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An Analysis of Fires on Pleasure Boats in Primorje-Gorski Kotar County

Abstract

Fires on pleasure boats represent a serious safety threat due to confined spaces, the presence of flammable materials, and the frequent lack of adequate or appropriate fire protection equipment. In addition to the direct endangerment of human life and material property, such incidents also have a significant adverse impact on the marine environment as a result of the potential release of fuel and other hazardous substances.
The purpose of this study is to analyze the frequency, causes and consequences of fires on pleasure boats in Primorje-Gorski Kotar County, as well as to identify the key factors influencing their occurrence. The research results indicate that the most frequent cause of fires on pleasure boats was technical failure (93%), primarily associated with electrical installations, while fires resulting from human actions accounted for 7% of the recorded cases. Furthermore, fire incidents predominantly occurred during the summer months, particularly in areas characterized by intensive nautical tourism, suggesting a clear relationship between seasonality, increased utilization of pleasure boats, and an elevated risk of fire. The authors' contribution lies in the systematic analysis of available regional data on fires on pleasure boats and in the identification of risk factors that can serve as a basis for improving preventive measures, enhancing fire-protection, and increasing navigational safety.

Keywords: Fires on pleasure boats, safety, nautical tourism, Primorje-Gorski Kotar County

1. Introduction

A fire can be defined as the uncontrolled spread of flames within a space, causing material damage as well as potential injuries to the crew or passengers, and in some cases, tragic outcomes [1]. Fires on boats are among the most serious accidents in marine transport, as they can lead to the total loss of the vessel, damage to or destruction of cargo, environmental pollution, and severe injuries or loss of human life [2]. In addition to human casualties, fires can also cause substantial material damage [3]. The production of toxic smoke in fires has become recently (the past few decades) a major threat to victims of accidental fires [4]. In many countries, the direct annual fire losses amount to about 0.2% of a gross domestic product (GDP), but if the costs of intervention services, fire protection measures, premium of the fire insurance and consequent losses in the production and trade are added to this, the total costs of fires rise to approximately 1% of GDP [5].

Despite continuous improvements in navigational safety and development of fire-prevention and rescue technologies, serious accidents caused by boat fires continue to occur [6]. Therefore, it is essential to ensure the highest possible level of fire protection [7].

A fire can ignite in various environments [8], including pleasure boats located in harbors and marinas. Such fires pose a serious safety risk, as they can spread rapidly due to the proximity of other boats, confined spaces, and the presence of flammable materials. Furthermore, the complex conditions for firefighting at sea and in harbor areas further complicate effective intervention and increase the potential severity of the consequences.

The causes of fires can include direct contact with flames or heated materials, electricity, static electricity, explosions and explosive phenomena, friction, pressure, impact, spontaneous combustion, as well as natural causes such as lightning, earthquakes, or solar energy [9]. Determining the cause of a fire involves a combined forensic investigation conducted through the examination of burned objects [10]. The aim of this investigation is to establish whether the fire resulted from a technical failure or system malfunction, or whether it was intentionally set.

The paper is structurally divided into five main parts. After the introduction, the second part describes the stages of fire occurrence. The third part of the paper explains the importance of the procedure for determining the cause of fires on vessels, as well as the course of the procedure itself. The fourth part analyses fires on pleasure boats in the Primorje-Gorski Kotar County. The final, fifth part, consists of the final comments.

2. Stages of fire development

For combustion to occur, fuel and oxygen, or another substance that supports combustion, must be present in an appropriate ratio, and a sufficiently strong ignition source must be available [11]. The fire triangle (Figure 1) represents a basic model

illustrating the three key elements required for the initiation and sustenance of fire. These elements are **fuel** (such as wood, paper, oil), **oxygen** (from the air), and a heat source (spark, flame, or high temperature). A fire can be extinguished by removing any one of these elements, for example, by cooling, smothering, or eliminating the combustible material.

Figure 1. Fire triangle
Source: [12]

The development of a fire occurs through several characteristic stages, knowledge of which enables timely hazard assessment, appropriate operational decision making, and the effective implementation of fire-protection measures. The process of fire ignition and development on a pleasure boat may be classified into four stages (Figure 2).

