have been recorded in the past (for instance, in Italy: Ligurian Sea, Adriatic, Stromboli volcano, as the one occurred in 2002 described by Bonaccorso et al. 2003; Tinti et al. 2005). Moreover, it has to be considered that future tsunamis could occur in areas where they did not happen in historical times. For this reason, the hazard maps mentioned above take into account also potential tsunami sources in areas of non documented events but that are known for their seismic and tsunami potential (Basili et al. 2021).

In the Mediterranean, the percentage of earthquake induced tsunamis on the total number of known ones is even higher than at the global scale (almost 90% according to Maramai et al. 2014; 2019). Most of the reported events are not huge tsunamis like the 2004 and the 2011 events in Indonesia and Japan already mentioned, nonetheless many of them have produced damage and in some cases death. The EMTC catalogue also contains some devastating events, as the one originated in Crete in 365 AD, or the 1908 Messina-Reggio Calabria event, both triggered by earthquakes. While it is true that the frequency of damaging tsunamis is lower than that of earthquakes, it must be considered that their impact can be devastating. On the other side, we also know that whereas for strong earthquakes the only way to moderate their impact, in terms of human life losses, is reducing buildings' vulnerability, for tsunamis it is possible to reduce the exposure with efficient warning systems and people's awareness. It is therefore very important to implement all possible actions to mitigate the risk, starting from the improvement of speed and accuracy of TEWS, but also increasing citizens' awareness, preparedness and response.

In the Mediterranean, as well as in other regions worldwide, besides earthquake induced tsunamis there are several active volcanoes with a high tsunami potential, both in Greece (worth mentioning the eruption of Santorini (Thera) volcano around 1600 BC, the first documented tsunami for the Mediterranean), and in Italy. In our country, the most active volcano from this point of view is certainly Stromboli, with several documented tsunamis mostly due to the collapse of its northwestern flank, the so-called *Sciara del Fuoco,* or to pyroclastic flows on the same slope. The last damaging episode occurred in 2002, when the water reached an elevation on land (runup) of more than 10 meters (Tinti et al. 2005). On the island there is an experimental local tsunami warning system which is able to send an alert to authorities and citizens in a less than a minute from when a tsunami hits two measuring points offshore the Sciara (Lacanna and Ripepe 2024). This system is still formally considered experimental although it is directly connected with alerting systems like sirens and messaging to local authorities. A discussion on the benefits and criticalities of such a system is beyond the scope of this contribution. At present, a joint effort supported by Civil Protection Department to the Istituto Nazionale di Geofisica e Vulcanologia and the University of Florence that implemented the local TWS is ongoing to improve the system and integrate it in the regional one (the NEAMTWS).

3. TSUNAMI MONITORING AND WARNING SYSTEMS

The first monitoring and warning system for tsunamis of seismic origin was established in the Pacific Ocean after a strong event that occurred in the

Aleutian (Alaska) islands in 1946, immediately after the end of WW2. The tsunami, which was triggered by a powerful earthquake (magnitude 8.6, that means a released energy about 1400 times that of the strongest earthquake recorded in the Central Italy seismic sequence of 2016, with M6.5), destroyed the massive lighthouse of Scotch Cap, and caused more than one hundred and fifty victims in Hilo, Hawaiian Islands, that were reached - without any warning - several hours after the tsunami waves started from the Aleutian Islands. Some other important tsunamigenic earthquakes occurred in the following years in the Pacific Ocean, including another event in Nankai, Japan in the same year (M8.1-8.4), a M9.0 event offshore the Kamchatka peninsula (Russia) in 1952, and the huge Chilean, M9.5 earthquake, the largest seismic event ever recorded on Earth until now, only to cite the strongest ones. In the following years, both the U.S.A and Japan carried out important efforts to implement efficient seismic networks and their tsunami warning centers, that became fully operational (though not as fast and efficient as today) already in the 70's.

It was therefore a big shock when, several decades later, in 2004, another huge tsunami hit the Indian Ocean, also in this case caused by a big earthquake (M9.2), and reached people on the coastal areas without any warning. The tsunami waves were huge and caused more than 230,000 fatalities and massive damage in Indonesia and many other countries, including African countries that were reached by the tsunami waves several hours after the earthquake.

