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TREE FAILURES IN ITALY: ANALYSIS OF SINGLE EVENTS, CONSEQUENCES AND DISTRIBUTION

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ABSTRACT

Tree failures in urban environment are impossible to avoid, since this would require the absence of all trees themselves. However, the proper management of the urban forest through the use of current risk assessment instruments (e.g. ISA TRAQ qualification), the assessment of tree stability (e.g. V.T.A. protocol) and adherence to risk management practices can significantly reduce the occurrence of these events and their associated social costs. To be better understand the number of tree-related events that occur in Italy, the authors compiled information from news outlets covering such events for the period 2013 through 2015. Weather data was also collected to obtain information about the wind speed and precipitation associated with each event. Statistical analysis of the collected data returned a detailed view of the distribution within Italy of tree failures that resulted in negative consequences. Further, the relationship of meteorological events to these failures were analysed. The study suggests the importance of the adoption of data archives, such as a national tree failure database that can provide relevant information on causal agents relating to tree failures and consequences. The comprehensive on-going analysis of tree failures is essential to pursue the goal of reducing future negative events and to demonstrate the effectiveness of the proper management of trees, especially in urban areas, at the local, regional and national level.

Keywords: tree failure, urban forest, statistical analysis, TRAQ, VTA.

RÉSUMÉ

Les ruptures des arbres au milieu urbain ne sont pas évitables, puisque on obtient l'absence totale de ruptures seulement en absence totale d'arbres. Cependant une correcte gestion du patrimoine arboré selon des protocoles de diagnostic structurale et de gestion du risque internationalement reconnus (par exemple VTA protocole et ISA TRAQ qualification), peux reduire de manière significative le nombre de ruptures, en diminuant par consequence les coûts sociaux liés a chaque rupture d'arbre. Dans les années 2013, 2014 et 2015, chaque annonce lié aux ruptures d'arbe, intières ou partielles, apparu dans les journaux a été noté. Pour être noté, l'article devait decrire précisement la date et le lieu de la chute de l'arbre ou de la branche, le nombre des ruptures et les consequences des ruptures. Sur la base de la date et du lieu ils ont été recherché des donnés météorologiques sur la vitesse du vent et sur la présence, ou moin, de pluie et/ou neige.

Après, l'analyse statistique a permis de tracer la connection entre les ruptures et les conditions météorologiques. L'étude suggère d'adopter un Tree Failure Database national capable de fournir des informations précieuses sur les connections entre ruptures d'arbre ed leur consequences.

L'analyse détaillée des ruptures d'arbre est d'une importance fondamentale pour limiter autant que possible l'apparition d'événements similaires à l'avenir, et pour démontrer l'efficacité d'une bonne gestion des arbres, en particulier dans les zones urbaines, à la fois au niveau local et national.

Mots-clés : rupture d'arbre, parimoine arboré urbain, analyse statistique, TRAQ, VTA.

