2016

SURVEY AND ANALYSIS OF FATAL ACCIDENTS IN THE COMMERCIAL DIVING SECTOR

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01/09/2016

Acknowledgments

Many thanks to Kyra Richter for her valuable help in the translation of this document.

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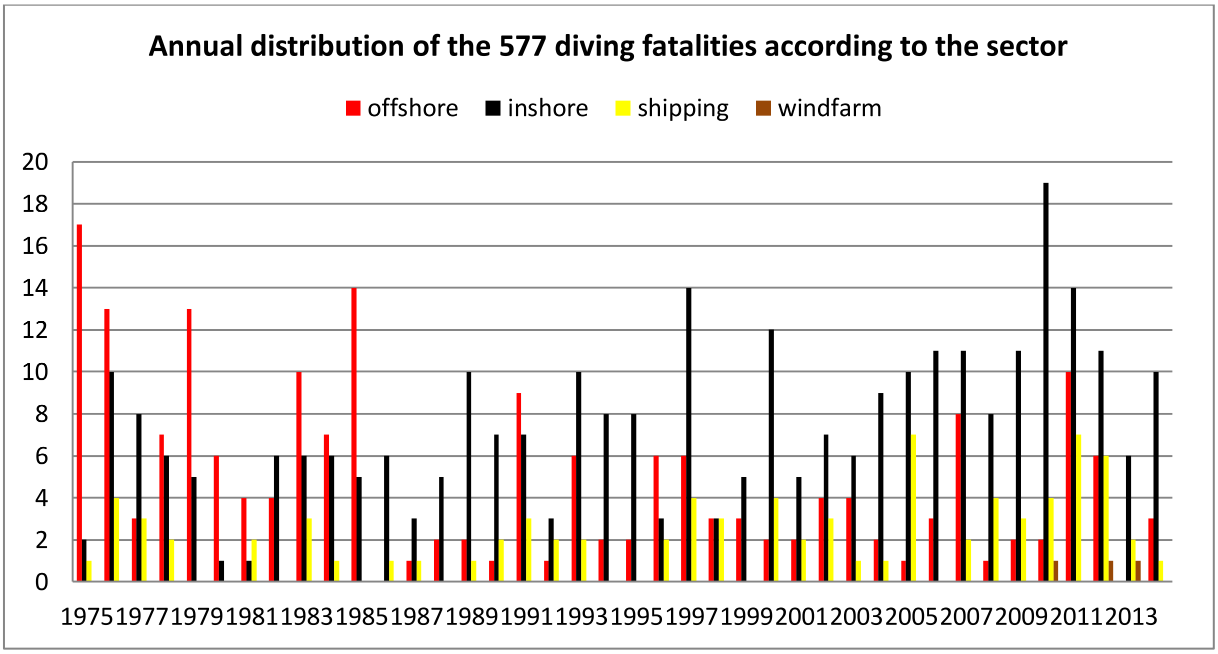
Abstract

Since always and whatever the category, professional divers encountered a lot of accidents which are, due to the environment often lethal.

As the causes of these accidents are often the same, the purpose of the present article is to highlight those most frequently encountered and therefore no less than 577 diving fatalities spread over the last forty years have been analyzed in this study.

The results of the survey led to the conclusion that many of these accidents could have been avoided.

Chart n° 1:



Object

It is a well-known fact that professional diving is a job which can, depending on the nature of the activity, prove to be hazardous or even fatal.

To date, very few studies have been conducted on the risks of this commercial activity, and rare are the organizations which recognize and list accidents in this sector. In the United States the OSHA (Occupational Safety & Health Administration) conducted such a study in 1998 on an estimated population of 3,000 American commercial divers and following this, the CDC (Centers for Disease Control and Prevention) concluded that the annual fatality rate was about 181 per 100,000 which, at that time, was about 40 times higher than that of all the other sectors[1].

Elsewhere, other countries such as England and France report significantly lower values, but are unfortunately still far superior to that of the construction sector of which the risk factor itself is already higher than other sectors.

Thus, in the UK the fatality rate ranges, according to figures published in 2010 by HSE [2], are from 20 to 40 per 100,000. This risk factor is 12.3 to 24.7 times higher than that of the construction sector [3]. While in France this rate is estimated at 112 per 100,000; which means a risk factor of 8 to 10 times higher than the same construction sector [4, 5].

Here in Belgium no official statistics have been realized, but according to the accidents (5 with 7 victims) which took place during the four decades included in this survey and by extrapolating some data, it can be concluded that the death rate is about 233 per 100.000 commercial divers, which is about 11, 9 times higher than the construction sector.

This death rate may seem high, but one has to be aware that in Belgium the number of people working in the commercial diving sector were and still are quite small (+/- 50 in 1975 and + / - 100 currently).

The purpose of the present article is not to validate or challenge these figures, but rather to highlight the types of accidents most frequently encountered in commercial diving depending on the underwater activity.

For this, several sources of information were consulted [6, 7, 8, 9, 10, 11] but the most important is the Incidents Diving 2100.xls [12] list that thanks to the professional community identifies and tracks data worldwide.

Currently, this database lists no less than 2738 incidents / accidents from 1841 to date.

Despite this high number, it is likely that it concerns only a fraction of the reality, because many incidents, especially before the era of the Internet, were known only by local diver communities or, in some cases, were / are kept secret.

The lack of data of some facts should not normally interfere too much on the results of this study, because it is based on a discrete period going from 1975 to 2014 during which no less than 577 fatalities were analysed to determine the causes of death.

Finally, this study is intended to be international as so rightly said by Kyra Richter [9] "after all 150 feet (45 m) of water here is equivalent to 150 feet (45 m) of water off the coast of Africa" and therefore a commercial diver working at that depth will be in function of the underwater activity he is doing confronted to the same risks.

DESCRIPTION OF THE ELEMENTS INCLUDED IN THIS SURVEY

Diving sectors

The diving sectors of this study are respectively:

- Offshore.
- Inshore / Inland.
- Shipping.
- Wind farm.

These four categories are part of what is commonly known as commercial diving.
There are also other sectors in which divers are paid when they go to water.

These are, among others:

- Shellfish and aquaculture.
- Archaeology.
- Rescue services.
- Police.
- Military.
- Scientists.
- Diving monitors.

These various categories also make part of the professional diving world, but, although the number of accidents listed in these categories during the last forty years is relatively high (457), they are not included in this article because the work done by these divers is different from those made by commercial divers.

Diving modes

Commercial divers have several modes of diving to reach their work site.
Those used in this study are respectively referred to as:

Scuba:

- Scuba diving with or without a lifeline.

SDD:

- Diving from the surface with an umbilical connected to a switchboard high pressure (HP) / low pressure (LP) or a LP compressor.

Diving bell and / or saturation:

- Bounce or saturation diving done from a bell (or fatality in the saturation chamber).

Causes

The main causes generating fatalities in the field of commercial diving are referred in this survey under the names of:

Delta P:
- Fatal accident caused by a pressure differential

Explosion:
- Fatal accident caused by an explosion during thermal or mechanical cutting.

Propeller:
- Fatal accident caused by the passage of the diver through the blades or when the umbilical was fouled by the wheel.

Trapped:
- Fatal accident caused by the entanglement or hooking of the diver with the impossibility of escape.

Gas:
- Fatal accident caused by the breathing of any toxic gas (exhaust gas, not adequate breathing mix, etc.).

Crushed:
- Fatal accident caused by any crushing and / or burial.

Helmet:
- Fatal accident caused by accidental loss or intentional removal of the helmet or band mask.

DCI / AGE:
- Fatal accident caused by a decompression illness (dci) or arterial gas embolism (age).

Card.arrest:
- Fatal accident caused by cardiac arrest.

Drowned:
- Drowning caused by the flooding of the helmet or the band mask.

Drowned / scuba:
- Drowning in scuba diving.

Other:
- Fatal accidents due to an unknown cause or not mentioned.