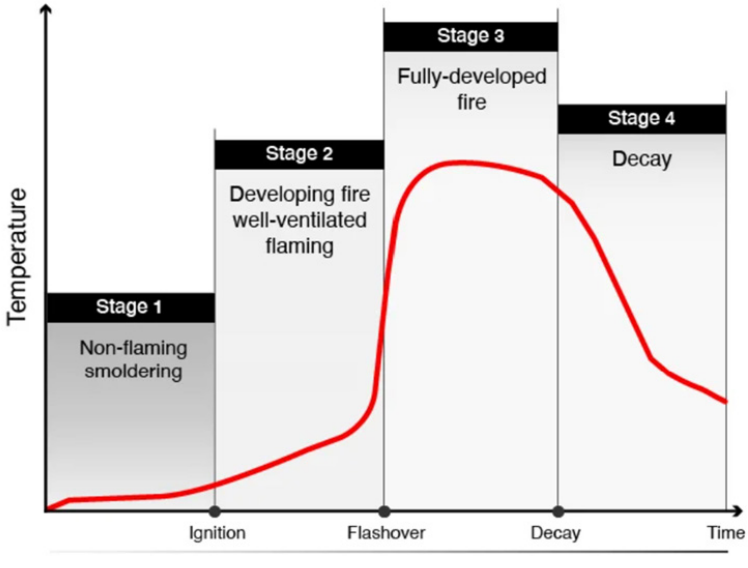

Figure 2. Fire development stages
Source: [13]

Stage 1 begins with the ignition of combustible material due to the action of an ignition source, such as electrical faults, engine overheating, mechanical sparks, or the presence of an open flame. Combustion during this stage is characterized by low intensity, a limited area of impact, and relatively small releases of heat energy and combustion products. Fires in this stage often go unnoticed due to the subtle nature of these indicators. However, it is precisely at this point that conditions are most favorable for rapid containment and successful extinguishing with minimal consequences. During the incipient stage, surrounding combustible materials gradually heat up, creating conditions for further fire development. The transition from the incipient stage to the growth stage is not strictly defined but is indicated by an increase in the volume and temperature of the burning layer, as well as accelerated fire growth due to the continuous supply of oxygen. Smoke at this stage is weak, light in color, and has limited buoyancy, so its height and volume remain small.

In stage 2, the burning area gradually expands, accompanied by a significant increase in temperature. The increased release of heat, together with the accumulation of smoke and toxic gases, reduces visibility. At the same time, the thermal load on structural elements rises, creating conditions for accelerated fire growth. Convection and thermal radiation transfer heat to surrounding surfaces, further promoting flame spread. The heat flux is intensified by the combined effects of radiative and convective heat transfer. Smoke serves as a primary indicator of combustion intensity and fire development. Timely detection and effective intervention during this stage are crucial to preventing the transition to a fully developed fire, at which point the fire becomes much more difficult to control.

The fully developed fire stage (stage 3) is characterized by maximum combustion intensity, during which most or all of the available fuel within the space is involved. Temperatures reach extreme levels, and the rate of heat release is at its peak. In enclosed spaces, a flashover may occur, making a sudden transition from the early fire growth stage to a fully developed fire. Flashover is a thermal instability phenomenon characterized by a rapid transition from the growth period to the fully developed fire [14]. Flashover promotes rapid flame spreading from a relatively small local area over all the combustible surfaces [15]. Extinguishing a fire at this stage is extremely complex and hazardous.

The fire decay stage (stage 4) occurs after the depletion of combustible materials or as a result of successfully implemented extinguishing measures. During this stage, the intensity of combustion and temperature gradually decrease; however, the space may still pose a serious hazard due to the presence of toxic and potentially explosive gases, as well as the risk of re-ignition upon contact with oxygen. Although oxygen concentration decreases, in poorly ventilated conditions temperature within the space may continue to rise, further increasing the risk of secondary ignition. Continued gradual extinguishing requires systematic cooling of affected surfaces, thorough inspection and removal of remaining combustible materials, and continuous monitoring to ensure complete stabilization and prevent fire reactivation. This stage is typically

the longest in the fire cycle, lasting until combustion fully ceases and all combustion products and toxic gases are completely cleared from the space.