INTRODUCTION

The risk assessment of tree as it is currently applied in Italy involves determining the potential for a structural failure that results in negative consequences, such as injury, property damage or the loss of services. Due to the continuous monitoring of trees and the early detection of high-risk situations many failures are effectively prevented. However, because trees are biological structures and that numerous variables are affecting tree stability and response, site conditions and target variations, tree failures are impossible to avoid completely. (Lilly S.J., 2010; Dunster J.A. *et al.*, 2013). Moreover, despite the protocols of hazard and risk assessment are continuously updated according to the latest scientific evidences, some methodological limitations are present (Duntemann M. *et al.*, 2016). However, in order to identify key factors that may lead to failure, some studies were able to determine the thresholds for defining the significance of structural defects (e.g. cavities, rot, fungi infection) in relation to tree failures, and the general circumstances (e.g. site conditions, metereological events) related to tree failures (Edberg R. and Berry A., 1999; Costello L.R. *et al.*, 2013; Costello L.R. and Jones K. S., 2014; Costello L.R. and Jones K. S., 2014; Costello L.R. *et al.*, 2015; Tso J. *et al.*, 2014; Tso J. *et al.*, 2015). Such retrospective studies were conducted at local level in the U.S.A. on specific species with the use of a particular data collection instrument, such asTree Failure Database (Smiley T. *et al.* 2006). These databases can provide statistical information on the causes and consequences of tree failures. Additionaly, the correlation between failures and atmospheric phenomen and tree failure distribution throughout a country in relation to the meteorological events can be further studied.
In this article the authors propose the first data analysis about tree failures in Italy. Over a three year period (2013-2015) the authors collected information from new items related to tree failures, when sufficient details were present in terms of: date, number of failures, place and consequences of the crashes. Weather data was also collected in order to obtain information about wind speed, presence or absence of rainfall and/or snowfall. Statistical analysis of the collected data returned a detailed view of tree failures in Italy and how they are distributed throughout the country in relation to meteorological events and their consequences. This data analysis suggests the importance of the adoption of specific databases, such as the Tree Failure Database that, alongside continuous monitoring of trees, can concretely demonstrate the evolution and the occurrence of tree failurures, investigating precisely on their possible causes, consequences, actual preventability and, finally, possible reduction within a physiological limit.

MATERIALS AND METHODS

TREE FAILURE EVENTS AND WEATHER DATA COLLECTION

From 2013 through 2015, new items related to tree failures in Italy were sought on a weekly basis, using “tree failure” as a keyword for the web search. When sufficient minimal details were present, (i.e. the date, number of failures, species, location and consequences) the data was categorized and stored into an Microsoft Excel spreadsheet. Weather data associated with the tree-failure location and date was collected from the public website http://www.ilmeteo.it/portale/archivio-meteo. The weather data retrieved for each event included the maximum wind speed (km/h), gust speed, when registered, (km/h), and the presence of any form of precipitation.

DATA ELABORATION AND STATYSTICAL ANALYSIS

The data was categorized in four ways : wind and gust speeds, land use type, species type, regional location in Italy. Maximum wind speed and gust speed values were classified into the twelve categories of the Beaufort Scale. The distribution of tree failures in relation to the Beaufort Scale were graphed. Normality test and T-test were performed using Microsoft Excel. Tree failures were grouped into five different land use: street, public garden, school and hospital, private garden, and rural context. Species were categoried in to three trees types: broad-leaved, conifer, palm tree.

Tree failures were also categorized geographically to the twenty different regions of Italy: Abruzzo, Basilicata, Calabria, Campania, Emilia-Romagna, Friuli-Venezia Giulia, Lazio, Liguria, Lombardia, Marche, Molise, Piemonte, Puglia, Sardinia, Sicily, Tuscany, Trentino-Alto Adige, Umbria, Valle d'Aosta, and Veneto. Area data for each region (km^2) was obtained from the official websites of the regions. The number of tree failure per km^2 was calculated for each region. Tree failures were also categorized geographically by the Eurocodice 1 index (CNR,2009; H. Gulvanessian et al., 2009), which divides and groups the regions of Italy in to nine different macro-areas according to the anticipated wind speed. The number of tree failure per km^2 for each Euocodice zone was calculated.

RESULTS

DATA ELABORATION AND STATYSTICAL ANALYSIS

A total of 383 news media identified tree-related failures were recorded from 2013 through 2015, recorded and analyzed (Fig. 1). Of the 383 trees, 90% (345) of the failures involved the entire tree, while the remaining 10% (38) involved branches. In 70% of cases precipitation was present, 67% for rainfall and 3% for snowfall. Fatality cases comprised 2% of the total number of incidences assessed, while persons injured by or people involved in tree failures reached 86%. Cars were struck in 52% of cases while damage to buildings was 15% of the time. Other damages (electrical lines, railways, water pipes, street lamps, garbage dumpster, cable car, metro) comprised 8% of the events.