After this disaster, the United Nations Educational, Scientific and Cultural Organization (UNESCO) took the lead to coordinate a global tsunami warning system that could cover all the coastal areas of the world. Four Tsunami Warning and mitigation Systems were established, namely the (already existing) Pacific (PTWS), the Indian Ocean (IOTWS), the western Atlantic/Caribbean (Caribe TWS), and the North-Eastern Atlantic, Mediterranean and connected Seas Tsunami Warning System (NEAMTWS), that of course includes Italy.

3.1. THE NORTHEAST ATLANTIC AND MEDITERRANEAN TSUNAMI WARNING SYSTEM(NEAMTWS) AND THE ITALIAN "SIAM"

In this international context, Italy has gradually built up the necessary skills to create a defense system for coasts exposed to the risk of tsunamis that could be generated in the marine and coastal seismic areas of the Mediterranean. It took several years to set up a coordinated Euro-Mediterranean seismic network and a sea level monitoring network, building on UNESCO Member States national funding with the support of projects funded by the European Commission (Amato 2020). In October 2014, in close collaboration with the National Department of Civil Protection, the INGV began its monitoring activities of strong Mediterranean earthquakes that could generate tsunamis, after two years of testing. As a result, the Tsunami Alert Centre (Centro Allerta Tsunami) was created within the Istituto Nazionale di Geofisica e Vulcanologia (CAT-INGV). The CAT, in addition to monitoring earthquakes and providing a rapid alert in the event of a potentially tsunamigenic seismic events, analyses sea level data for confirmation or cancellation of the alert. In fact, immediately after an earthquake, it is not possible to know if a tsunami has been generated by the shock or not. The first direct instrumental evidence of tsunami waves come either by tide gauges in the harbors (or offshore buoys, but there are not yet in the NEAM region) or by observations by people or webcams. These latter cannot be used by alert centers to quickly verify the occurrence of an ongoing tsunami for obvious reasons (timing of report, reliability, etc.), so we must rely on the tide gauges. Unfortunately, these are not so densely distributed along the Mediterranean coasts, so it takes several tens of minutes to have a reliable confirmation of a tsunami.

For Italy, these data come from ISPRA's National Mareographic Network, which homogenously covers our coasts; the CAT also analyses in real time seismic and tide gauge data from numerous institutes in the Euro-Mediterranean area and globally through international agreements. It must be said that the distribution of these instruments is far from being dense and homogeneous, there are entire regions like the north African countries or even the eastern side of the Adriatic in which they are absent or very rare. This strongly limits the efficiency of the TWS to have timely and effective information about ongoing tsunamis. The only way to send rapid alert messages is the "blind" assessment based only on earthquake information.

In 2016, following an international assessment and evaluation procedure within the NEAMTWS, the CAT-INGV has been recognized by the UNESCO-IOC as an official Tsunami Service Provider for the Mediterranean region. Since then, it has provided alert messages to most of the Euro-Mediterranean countries and other international Institutions. Details of how the system is operated can be found in Amato et al. (2021) and in Lorito et al. (2021).

At the same time, the “twin” centers of France, Greece and Turkey (CENALT, NOA, KOERI) also received accreditation within the NEAMTWS framework, for partial sectors of the Mediterranean, the Northeast Atlantic (France) and the Black Sea (Turkey). Later, also Portugal with its IPMA, became a Tsunami Service Provider for the North-East Atlantic. Since 2017, CAT-INGV has been providing the alert service to the national Civil Protection system, to the four TSPs and CTSPs of Greece, Turkey, France and Portugal; to Lebanon, Israel, Egypt, Cyprus, Malta, United Kingdom, Germany, Morocco, Spain; to the UNESCO IOC and to the European Commission (ERCC and JRC).

At national level, the activities of the CAT-INGV are articulated in the context of the National Tsunami Warning System (Sistema nazionale di Allertamento per I Maremoti di origine sismica, SiAM), which is composed by INGV, ISPRA (the Istituto Superiore per la Protezione e la Ricerca Ambientale) and the National Department of Civil Protection (DPC), which has functions of coordination and dissemination of the alert on the territory. The activities of the SiAM are regulated by the PCM Directive of 17/2/2017 (published in the Official Gazette on June 5, 2017). Following this Directive, DPC issued an important document in 2018, containing the Guidelines for local authorities to implement their civil protection procedures for the tsunami risk (published in the Official Gazette on 15 November 2018). Although the deadline for this adjustment was just a few months after its release, it must be said that very few Italian coastal municipalities have updated their civil protection plans to cope with tsunami risk and to be compliant with the civil protection guidelines.