OVERVIEW OF THE GENERAL SITUATION

Chart n° 2:

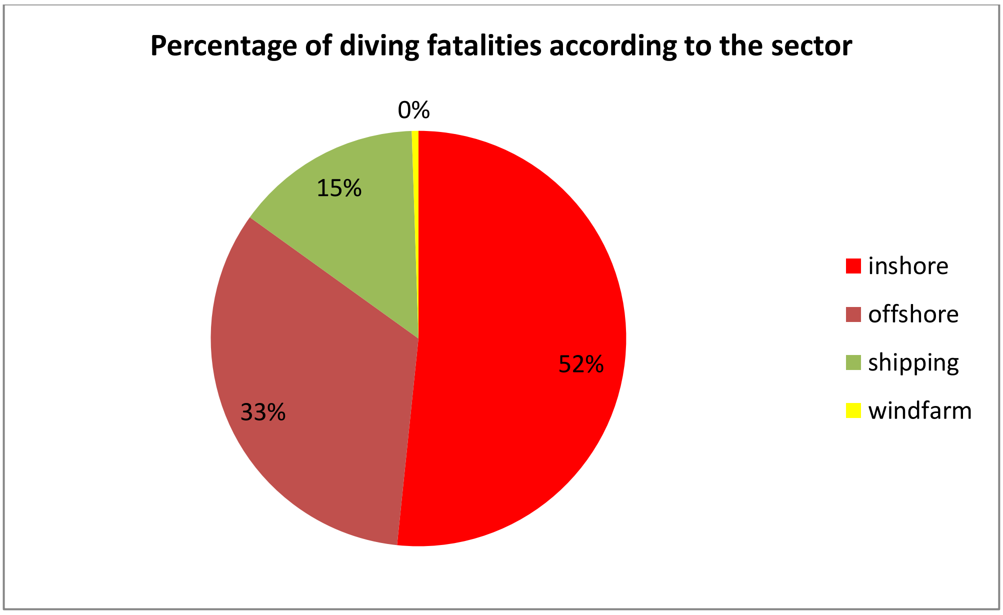


Chart n° 3:

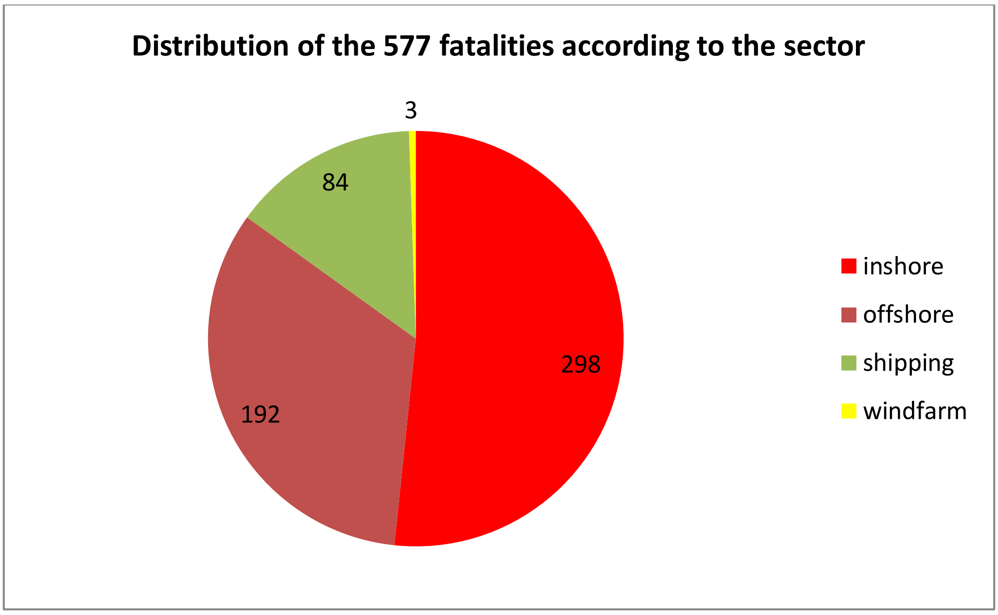
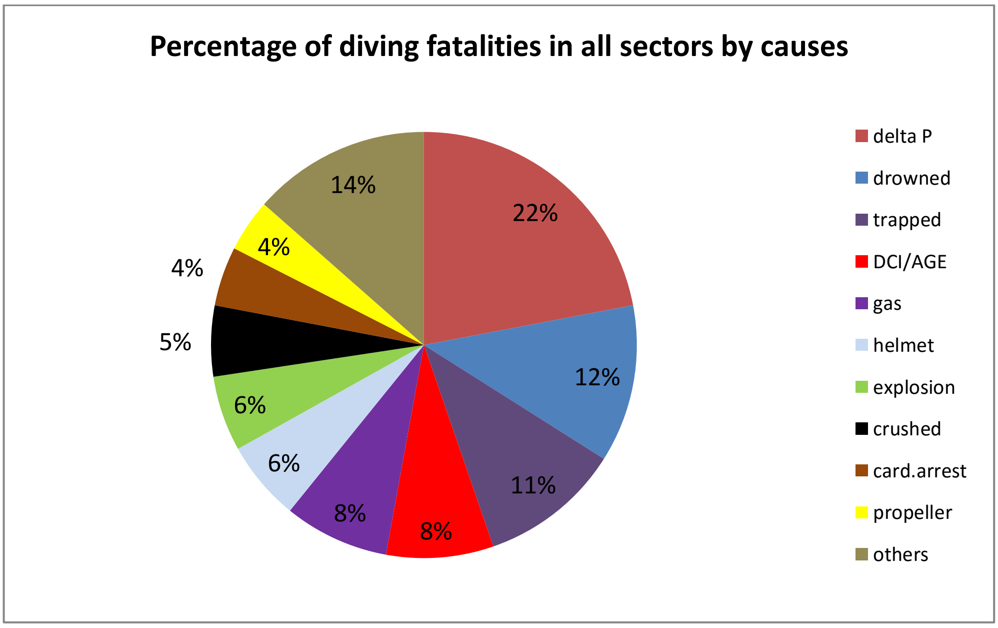


Chart n° 4:



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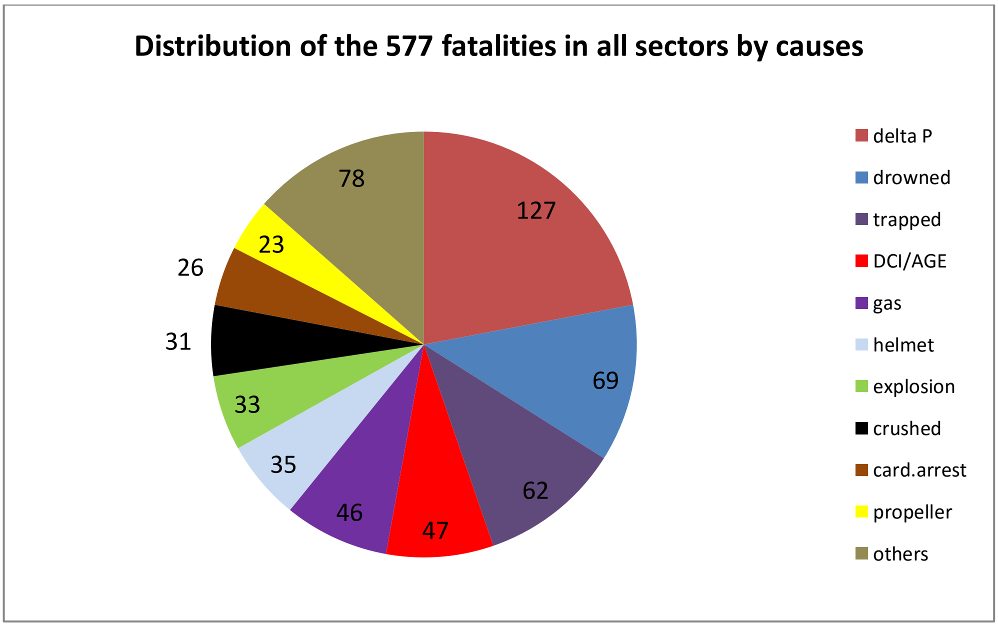