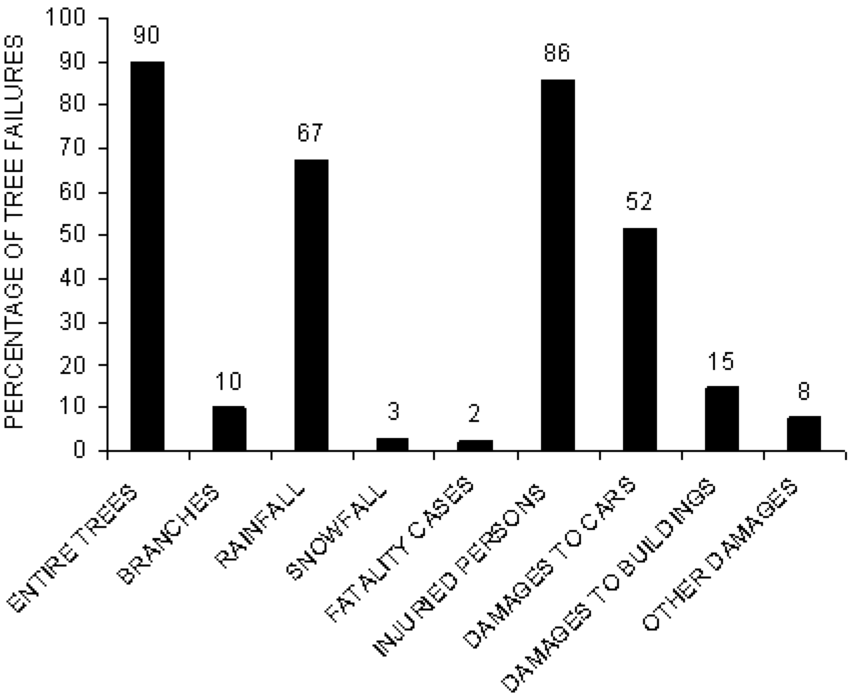

Figure 1 : Percentage analysis of tree failures in Italy from year 2013 to year 2015: cases of tree failure and branch failure, frequency of precipitations, fatality cases, injuried persons, and other damages.

Figure 1 : Analyse en pourcentage des ruptures d'arbre en Italie de l'année 2013 à l'année 2015: les cas de rupture d'arbres entiers ou de seules branches, la fréquence des précipitations, les cas de décès, les personnes blessés, et d'autres dommages.

Analysis of tree failures in relation to maximum wind speed shows that all tree failures are normally distributed among an average value of 5 on the Beaufort Scale, which equated to the calculated mean

value of 33 km/h (Fig. 2A). In the description of the Beaufort scale, the value of 5 indicates a fresh breeze where branches of a moderate size move and small trees in leaf begin to sway.
However, in 58% of cases the wind was gusty so we could further analyze tree failures in relation to wind speed according to the presence or absence of gust (Fig. 2B), and significant differences were observed (*P*<0,01). In fact, when gusty, tree failures in relation to maximum wind speed are normally distributed among an average value of 6 Beaufort, which correspond to the calculated mean value of 42 km/h. In the description of Beaufort scale, the value of 6 indicates a strong breeze where large branches are in motion, whistling in overhead wires is heard, the use of the umbrella becomes difficult and empty plastic bins tip over. In these cases, tree failures are also normally distributed among an average value of gust of 7 Beaufort, which correspond to the calculated mean value of 62 km/h. In the description of Beaufort scale, the value of 7 indicates strong wind or moderate gale, where whole trees are in motion and an effort is needed to walk against the wind.
When not gusty, in the remaining 42% of cases, tree failures are normally distributed among an average value of maximum wind speed of 4 Beaufort, which correspond to the calculated mean value of 22 km/h. In the description of the Beaufort scale, the value of 4 indicates a moderate breeze where dust and loose paper is raised and small branches begin to move.