Since January 1, 2017, CAT-INGV has been carrying out the alerting service in operational mode, in direct connection with the DPC’s *Sala Situazione Italia* to which alert messages are sent. From here, the alert is delivered to local authorities and all the components of the civil protection system (prefectures, regions, fire brigades, national transportation and industrial facilities, etc.). The alert messages (which should be called more correctly “threat” messages, according to the international indications, to point out the distinction between the scientific assessment of a potential THREAT as determined by Tsunami Service Providers and the definition of the ALERT levels which is under the responsibility of civil protection authorities) sent by CAT-INGV to DPC and to the international recipients, contain the estimated level of alert/threat (red, orange, or just an information/no alert levels) for a series of pre-determined “forecast points” along the coasts, and the expected arrival time of the first tsunami wave at these points.

It is important to emphasize that, unlike what is commonly done for other risks, the tsunami alert messages are delivered directly by DPC to the end-users (local authorities, prefectures and all CP components) without any intermediate evaluation. In the near future the alert messages will be delivered directly to people living in or passing through the cell broadcast technology named IT-ALERT. In other words, the quick assessment of a tsunami threat carried out in a few minutes by a suite of scientific choices and software will reach directly any single person located permanently or temporarily near the coast at risk. It is evident that, in case of a missed alert or even a false (or overestimated) assessment, there is a high chance for scientists managing the TWS of being involved in a judiciary investigation. In the first case this can even bring to a criminal offence for manslaughter, possibly involving both the researchers who developed the detection software as well as those present during the event, for instance during their shift in the operating seismic and tsunami warning room.

The decision to send the alert messages automatically to the local authorities and the population directly, without any filter by the civil protection officers, is due the timing of the tsunami threat which can be very short in case of earthquakes occurring very close to the coast (or in case of tsunamis induced by a volcano flank collapse like in the 2002 Stromboli event). It was the case of the recent Samos tsunami in 2020 (October 30), well documented by webcams, video clips and pictures, when the first waves reached the coast of the Samos island 3-4 minutes after the shock. Similar timing was observed for the Palu (Sulawesi, Indonesia) tsunami in 2018, whereas slightly larger times (5 to 10 minutes) have been reported for the 1908 Messina-Reggio tsunami (Baratta 1909; Platanìa 1910). Of course and luckily, not all the tsunamis have similar timing problems. We will see later that, despite the relative small size of the Mediterranean Sea compared to the Pacific, Atlantic and Indian oceans, the propagation times for tsunamis originating in the distant corners of the basin are of several hours. This is an advantage for managing the risk in distant coastal regions, but for the NEAM area it could also be a source of problems due to the lack of correct procedures. In fact, at the establishment of the NEAMTWS it was decided to eliminate one of the threat levels (level 1) currently used in the Pacific TWS, i.e., the so-called “Watch level”, that corresponds to the following indication: *There is a potential for tsunami impact, but given* *the travel time, no response of the public is necessary at the moment* (Intergovernmental Oceanographic Commission 2016). The alert levels for the NEAM region are three, issued after earthquakes of magnitude equal to or larger than 5.5 at sea or on the coasts: Information level, for smaller events (no tsunami expected); ADVISORY level, when the runup expected is less than 1 meter; WATCH level[1] for runup larger than 1 meter. The areas to be alerted are defined, for earthquakes with increasing magnitudes, as "local", "regional", or "basin-wide", with radius of 100 km, 400 km or the whole basin, respectively. From this very rough classification one can immediately understand that at the moment there are no upper limits to the expected inundation in case of a WATCH level, and this represents a serious problem for risk management. In Italy, the SiAM decided to adopt a methodology that is based on the estimated long-term hazard. In other words, the more hazardous regions will likely have larger inundation (and evacuation) areas (see the documentation in: https://sgi2.isprambiente.it/tsunamimap/).

3.2. RECENT EVENTS IN THE MEDITERRANEAN REGION POTENTIALLY AFFECTING ITALY

After a few years of testing and optimization of the procedures, the CAT was accredited as a NEAM Tsunami Service Provider for the Mediterranean in 2016, and started its operational activity for the Italian civil protection service in January 2017. Since then, more than 40 events have occurred in its responsibility area (the whole Mediterranean Sea), for each of them alert or information messages have been issued to the Italian and the Euro-Mediterranean countries. Most of them were INFORMATION messages, for earthquakes of magnitude between 5.5 and 6.3, but there have been also 12 events that triggered ADVISORY (7) or WATCH (5) levels for earthquake with magnitude between 6.1 and 7.8 (see https://cat.ingv.it/it/ for details on the data and on the procedures).