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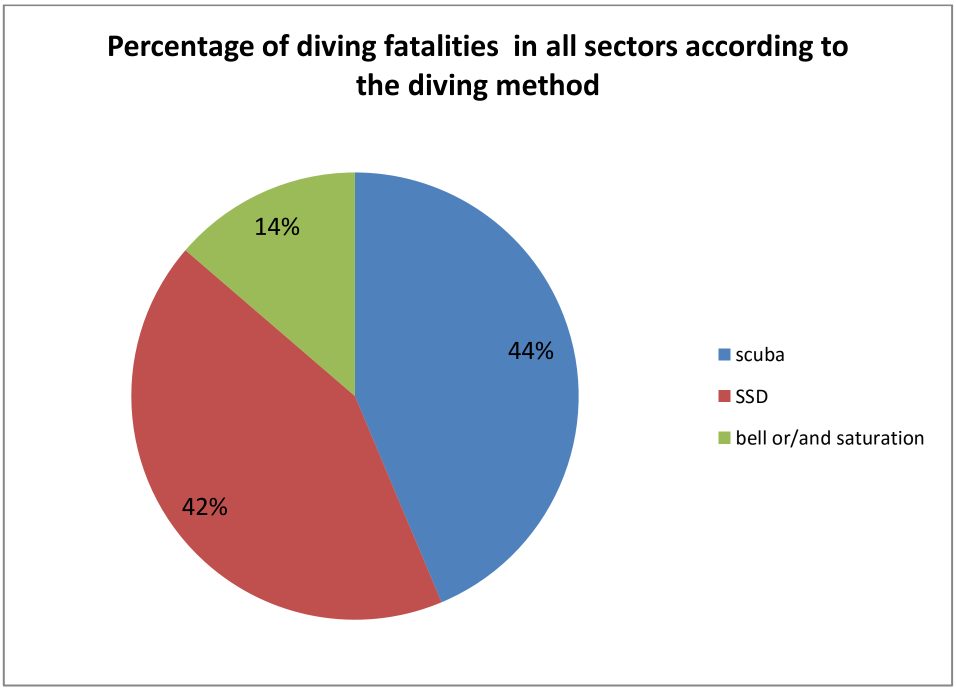

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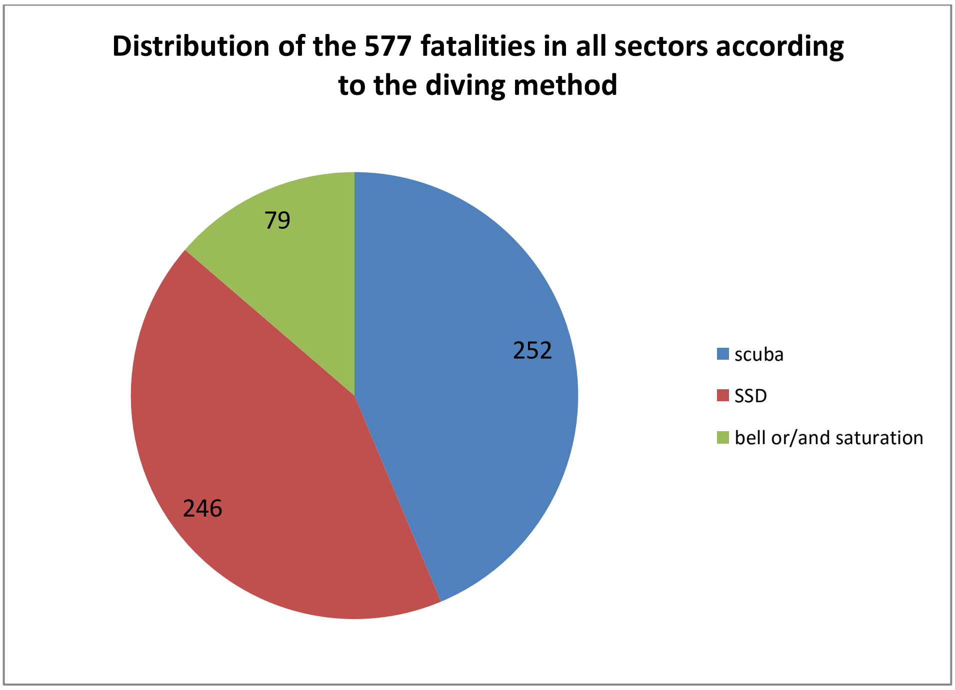

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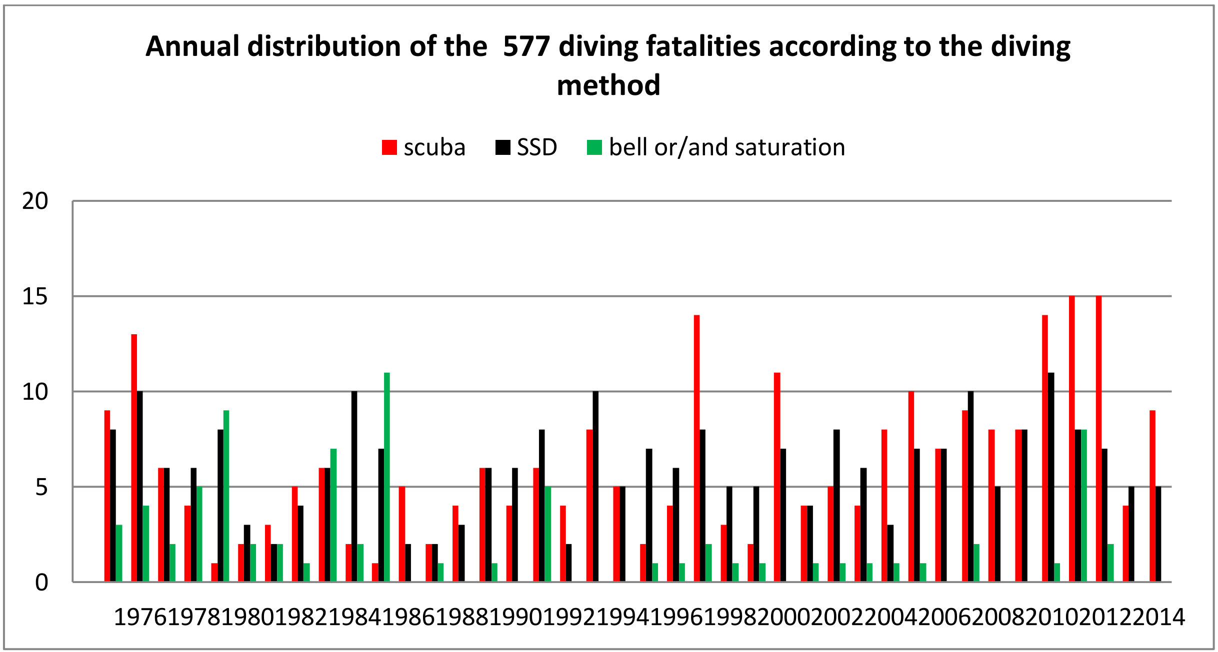


<u>Comments</u>

As can be seen by watching this first series of charts, three areas are particularly affected by accidents in diving.
The causes of death are varied, but we clearly see that in all sectors the predominant causes are related to delta P, drowning and entanglement or hooking of the diver.
We also note that many of the accidents occurred during scuba diving which justifies the high percentage of drowning.
Seen like this, the distribution of accidents is still not very clear but it will become over the following pages.

OFFSHORE DIVING

Description

Offshore diving began in the Gulf of Mexico during 1947.
In those days it was done by hardhat divers working alone or in small teams who made their dives from the surface.
Modern offshore diving as we know it today was started in the second half of the sixties.
Dives are made in various modes:

- Surface demand.
- Wet bell.
- Bounce diving.
- Saturation diving.
- Scuba diving.

Team size depends on the used dive mode.
The tasks performed by commercial oil divers are mainly installation, connection and handling of underwater structures.
The statistics in this section concern the fatal accidents that occurred while diving on diving support vessel's (DSV) and on offshore facilities or in a saturation chamber.