Fires on nautical tourism vessels represent a specific safety risk due to confined spaces, flammable materials, and the presence of fuel in close proximity to heat sources. On yachts, sailing boats, and motorboats, common causes of fires include electrical system failures, fuel leaks, engine overheating, and improper handling of gas installations in galleys. Compared to fires on land, firefighting is more difficult because vessels are isolated, fire can spread rapidly, and access to emergency services is limited, especially when at sea.

A particular challenge arises in marinas, where a fire can quickly spread from one vessel to another due to the short distance between them and the large amount of combustible materials present. In such situations, early fire detection systems, onboard firefighting equipment, and a prompt response by the crew and marina staff play a crucial role. Prevention, regular technical inspections, and the education of boaters are therefore essential for reducing the risk and consequences of fires in nautical tourism.

3. Procedure for determining the causes of fires on pleasure boats

Determining the cause of a fire is carried out through a systematic and interdisciplinary procedure that includes on-site investigation, the collection of relevant data, and expert examination of recovered traces and materials.

Before initiating the procedure for determining the cause of a fire on a pleasure boat, it is necessary to inspect the scene and establish the following facts [10]:

- ◊ The location and time of fire ignition
- ◊ Identification of the affected party (owner or operator of the pleasure boat)
- ◊ Type of pleasure boat, year of construction, model, and registration number
- ◊ Technical specifications of the pleasure boat, including number, type, and power of engines; overall dimensions (length, beam, draft); and displacement
- ◊ Collection of eyewitness accounts detailing the time and sequence of events, with review of any available photographic or video evidence of the fire
- ◊ Time of fire report and arrival of firefighting units
- ◊ Information from firefighting personnel regarding the progression and extinguishing procedures, supplemented by any photographic or video documentation captured during firefighting operations
- ◊ Review of surveillance camera footage
- ◊ Acquisition of technical documentation and schematics for pleasure boats of the same model as the affected boat
- ◊ Comparative inspection of a similar model pleasure boat, if available at the marina or port, to assess structural and technical characteristics
- ◊ Determination of the operational status of the pleasure boat at the time of fire (moored, dry-docked, or underway)

◊ Identification of the boat's power supply system (220 V AC shore power, 12 V or 24 V DC battery, or solar powered via photovoltaic modules).

In the event that one or more pleasure boats have burned and, as a result of fire related damage, have sunk, the recovery of the sunken boats must be carried out prior to conducting the site inspection. Furthermore, all detached components of the boats that sank to the seabed during the fire must also be retrieved. After recovery, in the case of multiple burned boats that were moored in a marina, the boats should be repositioned according to their previously established order, i.e., in the same sequence in which they were originally moored.

All of the aforementioned facts must be identified and documented in order to ensure a comprehensive and reliable basis for further proceedings. Only after the on-site inspection has been completed and relevant data have been collected can an expert determination of the cause of the fire be undertaken.

The determination of the cause of fire on pleasure boats begins with a visual inspection of the boat damaged by fire and the surrounding area. During the initial examination, thermal damage to the exterior of the hull, mooring lines, fenders, as well as to the engine room, passenger areas, cabins, and the bridge is assessed. Particular attention is paid to electrical systems, whereby a detailed inspection is conducted to identify thermal damage to battery banks, cable harnesses, and electrical installations connecting the batteries to the starter motor, alternator, bilge pump, and distribution panels.

Power supply cables for alternating current (220 V) and direct current (12 V and 24 V) are analyzed, along with distribution panels containing fuses and relays, battery chargers, generators, and other electrical equipment. Thermal damage on the bridge, including the control console, is also documented.

In the event that a pleasure boat has sunk as a result of a fire, following its recovery from the sea it is necessary to inspect the remaining structure of the boat as well as any components that became detached during the fire, and to determine the extent and nature of their damage. All observed thermal damage and traces are documented by photographic recording, after which disputed or relevant traces are collected and preserved for further laboratory examination.

4. Analysis of fires on pleasure boats in the Primorje-Gorski Kotar County

In this study, fire incident data collected over a six-year period (2019–2024) were systematically analyzed. The dataset was obtained from official records compiled by inspectors of the Fire Protection, Explosives, and Weapons Inspection Service, who conduct on-site investigations and document the circumstances, causes, and consequences of fire events. The use of these authoritative and professionally verified sources ensures the reliability, accuracy, and credibility of the analyzed data.

The data were classified according to the type of incident, and the fires were grouped into the following categories: structures, open areas, vehicles, vessels and explosions (Figure 3).