As for the historical catalogue (Maramai et al. 2021), also the recent events outline the most hazardous regions of the Mediterranean: Several events originated in Greece (both in the Aegean Sea and along the Hellenic arc) and in Türkiye, but almost all other active regions were affected by

1 For some unclear reasons, the naming of the alert levels adopted in the NEAM region are not the same as for the PTWS. In particular, in PTWS the WATCH level means that there is time to take decisions, whereas in the NEAM region the WATCH level is attributed to the largest threat (expected runup larger than 1 meter, without regard to the timing of the tsunami propagation).

some marine earthquakes, as in the northern coast of Africa, in the Sicily Channel, the Adriatic, the Cyprus arc, and the easternmost side of the Mediterranean, with the devastating earthquake in Turkey of February 6, 2023. As anticipated before, this event deserves a particular description for its impact on the Italian Tsunami Warning System. Before that (next section), it is worth describing briefly some of the previous events that triggered some actions (or non-actions) in the civil protection systems of the Mediterranean countries, and particularly the Italian one.

Two tsunamigenic earthquakes occurred in the Aegean Sea in 2017 (Kos Island, M6.8) and in 2020 (Samos Island, M7.0). In both cases the tsunami alert messages were issued by the NEAM Tsunami Service Providers within 8 to 10 minutes after the events. The alert level in both cases was a local WATCH (or RED according to the Italian nomenclature the maximum within a distance of 100 km from the epicenter), ADVISORY (for 100 to 400 km from the epicenter), INFORMATION for more distant regions. In both cases the Italian coasts were outside the alerted areas, therefore no civil protection actions were put in place, nonetheless the INFORMATION messages were delivered to the whole recipients (local authorities, prefectures, etc.) immediately after the events. The tsunami reached heights of 2-3 meters, and in both cases the second wave was the largest, at least in the locations were videos were taken either by webcams or by eye witnesses. This happens frequently, and is a relatively lucky circumstance because the first wave (that may include a sea withdrawal) represent “natural warnings” that can safe lives, if people are aware of the risk and know how to behave. Unfortunately, experience from these and other events show that this awareness is not always present, not even among people living in coastal regions and even less among tourists. Despite the relatively modest size of the two local tsunamis, both caused damages on harbors and beach resorts, due to the speed and the length of the waves carrying a lot of energy. In the Samos case, a woman was killed by the tsunami when it reached the nearby coasts of Türkiye. These two events represented important reminders, particularly for our Greek and Turkish colleagues but also for the whole NEAM community, that even “small” tsunamis are dangerous. Even if they do not generate kilometers-long inundation areas and very high waves like the mega-tsunamis described in the previous section, they are more frequent than those, and are able to produce damage and even casualties.

We have used a video taken by a webcam in a Samos beach resort to point out the issue of the danger of small tsunamis, adding comments and sings on the images. To date (September 2024) the video has been viewed by four million people, as evidence of the strong interest in this topic and the importance of using effective communication tools, especially with the new generations (https://www.youtube.com/watch?v=YM6hha4n5W4). For some reflections on risk communication and on the social impact of tsunamis, readers can also see the contribution by L. Cugliari (this volume).

Another interesting case is the earthquake of magnitude 6.8 that occurred in 2018 in the Ionian Sea near the coast of Zakynthos, not far from the coasts of southern Italy. In this case, the "yellow area" (the 400 km radius area surrounding the epicenter) included Apulia and Calabria. The two regions and all their municipalities were alerted (ADVISORY, or yellow level) during the night of October 25, 2018. The travel times of a tsunami from Zakynthos to the closest Italian coasts are of about 30-40 minutes. Since the alert message was issued 8 minutes after the earthquake, there was sufficient time to take some action (in a case like this, it would be enough to warn people to stay away from the beach and the coastal areas).