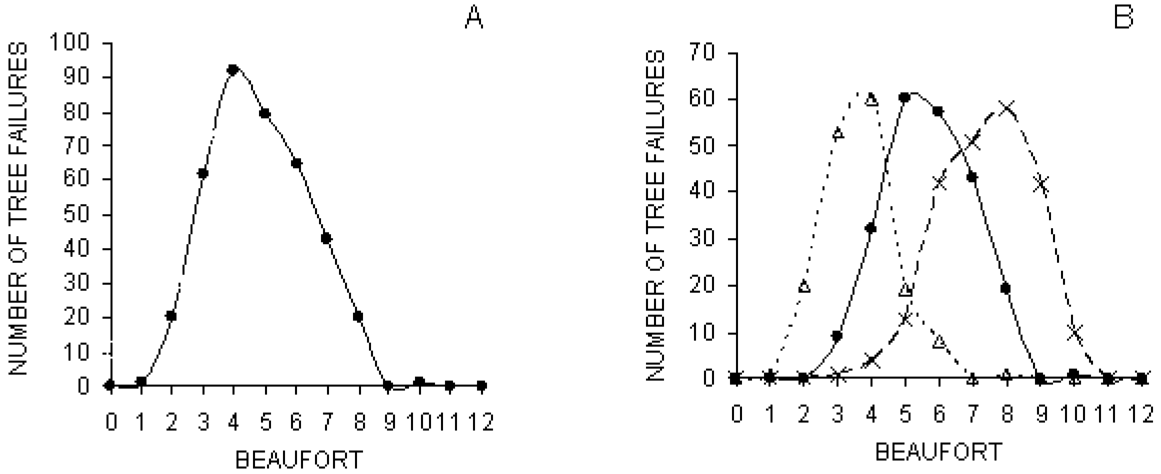

Figure 2 : Distribution of tree failures in relation to wind speed (Beaufort). **A**: tree failures are normally distributed around an average value of maximum wind speed of 5 Beaufort. **B**: when the wind is gusty, tree failures are normally distributed around an average value of maximum wind speed of 6 Beaufort (•) and normally distributed around an average value of gust speed of 7 Beaufort (×). When the wind is not gusty, tree failures are normally distributed around an average value of maximum wind speed of 4 Beaufort (Δ)
Figure 2 : Distribution des ruptures d'arbre par rapport à la vitesse du vent (Beaufort). A: les ruptures d'arbre sont normalement réparties autour d’une valeur moyenne de la vitesse maximale du vent de 5 Beaufort. B: quand le vent est en rafales, les ruptures d'arbre sont normalement réparties autour d’une valeur moyenne de la vitesse maximale du vent de 6 Beaufort (•) et normalement réparties autour d’une valeur moyenne de la vitesse de rafales de 7 Beaufort (×). Quand le vent ne souffle pas en rafales, les ruptures d'arbre sont normalement réparties autour d’une valeur moyenne de la vitesse maximale du vent de 4 Beaufort (Δ)

When land use was analyzed, the majority of tree failures (82%) occurred in streets, while 8% of tree failures occurred in public gardens, 4% occurred in schools and hospitals, 3% occurred in private gardens and 2% in a rural context (Fig. 3).
The number of tree failures per km^2 was calculated for each region of Italy, and Lazio, Liguria and Campania resulted to be the regions with the higher frequency of tree failure (Fig. 4). Molise, Basilicata and Valle d’Aosta had no crashes at all in the analyzed period.