Chart n° 9:

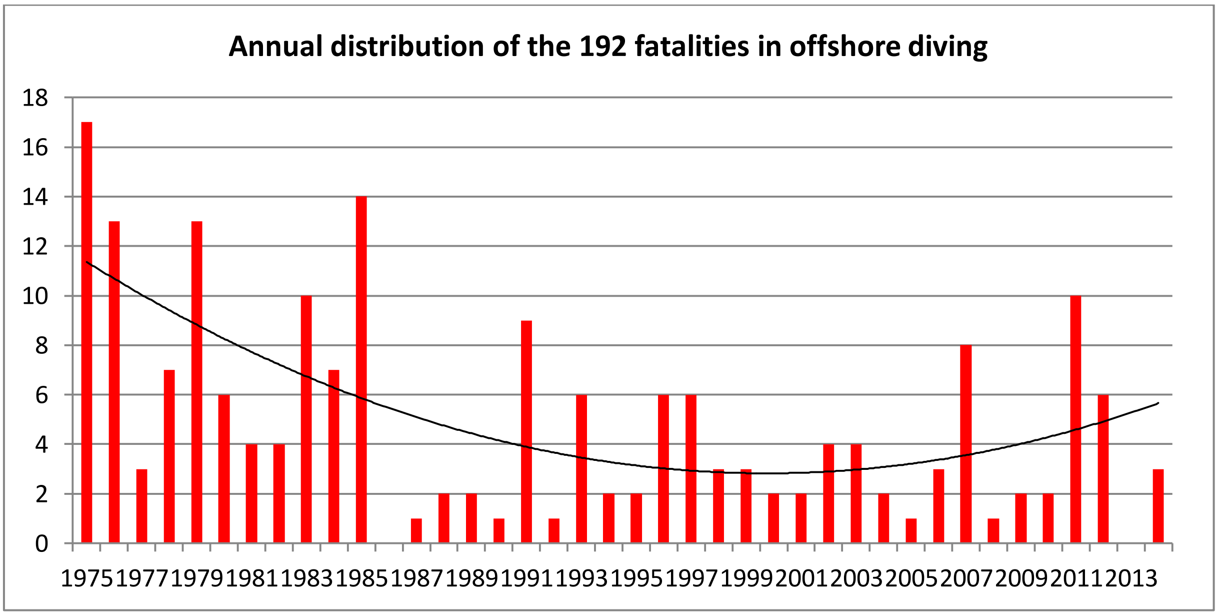


Chart n° 10:

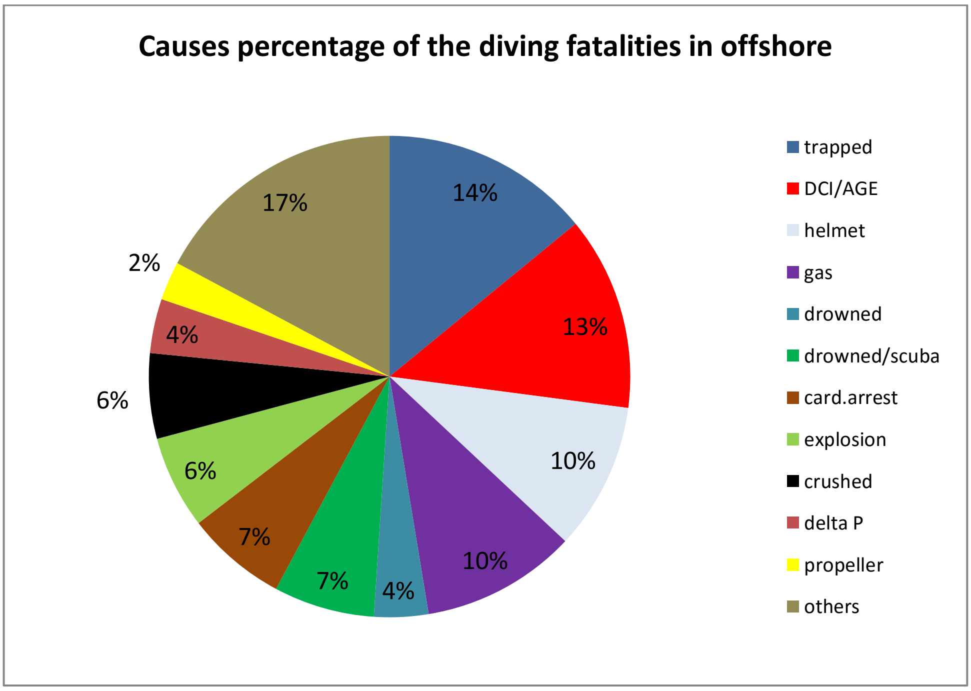


Chart n° 11:

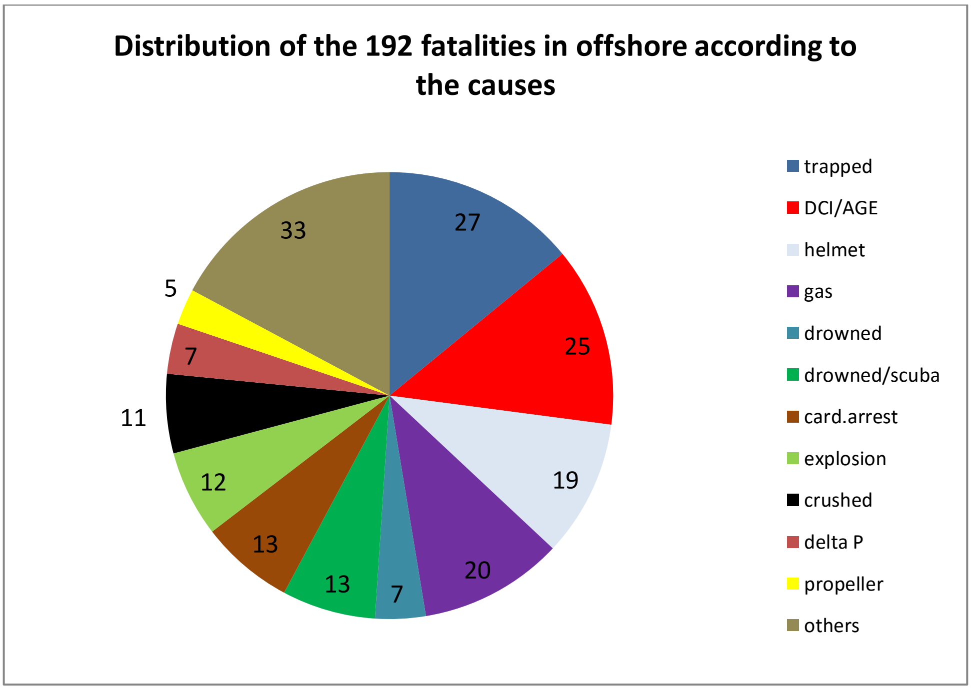


Chart n° 12:

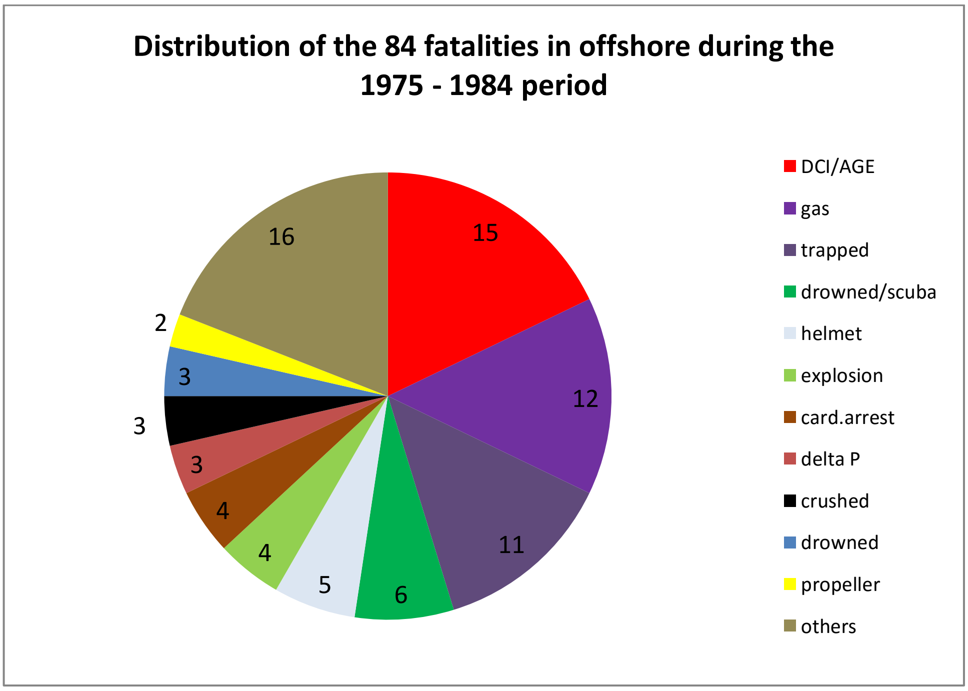
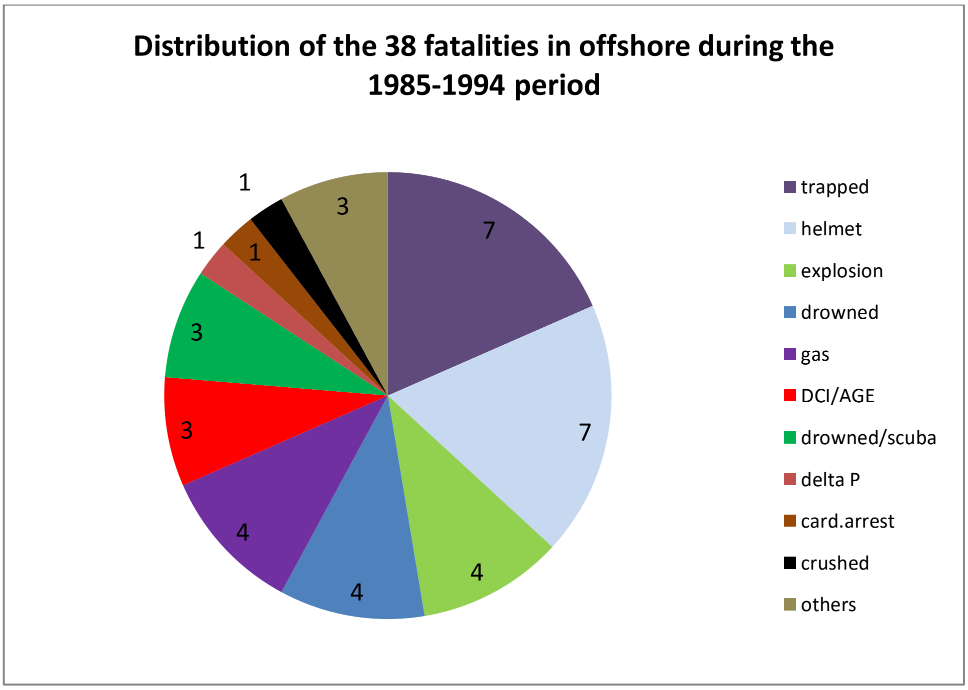