Although the SiAM Directive mentioned above had been already approved from almost two years, and the DPC Tsunami Risk's Guidelines for municipalities were published some months before this event, at the time of this event not many local authorities had implemented the civil protection plan. Particularly surprising was the reaction of a mayor of an important municipality in Apulia, who the day after declared to a journalist that he had received the alert message a few minutes after the event (and this was a good news) but he decided to go to sleep again and not doing anything because the expected (tsunami) wave height was "only" up to 1 meter, and people there were used to sea waves of 2-3 meters. This second statement was of course completely wrong because tsunami waves of one meter, or even half a meter, are very different and more dangerous than a typical sea wave generated by the wind. This is demonstration of the general underrating of the tsunami risk, not only by local authorities but also by citizens, as demonstrated by risk perception studies carried in the last few years by our team of social scientists (Cerase et al. 2019; Cugliari et al. 2022a,b; Amato et al. 2024; Moreschini et al. 2024). The Zakynthos earthquake did not generate a relevant tsunami (tide gauges recorded anomalous sea level changes of only 10-20 cm referable to the tsunami) because, contrary to the Kos and Samos events described above, the fault movement in this case was mostly horizontal, thus not being able to deform the sea bottom and pushing the water up and down as necessary for tsunami generation.

3.3. THE TÜRKIYE EARTHQUAKE AND TSUNAMI ALERT OF FEBRUARY 6, 2023

This event is particularly significant not only for its huge impact on the Turkish and Syrian territories (more than 60,000 deaths and more than 120,000 injured), but also for its impact on the NEAMTWS. The earthquake was very strong, magnitude 7.8, with a fault rupture of about 300 km along the East Anatolian Fault (EAF) and a relative motion between the blocks of several meters, mostly but not only horizontally. The epicenter was located at less than 100 km from the sea, and the rupture propagated in both directions (northeast and southwest) reaching the coastal areas of Eastern Mediterranean. Since the epicenter was located within 100 km from the coast and due to the high magnitude, the CAT-INGV issued a WATCH (red) alert for the whole Mediterranean. A similar assessment was done by the KOERI, the Turkish Tsunami Service Provider, whereas the NOA (the Greek TSP) did not release any alert message because their location was slightly more distant from the coast (more than 100 km) and in this case the Standard Operational Procedure (SOP) does not require to issue an alert. This different behavior among the three TSPs operating in the Eastern Mediterranean area enhances the limitations of the approach followed up to now by the TSPs, i.e., a rigid Decision Matrix with fixed thresholds and strict boundaries. We will discuss later on the benefits and the risks of abandoning the Decision Matrix approved by the IOC-UNESCO for a more reliable and scientifically sound method which is however original and innovative and has not been officially approved by any international organization.

The earthquake occurred at 2:17 Italian time of February 6, and the alert was issued by the CAT-INGV at 2:25, eight minutes after the earthquake. The estimated arrival time of the hypothetical first tsunami wave at the closest Italian coasts were around 7 a.m., more than four hours and a half after the shock. One hour after the first message the tide gauge of Iskenderun (in Eastern Turkey) recorded the tsunami, that was of only of about 40 cm peak-to-peak, but enough to trigger a confirmation message by the two TSPs of Türkyie and Italy. In the meantime, in Italy the civil protection measures had been activated: the initial message (and later the confirmation one) was delivered by DPC to the local authorities and to all the civil protection system components. The messages contain the level of threat (WATCH, or red alert) and the time of the expected tsunami arrival times at the different locations (the forecast points). For Italy these were between 4.5 hours for the closest points to more than 7-8 hours for the distant ones (e.g., Veneto, Liguria).

Many Regions activated their emergency plans, sending messages to the municipalities asking to activate the local emergency centers. Some of the Regions decided to wait considering the long propagation times, actually departing from standard operational procedures (SOP) for emergencies, or better interpreting them in a peculiar way, since no indications of delayed actions were included in the SOPs. Moreover, early morning trains were stopped in some regions, some schools were kept closed, in Catania the very popular religious procession of Sant'Agata that was going on that night was stopped with thousands of people in the street (then it was started again after reception of the second message where the two readings of tsunami waves were small – another departure from SOPs and an unjustified decision).

The alerting phase was definitely closed after almost 5 hours, at 7:02 (Italian time), because very few tide gauges were operating in Eastern Mediterranean, and we decided to wait until the expected tsunami arrival times at the first Italian tide gauges were reached, without showing any anomalies. It was probably a conservative decision, since the few available sea level data (in Turkey and Greece) showed very small or zero anomalies. Despite the early time of the tsunami ending (7:02 in the morning), several civil protection actions were maintained for the whole morning (like school closed), also in this case departing from the procedures. It is worth mentioning that the Türkiye TSP (the KOERI) closed the alert even later, around 12, ten hours after the event.