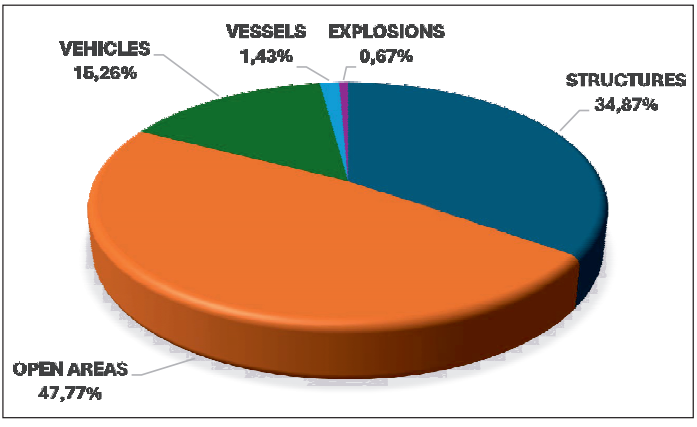

Figure 3. Fires by category

Based on the presented data, a clear difference in the frequency of individual types of fires can be observed. Fires in open areas account for the largest share (933 cases) while fires involving structures (681 cases) also represent a significant proportion of the total number of interventions. Fires involving means of transport were recorded in a considerably smaller, yet still relevant, number (298 cases). In comparison with the aforementioned categories, fires on pleasure boats (28 cases) and explosions (13 cases) occur relatively infrequently. However, despite their lower incidence, these events are characterized by a high level of hazard, as they often result in severe consequences for human life, property, and the environment.

Fires on pleasure boats, although accounting for a relatively small share of the total number of fires (1.43%), represent a specific and particularly high-risk category of emergency incidents. Their low frequency does not diminish the seriousness of the potential consequences, as such fires occur in confined spaces and often under conditions that complicate evacuation and firefighting, especially at sea or within port areas.

An analysis of the causes of fires on pleasure boats revealed that technical factors were predominant during the observed period, accounting for 93% of all recorded incidents. Within this category, the most frequent cause was failure of electrical installations. Fires resulting from human action, including deliberate ignition, represented the remaining 7% of cases. A total of 17 fires were recorded in marinas, of which three occurred at dry dock, while 11 were reported in harbor areas. The number of fires on pleasure boats during the observed period is presented in Figure 4, and their distribution by month is shown in Figure 5.

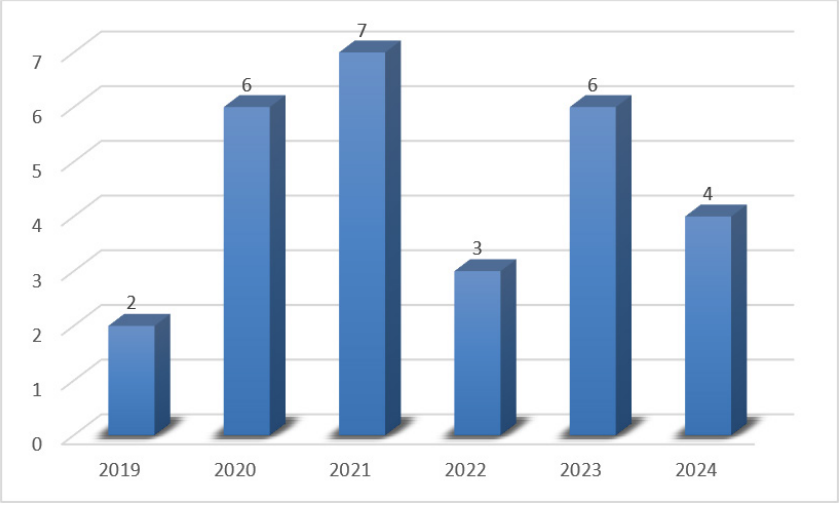

Figure 4. Number of fires on pleasure boats, 2019-2024.

The analysis of the number of fires in the period from 2019 to 2024 indicates moderate year-to-year fluctuations, without a clearly defined long term upward or downward trend. Following a relatively low number of fires in 2019, a pronounced increase was recorded in 2020 and 2021, reaching a peak in 2021. In 2022, a significant decrease in the number of fires was observed. However, an increase is again recorded in 2023, followed by a slight decrease in 2024.