Chart n° 13:



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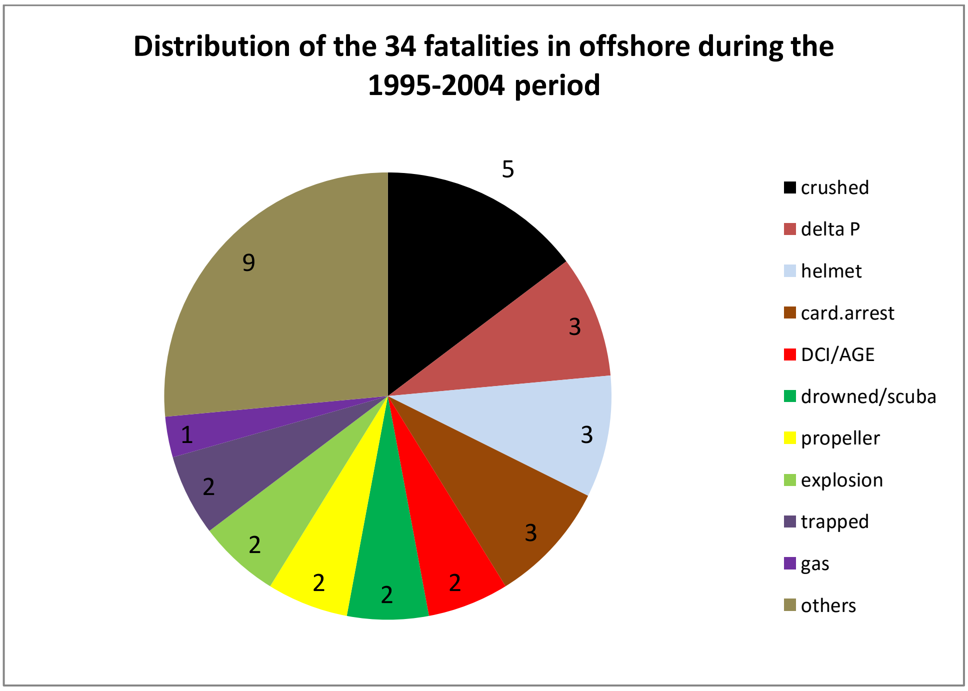


Chart n° 15:

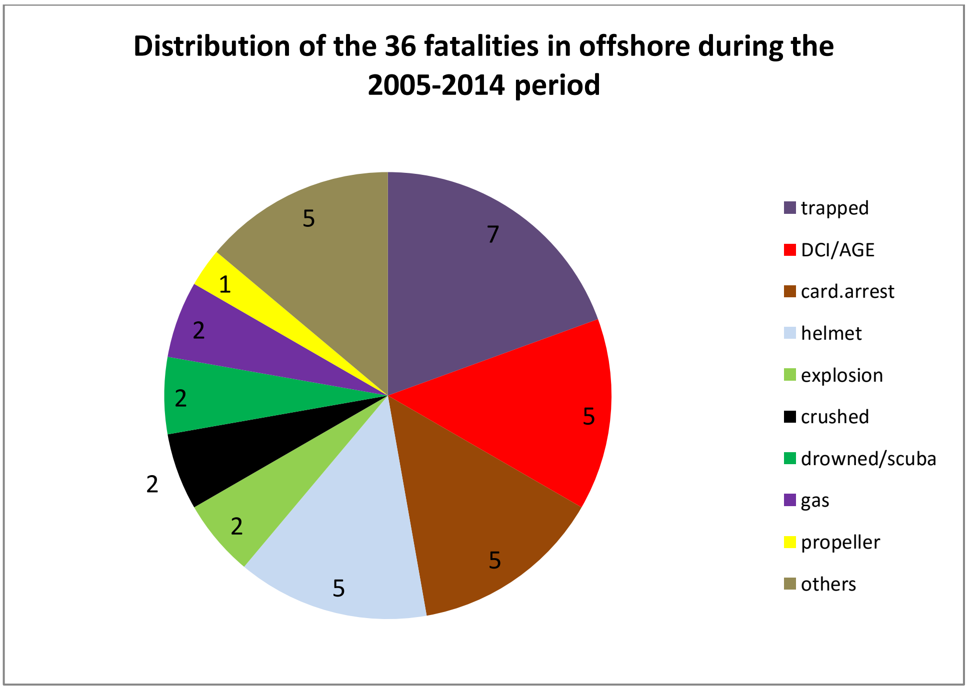
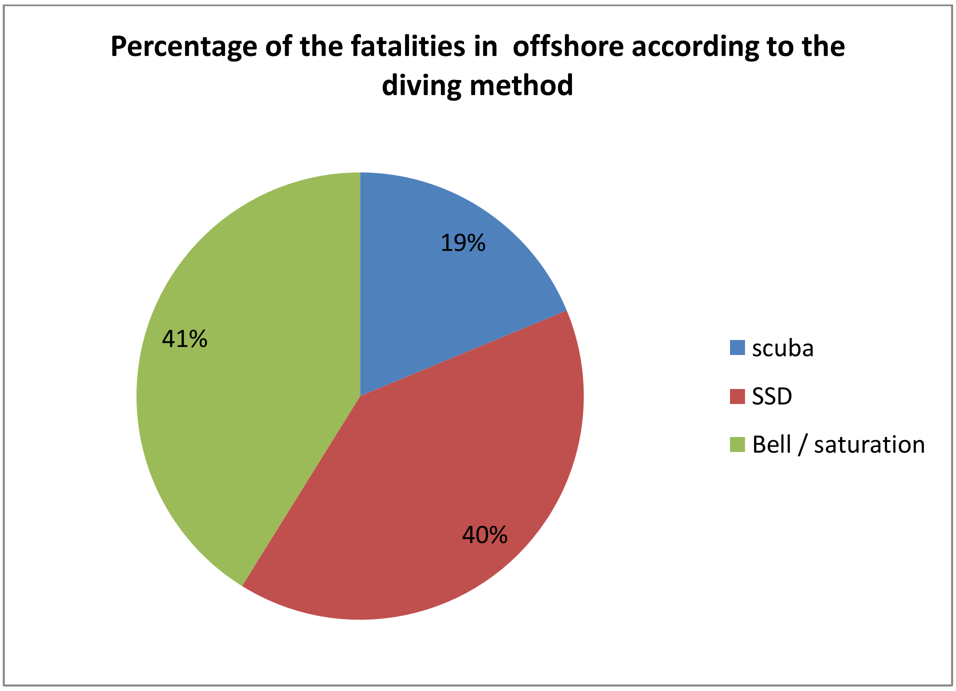


Chart n° 16:



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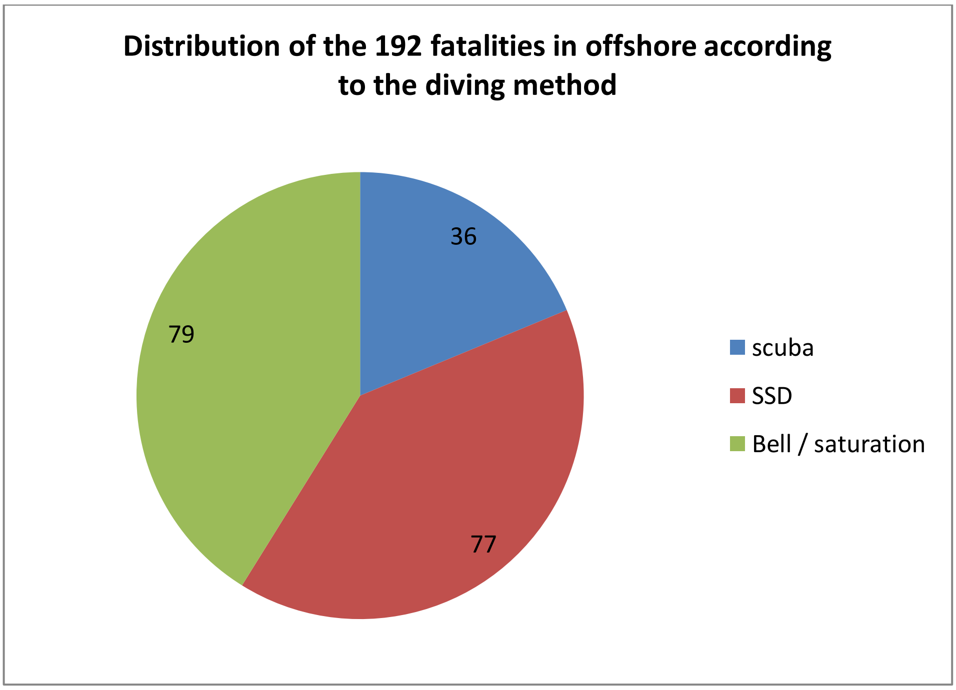
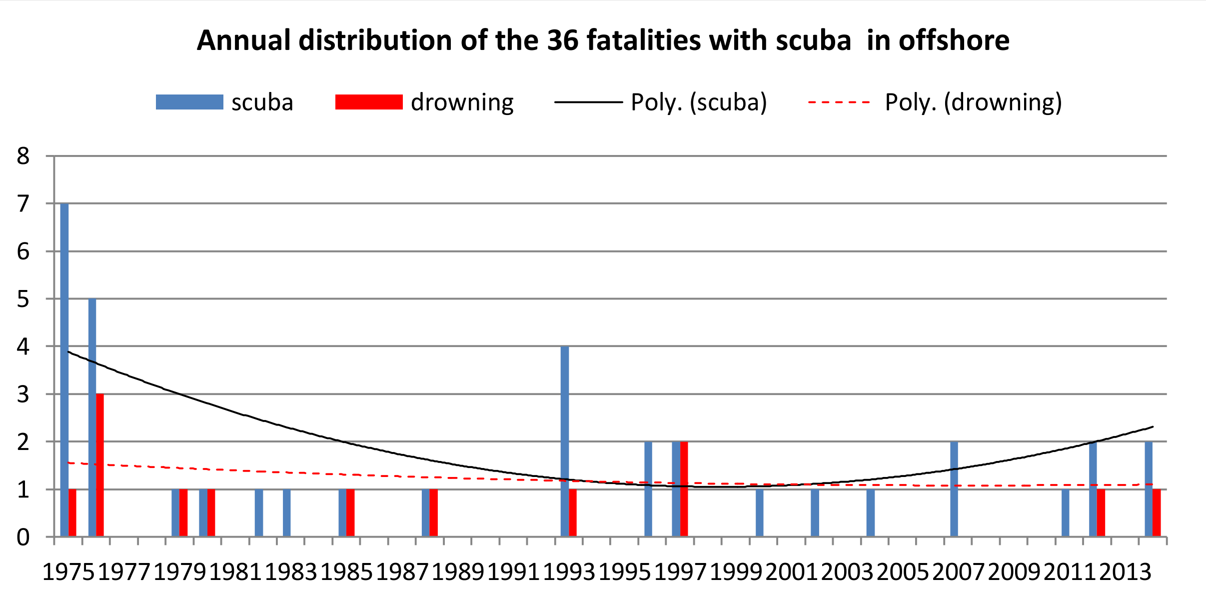


Chart n° 18:



Comments

192 deaths were recorded during the period between 1975 and 2014.

As seen in Chart n° 9, fatalities were quite high during the first decade. At the time, many of the offshore dives were conducted in the North Sea where it was estimated that at the beginning of 1975 the death rate was close to 1.25% [13].

This was due in part to working conditions which were quite difficult because of the environment, but also and especially because of the fact that in four years the number of divers had increased from 400 to 2000 and to meet demand, firms hired staff with sometimes very little qualification and experience [14].

This same problem was also encountered with the supervisory personnel where, to cope with the increasing number of dive teams, some incompetent diving supervisors were sometimes appointed [15, 16].

Subsequently the number of deaths began to decline with the introduction of new diving regulations as well as tailored training programs.

As can be seen, the number of fatal accidents in this sector has decreased steadily since 1985 with exceptions in 2007 and in 2011 where, following the sinking of the DSV Kooscha [17] on 20th October 2011, six commercial divers died in saturation.

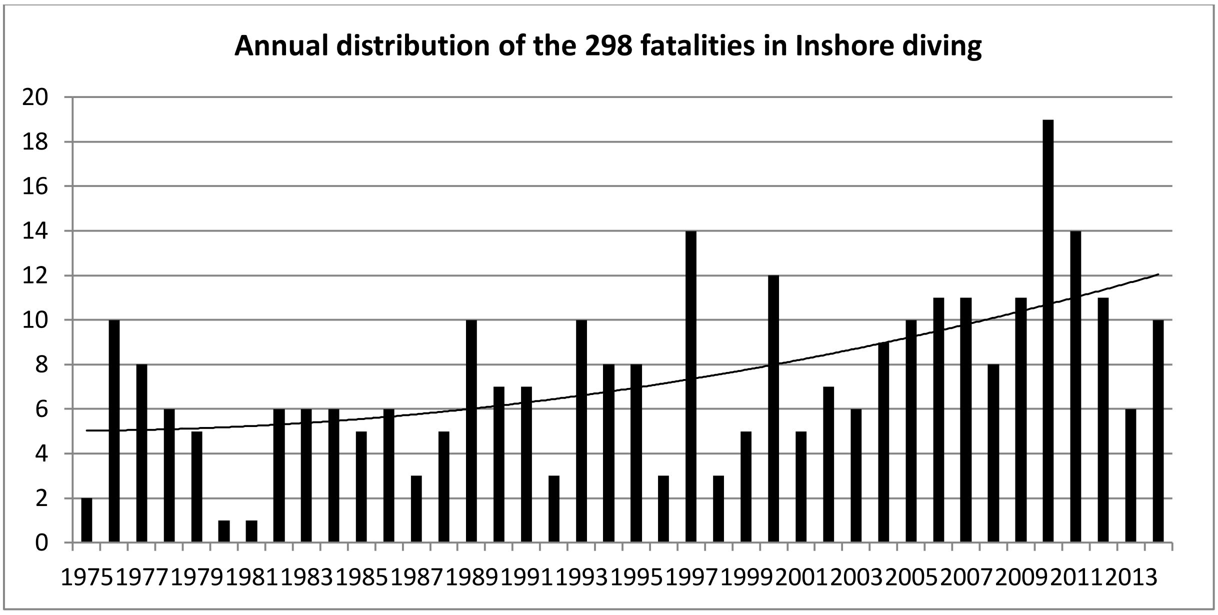
If we go back behind the n°10 and n° 11 charts we see that the main cause of offshore diving deaths during the study period is strangely due to the diver's entanglement and to entrapment and this case remains among the most important for 3 decades.

During the period 1975 - 1984 it was decompression sickness and arterial gas embolism which killed the most. This may be justified in part by the fact that in this sector the depths of the intervention are often important, but is probably also as stated above, due to the incompetence of some diving supervisors, as it is clearly seen that the risk of DCI / AGE decreases during the other decades.

It’s the same for the accidents related to improper gas breathing because we see that they also begin to decline after the beginning of the LST (life support technician) and diving supervisor training programs.
As regards the other causes of accidents, we see that they appear at random not making it possible to emphasize any of them.