In summary, this event was a very complex case, described by someone as a "false alarm" (which was not completely), during which several unexpected reactions in emergency response were prompted. Luckily, no harm nor damage was provoked by these actions, therefore no legal action was undertaken. Actually, there were probably indirect economic losses for companies and families, but this was not enough to attempt prosecutions.

Also for Tsunami Service Providers and Civil Protection authorities, this event represented a turning point. First of all, the dismissal of the decision matrix in favor of a more complex but more rigorous method has been accelerated (although not yet implemented at the time I write, October 2024). The method (called Probabilstic Tsunami Forecasting, or PTF) is a real time probabilistic assessment of the tsunami based on a huge suite of pre-calculated scenarios (Selva et al. 2021a). In practice, once an earthquake occurs in a specific area, all the geological, seismological, historical information on that area are used to make an initial estimate of the more likely tsunami impact along the coasts, considering (and this very important) the related uncertainties. The level of "conservatism" is therefore decided a priori by the decision makers, trying to balance between possible false and missed alerts. As previously mentioned, this step, which is almost a paradigm shift for tsunami warning, is brand new and is not applied as such in any warning centers (although some of them are testing similar procedures). This means that adopting it without a full consensus from the scientific authorities coordinating the global and the regional TEWS could be dangerous from a legal point of view. If the method fails in issuing correct alert messages during a real tsunami with damages and fatalities, it is possible that the TSP scientists who decided to adopt it will be in trouble. On the contrary, how to stay with a Decision Matrix that has proved to be too simplistic (although very conservative) and ignore that there is a better methodology that can avoid many problems and above all be more accurate to forecast the tsunami impact? This is an interesting issue not only for seismologists and tsunami experts, but also for law experts (see the contribution by C. Valbonesi in this volume) and for social scientists.

3.4. THE LAST MILE

Until here we have seen the relevant progress made by the TEWS in the last twenty years, improving more and more the rapidity and the accuracy of the forecasting procedures, i.e., the so-called upstream component. This is the first but not the only element needed to maximize the impact of such systems. Indeed, an efficient Early Warning system must include the so-called "last mile" (or downstream component), in other words must respect two main conditions: a) to reach all the citizens, and b) the citizens must know how to respond and what to do. For this reason, one of the main indications of the Sendai Framework for Disaster Risk Reduction (SFDRR 2015-2030), is focused on "people-centered" actions (Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction):

> «To invest in, develop, maintain and strengthen people-centred multi-hazard, multisectoral forecasting and early warning systems, disas-

> ter risk and emergency communications mechanisms, social technologies and hazard-monitoring telecommunications systems; develop such systems through a participatory process; tailor them to the needs of users, including social and cultural requirements, in particular gender; promote the application of simple and low-cost early warning equipment and facilities; and broaden release channels for natural disaster early warning information« (UNISDR 2015)

As can be seen, words like "people-centered", "social technologies", "participatory process", "the needs of users", "social and cultural requirements", indicate a strong attention towards the involvement of people in the decision process and emphasize their role in the risk reduction actions.

The Italian legislative decree n. 1/2018, reforming the Civil Protection sector, states this clearly in art. 31 (comma 1 and following):

> «1. The (Civil Protection) National Service promotes initiatives aimed at increasing the resilience of communities, encouraging the participation of citizens, both individual and associated, also through professional training, in civil protection planning as regulated by Article 18, and the dissemination of civil protection knowledge and culture.

On the other side, if it is necessary for authorities to put all the possible efforts to inform and involve citizens in the risk reduction activities, also citizens should be active actors in this. As discussed by Valbonesi (2021), the Decree 1/2018 failed in introducing a mandatory role of citizens in the practice of risk reduction. In other words, the (unfortunately) frequent attitude of citizens of not feeling actively involved in the risk and emergency management would not imply their liability in case of accidents due for instance to their incorrect behavior.

Many efforts have been put in the last few years in all the global Intergovernmental Coordination Groups, including the NEAMTWS, to improve this sector of the risk mitigation chain. The ICG/NEAMTWS has recently approved its 2030 Strategic Plan, which in the first page reports the following statement by the United Nations Tourist World Organization:

> "A rise in coastal activities and population increase vulnerability and risk. It is estimated that the Low Elevation Coastal Zone (LECZ) (< 10 m height) in the NEAMTWS region is home to about 116 million inhabitants. With 1,403 million international arrivals in 2018, the Mediterranean has become the world's primary tourist destination" (UNTWO 2019)."