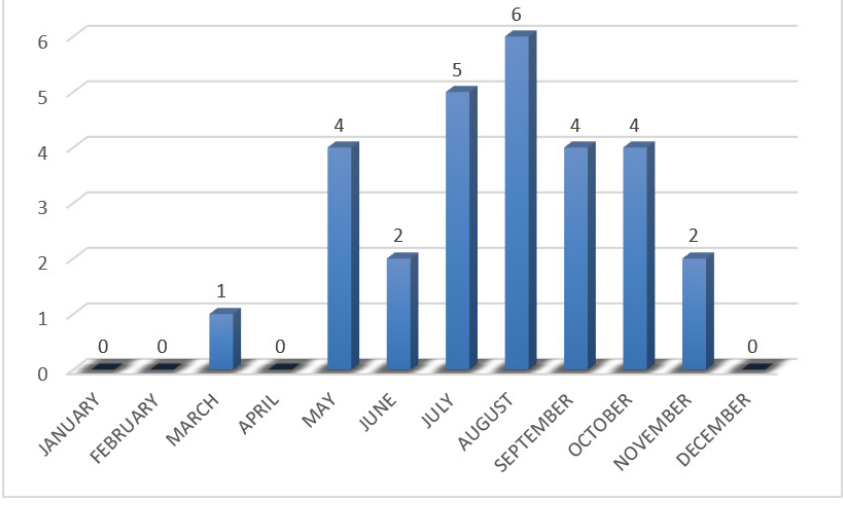

Figure 5. Number of fires on pleasure boats by month, 2019-2024.

Overall, the data indicate a correlation between the number of fires on pleasure boats and the seasonal intensity of their use, which is particularly pronounced from May to October. These findings emphasize the need for enhanced preventive measures, increased supervision, and the education of pleasure boat owners and users.

5. Conclusion

The conducted research on fires on pleasure boats in Primorje-Gorski Kotar County provided a systematic and analytically grounded insight into the frequency, causes, and circumstances of these extraordinary events during the period from 2019 to 2024. One of the key achievements of the study is the determination that technical factors represent the dominant cause of fires (93%), with failures of electrical installations standing out as the most common initial cause of ignition. This clearly confirms the need for regular technical inspections, monitoring of electrical systems, and timely vessel maintenance.

The research also demonstrated a pronounced seasonality of fires, with the highest number of incidents occurring during the summer months, that is, during the period of intensive nautical tourism. This correlation between increased vessel use and a higher risk of fire represents an important contribution to understanding safety challenges in the nautical tourism sector and highlights the need for enhanced preventive measures precisely during periods of peak occupancy in ports and marinas.

The particular value of this study lies in the systematic processing of regional data and the identification of key risk factors, including the technical condition of vessels, mooring conditions, and the organization of safety measures in marinas. The obtained results provide a professional and analytical foundation for improving preventive activities, modernizing early fire detection and suppression systems, and further educating vessel owners and users.

In conclusion, although fires on pleasure boats account for a relatively small proportion of total fire statistics, their potential consequences for human life, material property, and the marine environment require continuous professional attention. This study contributes to enhancing the level of navigational safety through concrete findings that may serve as a basis for further research, the development of preventive strategies, and the strengthening of fire protection systems in the nautical sector.

The results of this research open up possibilities for further and more detailed studies. Future research should include extending the analysis to a longer time period and incorporating national-level data in order to compare regional and national trends. It is also recommended to conduct comparative studies among different coastal counties to determine possible differences in the frequency, causes, and consequences of fires on pleasure boats.

An additional research direction may involve a more detailed technical analysis of electrical installation failures, including laboratory testing of damaged components and assessment of the reliability of specific power supply systems. Special attention should

be given to the development and effectiveness of early fire detection and automatic suppression systems on smaller vessels, as well as to evaluating their cost-effectiveness in relation to potential damage.

Furthermore, it would be beneficial to examine the level of safety culture and awareness among vessel owners and users, including their familiarity with preventive measures and proper procedures in the event of a fire. The integration of technical, organizational, and human factors through an interdisciplinary approach could contribute to the development of a comprehensive risk assessment model, thereby further improving navigational safety and reducing the likelihood of fire incidents in the nautical tourism sector.

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