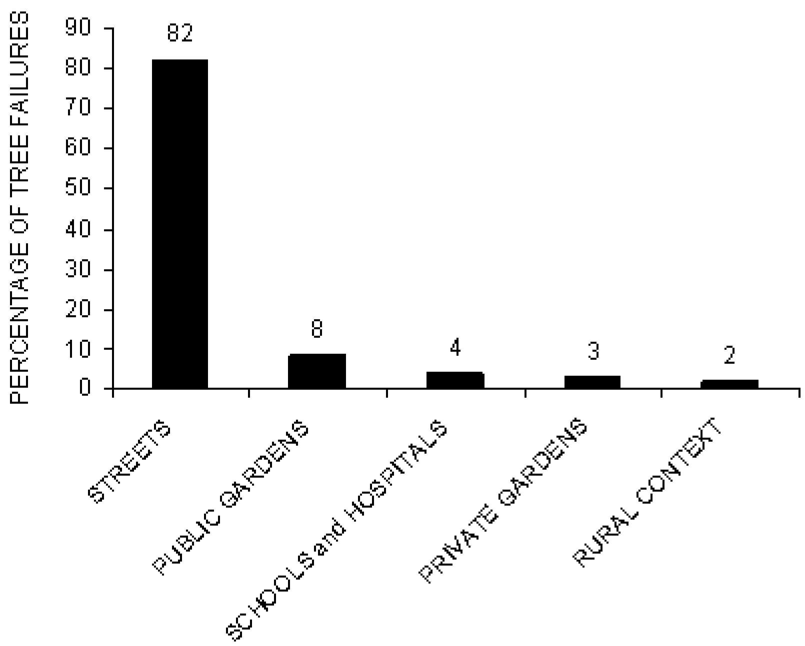

Figure 3 : Distribution of tree failures (percentage) according to different rooting sites.
Figure 3 : Distribution de ruptures d'arbre (pourcentage) par rapport aux différents sites d'enracinement.

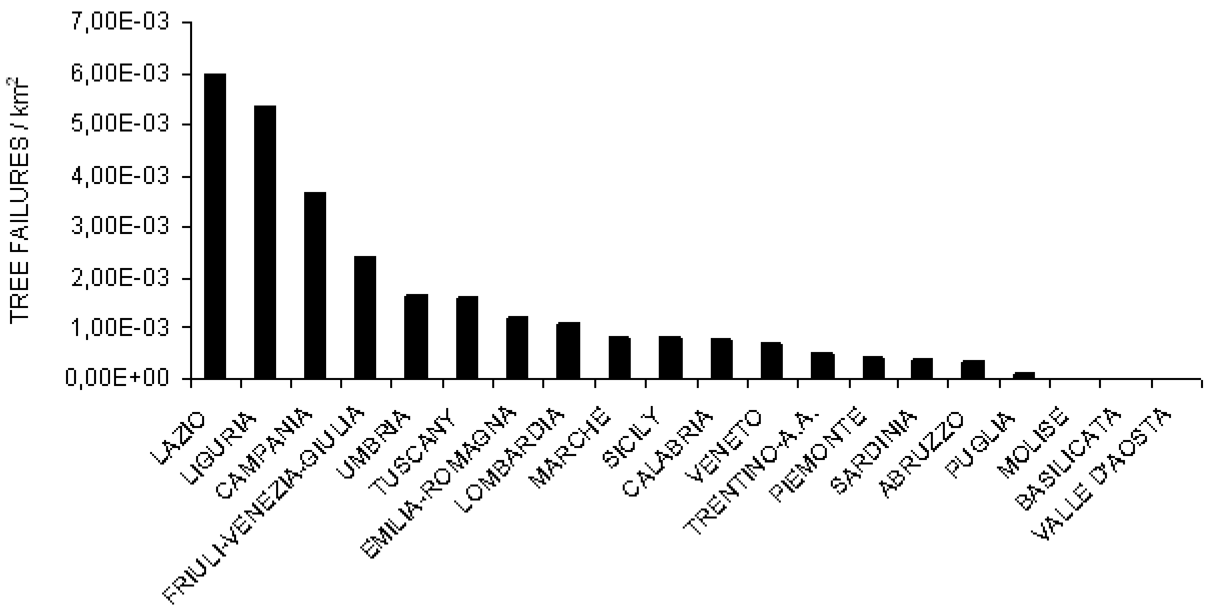

Figure 4 : Distribution of tree failures in the twenty different regions of Italy.
Figure 4 : Distribution de ruptures d'arbre dans les vingt Régions d'Italie.