Therefore, such an important presence of people in the zones at risk needs their active participation in order to reduce the risk.

The NEAMTWS Strategy is articulated in three main pillars: 1) Tsunami hazard and risk assessment; 2) Detection, warning and dissemination; 3) Awareness and response (Intergovernmental Oceanographic Commission 2023). Whereas the first two pillars involve an active role of scientists in all the steps of the processes, the third one implies the participation of people and defines the best tools to achieve a significant risk reduction. For this goal, it is important the involvement of social scientists who can help in understanding the perception of risk and in defining the best communication strategies (for more details on this the reader can see Cugliari, this volume).

4. BLACK SWANS OR GREY RHYNOS (OR BOTH)?

Based on what described in the previous sections, we may be temped to classify the tsunamis in two main categories: Black swans and grey rhynos, according to their size and destruction capacity. We have seen in the first part of this contribution that indeed both mega-tsunamis and small, still locally dangerous tsunamis may occur. However, we must consider first of all that between the two there is an almost continuous suite of cases that have occurred (and will occur) due to large or very large earthquakes, large or very large volcanic eruptions, large or very large landslides, and so on. Considering the earthquake typology, there are reports of tsunamis generated by events with magnitude above 6.5 (approximately) up to magnitude 9.5 (the largest earthquake recorded so far by seismic instruments, that occurred in Chile in 1960), with any value in between. For some seismic events characterized by a specific rupture mechanism in volcanic regions, tsunamis can be generated even at smaller magnitudes (5 to 6). Of course, very big earthquakes, like the 1960 Chilean one, as well as the 2004 event in Indonesia and the 2011 one in Japan, are very rare, both considering their frequency worldwide, and even more if we focus in a specific region. Moreover, the magnitude of the causative earthquakes is not the only parameter affecting the degree of "tsunamigenicity" of a specific event. The others are related to the characteristics of the fault that ruptures during an earthquake in or close to the sea (depth, sense of movement, etc.).

Indeed, also the 2011 Great East Japan tsunami was interpreted as a "black swan" by some authors, due to the fact that there were no recent, clear evidence of such big events in the documented history of Japanese tsunamis. Black swans are described as events which, a) are surprising for the observers, being "extreme outliers", b) have a major impact, and c) it is rationalized by hindsight as if it could have been expected (Taleb 2010). Indeed, after this event, evidence came out of similar big tsunamis that had been studied in the distant geological past of the country.

In an interesting comment written by Robert C. McCue after the nuclear accident that occurred during the 2011 Japan mega-tsunami, he reflects on the nature of this event (Fukushima Dai-Ichi – Black Swan Event or Engineering Design Error? https://www.mdcsystems.com/fukushima-dai-ichi-black-swan-event-or-engineering-design-error/):

> "Is this just the latest example of a Black Swan Event? At first glance it would appear to be one, but then what about the ancient warning system erected by previous generations which could have prevented the entire nuclear accident? Tsunami Stones, which have been in place on the Japanese coast for centuries, provided an ominous warning: "Do not build your homes below this point."

It is interesting the reference to the "tsunami stones", witnesses of previous destructive events and erected to preserve memories of the past and warn on the future.

Also Synolakis et al. (2015) have argued in a similar way, writing that "The Fukushima accident was preventable" (in the paper's title), and recalling that the adoption of international best practices and standards would have prevented the accident. In this case the focus is not so much on the earthquake-tsunami event but on the nuclear accident, but the call to best practice is certainly very important for all those who have to manage risk. Referring to the so-called "NaTech" disasters (i.e., "natural-hazard triggered technological" accidents, term coined by Showalter and Myers (1994), often they were labelled "black swans" (mostly by industrial companies), meaning that they could not be prevented. However, there is a vast literature contrasting this view and attributing the disasters to either human error or technological failure. For a review of these cases see Krausmann and Necci (2021), from which the sentence below is taken:

> "Adverse events come in all sizes, ranging from frequent minor incidents to rare catastrophic shocks. The standard line of attack to prevent or control any such incident is to apply appropriate risk-management strategies in fulfillment of some legal requirement and

> following industry best practice. Different types of risk (conventional, extreme, unknown) require different management approaches. There is no “one-size-fits-all” solution. Enter White, Gray and Black-Swan risks”.

Although the Authors refer explicitly to NaTech events, what above can be applied more in general to natural risks, in particular to tsunami risk, and should be considered for its management.

An evident example of what may happen if the procedures are not well defined, especially when the risk management is borne by various subjects, is the case of the 2010, Maule tsunami in Chile. The so-called “Caso Tsunami” is a very complex one, both from the geological and from the judicial point of view, and cannot be reviewed in detail here. The reader can refer to the volume by Valbonesi (2023) who emphasizes the importance of clear standard operational procedures and interactions among the various Institutions and individuals during an emergency.

Is the 2010 Chilean tsunami another black swan? As a geologist, I would definitely say no, if only because very large earthquakes and tsunamis are relatively frequent in Chile. Only fifty years before, in 1960, a magnitude 9.5 earthquake (the largest seismic event recorded in the instrumental era) hit the Pacific coasts of Chile with a big tsunami propagating troughout the Pacific Ocean. Many other events have occurred in Chile before that, including one in 1835 described by Charles Darwin who was there when the earthquake and the tsunami hit the area of Concepción. It is interesting to note how the 2010 disaster served as an important lesson to the Chilean Institutions and authorities, who redefined radically the tsunami alert system. When another big event occurred in 2014 in northern Chile (earthquake magnitude was 8.2) the warning procedures work correctly and thousands of people were evacuated successfully. In the four years between these two events many drillings were organized in Chile, as well as information campaigns that surely improved the preparedness and response of citizens.

So, are these mega-events really black swans, or rather grey rhynos? Grey rhynos are highly probable, high impact but neglected threats. They are not random surprises, but occur after a series of warnings and visible evidence. In our case, the “visible evidence” is the historical record and the geological knowledge, especially in regions where these phenomena are (relatively) frequent. Here the concept of “highly probable” must be contextualized. Tsunamis are clearly rare phenomena if we consider human life as a reference. However, if we think in terms of geological eras (therefore, hundred thousand, millions or tens/hundred million years), also recurrence times of centuries are to be considered frequent. In this frame, even the mega-tsunamis are not so rare and therefore cannot be considered real black swans. In some way, this follows on another level what Taleb describes in his book, i.e., that the perception of black swans depends on the observer. In this case the "observer" would be the eye through which we look at a specific phenomenon.

5. CONCLUSIVE REMARKS

In conclusion, the reduction of tsunami risk can be reached considering the complexity of the phenomenon in all its facets, from the scientific and technological aspects to the social and human ones. Among the second, it is extremely important to understand people's risk perception and raise their awareness and preparedness, with periodic campaigns and drills, organized with the active involvement of citizens, especially students and young generations. It is also important to reach people using the most common media communication streams, both social and classic broadcast media like TV. Risk perception surveys carried out in all coastal regions of Italy have shown that the television is still the most used tool to retrieve information on science issues (and on tsunami in particular) surprisingly even for young generations, much more than institutional channels such as Civil Protection or scientific institutions websites.

Among the first (scientific and technological challenges), there is certainly the need for faster and more accurate forecasting. This includes both the deployment of new instruments (tide gauges, offshore buoys, SMART cables, etc.) to have more and more precise and detailed measures of an ongoing tsunami during its propagation, and new, more accurate methods for an improved forecasting. As described for the Turkish alert of 2023, rigorous, although internationally validated procedures, can bring to problems like evacuations, school closures, train stopped, etc., with not negligible economic losses. This experience suggested us to accelerate the transition to a more accurate, though more complex, forecasting methodology. However, as described above, the introduction of new methods, not yet validated by the scientific community and by the international governing bodies of the tsunami risk (IOC-UNESCO coordination groups) is critical and deserves particular attention. Even if the scientific community has validated this method (Selva et al. 2021) and is convinced of its validity, the decision of using it in the standard operational procedures is critical and has involved several bodies, including the INGV Scientific Council, the Board of Directors, a panel of international experts. Its imminent adoption will be an important step forward in the path towards a better tsunami risk reduction, but will probably increase the liability and the legal exposure of scientists and all those involved in the alerting chain. Nonetheless, we believe as scientific community that it is not possible to postpone too much this decision. Another false alert like the one triggered by Turkey event of February 6, 2023, could seriously compromise the credibility of the system, both for the SiAM point of view and for the UNESCO member states of the NEAM region. Furthermore, there is the risk of further downgrading the authorities' and people's risk perception with possible dramatic consequences in case of a real damaging event. Great attention must be paid to drafting documentation of the operating procedures, in their validation and frequent updating, not only to limit scientists' and authorities' liability, but above all for a more effective management of tsunami risk and for providing a better service to society.

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