However, according to Eurocodice 1 (CNR, 2009), which subdivides and groups regions in nine different zones according to the planned wind speed (Fig. 5; CNR, 2009), Liguria (zone number 7) has the highest number of tree failures per km^2 (Fig. 6), followed by Trieste province (zone number 8), and zone number 3, which includes several regions: Tuscany, Marche, Umbria, Lazio, Abruzzo, Molise, Puglia, Campania, Basilicata, Calabria (except Reggio Calabria province). In the zone number 6 (West Sardinia) no tree failure was recorded.

Figure 5 : Map of the nine different zones of Italy according to the reference wind speed of Eurocodice 1 (CNR, 2009).

Figure 5 : Carte des neuf zones différentes de l'Italie par rapport à la vitesse du vent de référence Eurocodice 1 (CNR, 2009).

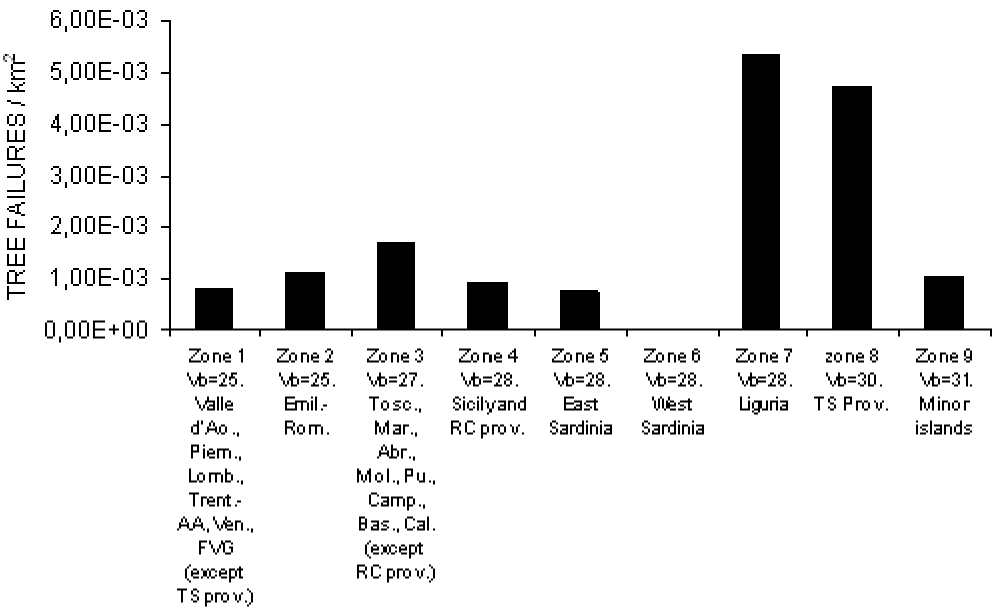

Figure 6 : Distribution of tree failures in the nine different zones of Italy according to the reference wind speed (Vb) of Eurocodice 1 (CNR, 2009).

Figure 6 : Distribution des ruptures d'arbre dans neuf zones différentes d'Italie par rapport à la vitesse du vent de référence (Vb) de Eurocodice 1 (CNR, 2009).

Concluding, in only 40% of cases we were able to obtain information about the species involved or, at least, the genus and we observed that, in 35% of cases, broad-leaved trees were involved in tree failures while the majority of failures was caused by conifers (62%). Only a small percentage of palms (3%) failed (Fig. 7).

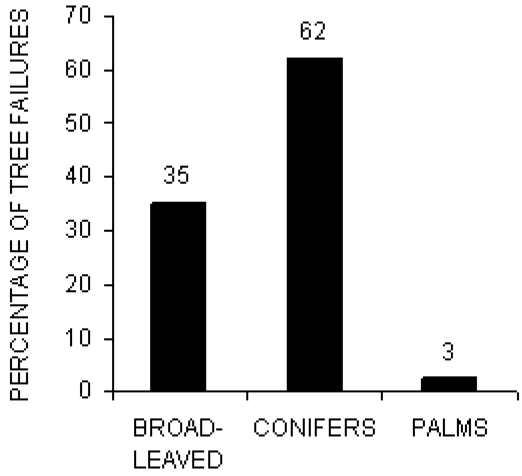

Figure 7 : Trees involved in failures (percentage).
Figure 7 : Arbres impliqués en crashes (pourcentage).

DISCUSSION

Tree failure is a natural phenomenon which is part of tree's biological cycle. However, in the coexistence between trees and humans, this type of event should be prevented and avoided as much as possible in order to minimize damages to people and property (Lilly S.J., 2010; Dunster J.A. *et al.*, 2013). Aiming to reach the minimum hazard and risk related to trees, the authors believe that, in addition to the continuous monitoring of trees and of risk assessment, the analysis of tree failure is essential to identifying the causes and the circumstances of such negative events. Therefore, data analysis here proposed aims to highlight some data about tree failures in Italy. First of all, data analysis here reported is limited, as regards individual or few tree failures, however sufficiently described in numerical terms. In case of storms where a generic multitude of trees failed, such data have been discarded from the analysis due to the lack of precise numerical information. In addition, the study was limited to failures reported from the chronicles and where weather data was limited to the nearest available metereological station.

However, data analysis of the years 2013, 2014 and 2015, returned interesting facts about tree failures. In most cases, whole trees were involved (90%), while a minority of failures (10%) involved the failure of branches. Possibly, trees are more susceptible to failure entirely, while branches are involved in the minority of crashes, or that collapse of branches does not cause significant damage to justify the media to report it. In any case, only 2% of tree failures lead to fatality cases, a very low percentage compared to the intimate coexistence of urban trees with the population, although people injured or involved cover a high percentage (86%). Property damages should not be underestimated because in 52% of tree failures a motor vehicle is involved. Buildings in 15% of cases suffered some damages and damages to power lines, railways, pipes, street lamps, garbage dumpster, cable cars, subways together hold 8% of crashes. In general terms, adding together individual percentages of material damages,a tree hits an object in 75% of cases while failing. This percentage analysis of harm to people and objects can be essential in the hypothesis of tree risk assessment campaigns. Therefore, considering the percentages of people either died or injured and property damage, social costs associated with tree failures must be very high.

Analyzing the meteorological circumstances of tree failures, despite the inherent imprecision of data collection, it has been possible to detect a statistical significance. In fact, at first glance, considering only the maximum wind speed, tree failures are distributed normally around a value of 5 Beaufort (fresh breeze), corresponding to the calculated average of 33 km/h (Fig. 2A). However in 58% of crashes gust speed was also recorded.Therefore, we further analyzed the crashes depending on gusty and not gusty wind (Fig. 2B). In fact, we have been able to observe particularly that the majority of tree failures (58%) occurs in strong breeze conditions (6 Beaufort) with gusts of strong wind or moderate gale (7 Beaufort). However, still a high percentage of tree failures (42%) take place even in moderate breeze conditions (4 Beaufort), in absence of gust, where only small branches are in motion. A wind strength apparently much less worrying for the occurrence of tree failures that emphasizes the static instability of many trees, which requires only a breeze to fail. Moreover in the 67% of crashes rainfalls are present. Therefore, rainfall seems to be a determing factor in tree failure, probably saturating the soil, thus overcoming the ability of roots (probably already compromised) to dissipate the wind energy intercepted by the foliage to the ground.

Interestingly, in most of the crashes (82%) road trees are involved. It is clear that the worst conditions for growth and self-sustenance of trees specimens occur in heavily urbanized contexts. Road trees are in fact the ones most exposed to repeated damages to root systems due to re-development of the road itself and installation of underground utilities that may deprive the tree of some of anchoring roots and expose to the risk of infection by fungi. Root system so weakened can make the trees more susceptible to failure than other urbanized contexts such as parks and gardens.

Analyzing the distribution of tree failures the authors identifed the Italian regions most affected by crashes. The first standings regions are Lazio, Liguria and Campania, followed gradually by the other regions. Understanding the causes of these primates is not simple. In part, the causes can be related to a greater propensity of these regions to be subjected to particularly intense meteorological phenomena and, in part, to a greater state of impairment of trees that facilitate the collapse.

A more standardized distribution of tree failures can be viewed in figure 6, where the regions of Italy are grouped into nine different zones depending on the planned wind speed, used for functional engineering calculations for the construction of buildings (Fig. 5; CNR, 2009). In this graph it is possible to identify the regions most affected by strong winds, where, in theory, we can expect a higher number of failures. In fact at first glance Liguria region (the only region constituent the zone 7 with a planned wind speed of 28 m/s) holds the record of tree failures. However also zones number 4, 5 and 6 have a planned wind speed of 28 m/s, therefore, a similar number of crashes/km^2 in these zones should be expected. Presumambly, the pronounced difference between zone 7 and zones 4, 5 and 6 is due to other environmental factors, beyond wind strenght. In fact, Liguria is a region particularly sensitive to flooding, landslides and overflowing of rivers and it is assumed that in addition to wind speed, the frequency of these environmental disasters can significantly predispose Liguria region to a greater number of tree failures compared to the homologous zones 4, 5 and 6.

Trieste province (constituting zone number 8, with a planned wind speed of 30 m/s) on the other hand holds the second place in terms of tree failures. In this case, however, it is possible to correlate the high frequency of crashes with the presence of a very strong wind called Bora, which blows frequently with gusts that can even exceed 150 km/h. Theoretically, even on the smaller islands, constituting zone number 9 with a planned wind speed of 31 m/s, we could expect a similar incidence of tree failures. However, since these islands are very small and less populated compared to the mainland, tree failures were probably not been reported in chronicles or, alternatively, the tree population is less dense and composed of native species well adapted to the local conditions.

Finally, the authors observed that the conifers are the most common class of trees involved in failures. However, only in 40% of crashes tree species was reported. This fact needs to be confirmed by more detailed data collection through the use of an official Tree Failure database where species should be indicated precisely.

CONCLUSIONS

Tree failure is a natural phenomenon and occurs following the normal Gaussian distribution in relation to wind strength. The observation of this natural phenomenon, although through approximate data collection, is extremely useful at both local and national level to monitor tree failures and to identify the categories of trees more susceptible to failure respect to the rooting site. Even in presence of a moderate breeze, in absence of gusts, tree failures occur, suggesting how wind becomes a significant factor especially when acts synergically with other phenomena, such as rainfall. Aboveground and underground human activities (pruning, work in progress) that interfere with trees impair their integrity, especially when located in extremy urbanized ares susch as roads. This category of trees seems to be above all the most susceptible to failure due to anthropogenic disturbances and monitoring road trees should be accomplished frequently and carefuly. Despite tree failures, few fatality cases occur, although a high percentage remains involved or injured. Similarly, damages to objects bear a high percentage. These conclusions, however have been reached analyzing data from media sources, therefore it is assumed that they can also not be strictly accurate and reliable for statistical calculation. Therefore, the adoption of a Tree Failure Database where data analysis can provide a more complete and comprehensive view of tree failures it is recommended, with the aim to identify the main causes and to confirm the effectiveness of tree stability assessment campaigns.

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