INSHORE / INLAND DIVING

Chart n° 19:



Description

Inshore / inland or civil engineering diving began around 1832.
From that time and until the 1950s it was practiced by hardhat divers.
Then from that decade in France, and in other countries, the heavy helmet was replaced by lighter equipment, the constant volume suit.
Later, due to the influence of the offshore sector, this equipment in turn was gradually replaced from the nineties on, with band masks and modern diving helmets.

Diving modes used in inshore diving are:

- Surface demand.
- Scuba diving.
- Wet bell diving.

Work carried out by commercial civil engineering divers is very diverse (construction, demolition, cutting, welding, desilting, concreting, inspection, etc.) and can be practiced wherever we find water (lock, dam, sewage treatment plant, nuclear power plant, lake, well, etc.).
In addition, it is often done with little or zero visibility.

Team composition is generally limited to the need of the project, but in some countries a legal minimum team size is compulsory:

- UK: 5
- Singapore: 4
- Canada 4 but 3 in certain circumstances
- Belgium: 3
- Denmark: 3
- United States: 3
- Germany: 3
- Spain: 3
- Norway: 3
- France 3 but 2 in certain circumstances
- Netherlands 3 but 2 in certain circumstances.

The statistics in this section concern the fatal accidents which occurred in the inshore / inland sector while diving or under pressure.
Although it may be considered a category apart, accidents that occurred during ship salvage work have also been included in the inshore sector because the majority of those listed here were held along a quay wall or in a river.

Chart n° 20:

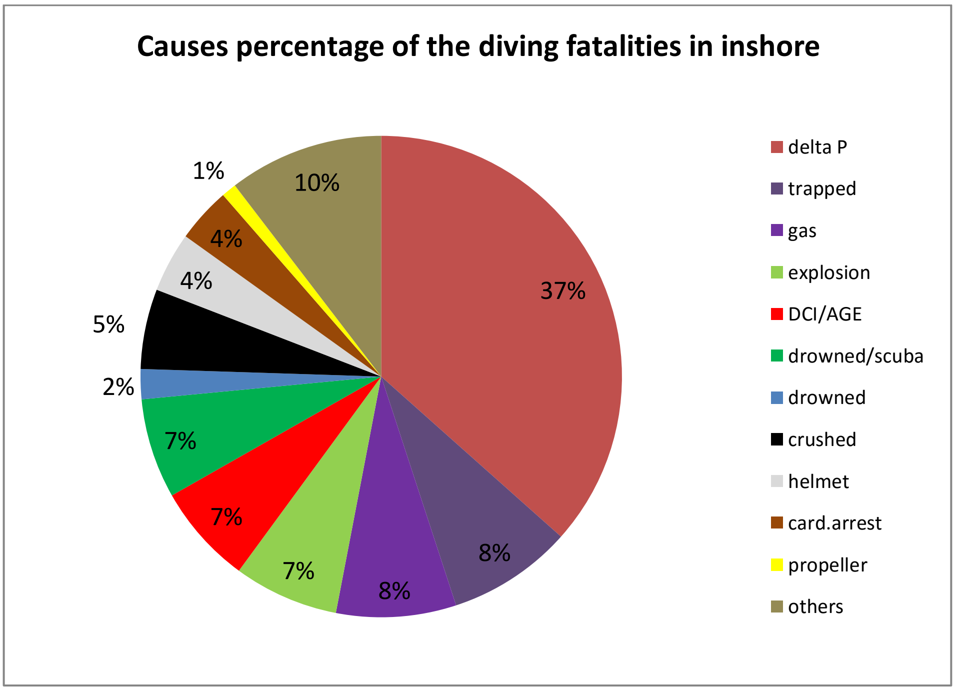


Chart n° 21:

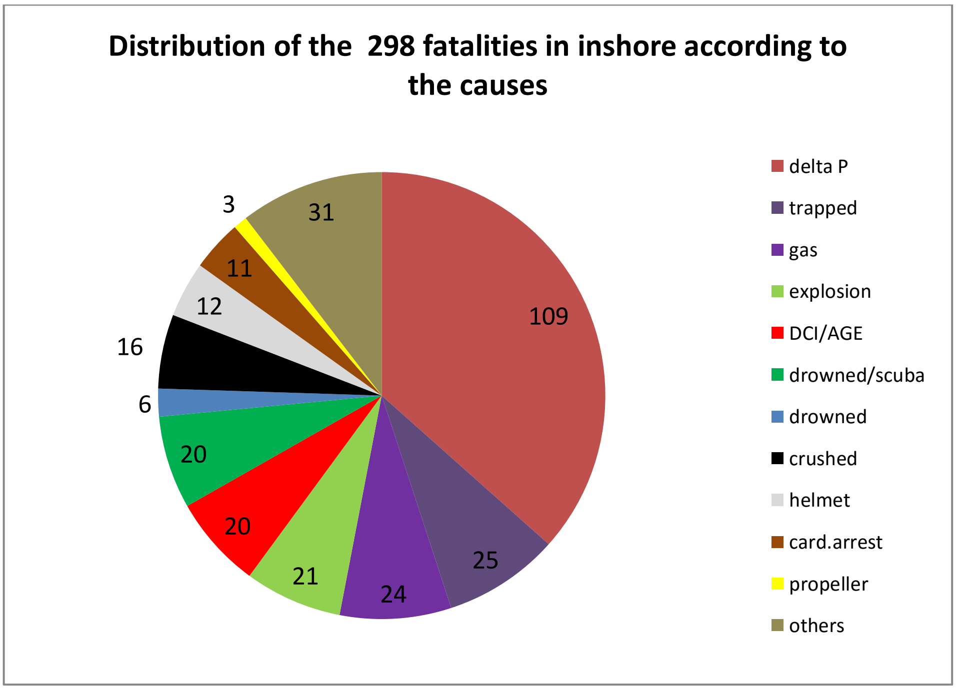
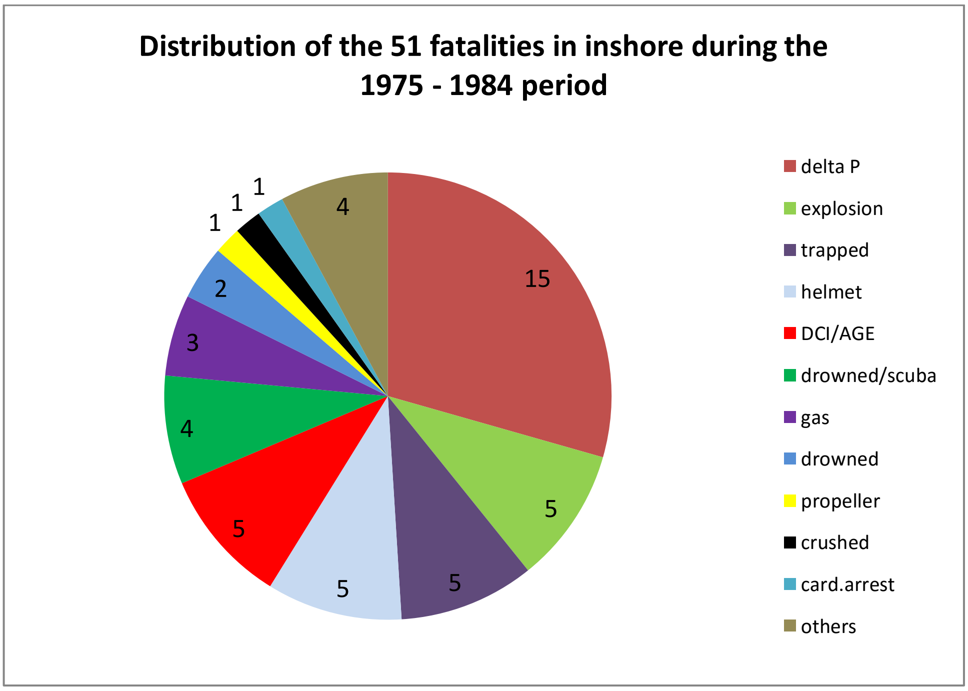


Chart n° 22:



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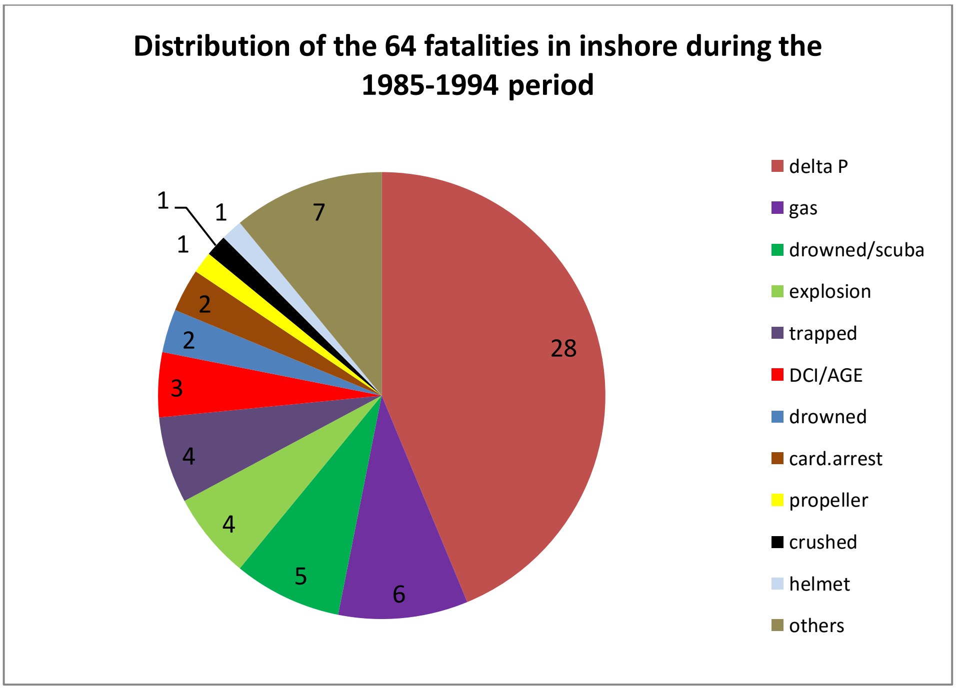

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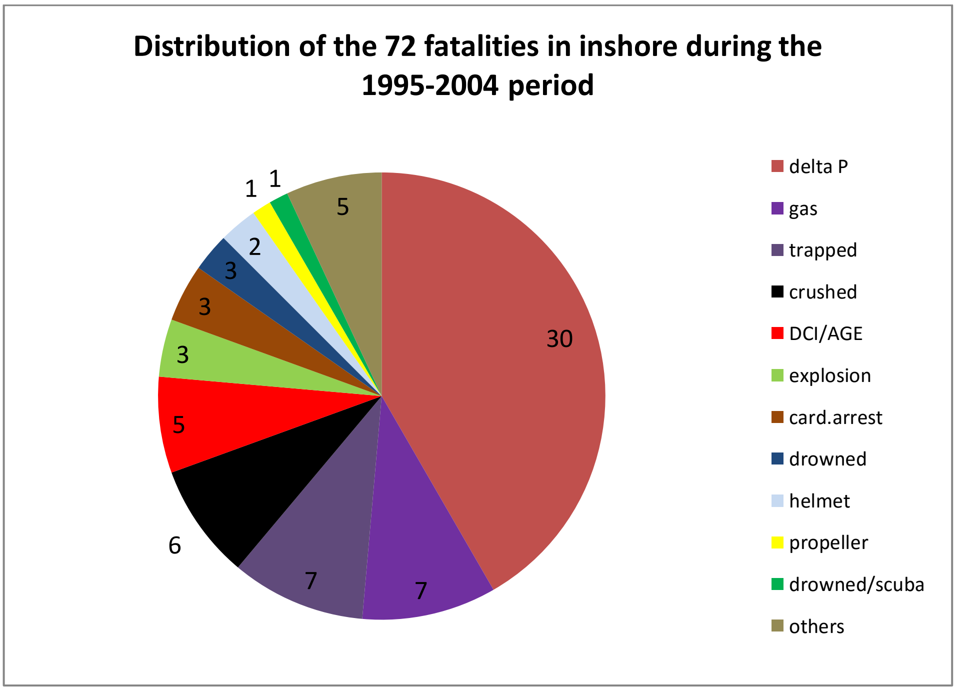

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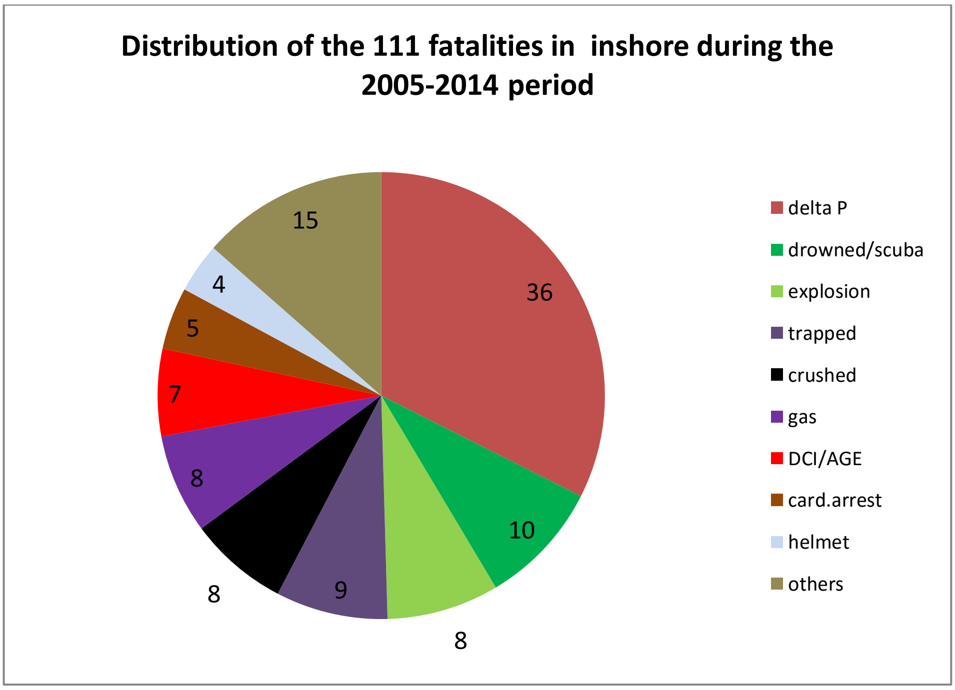

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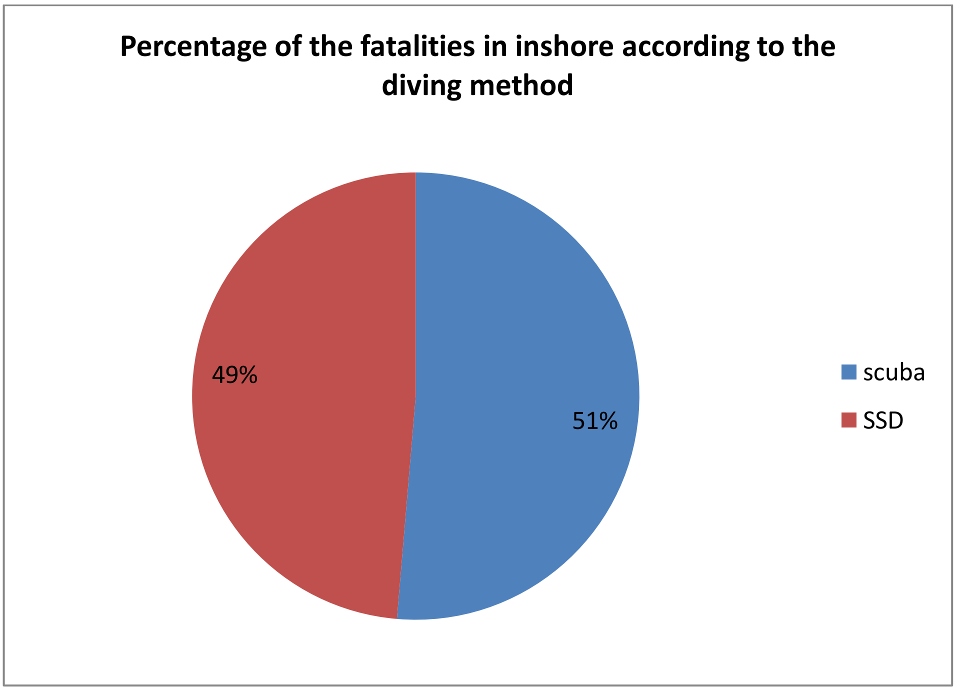
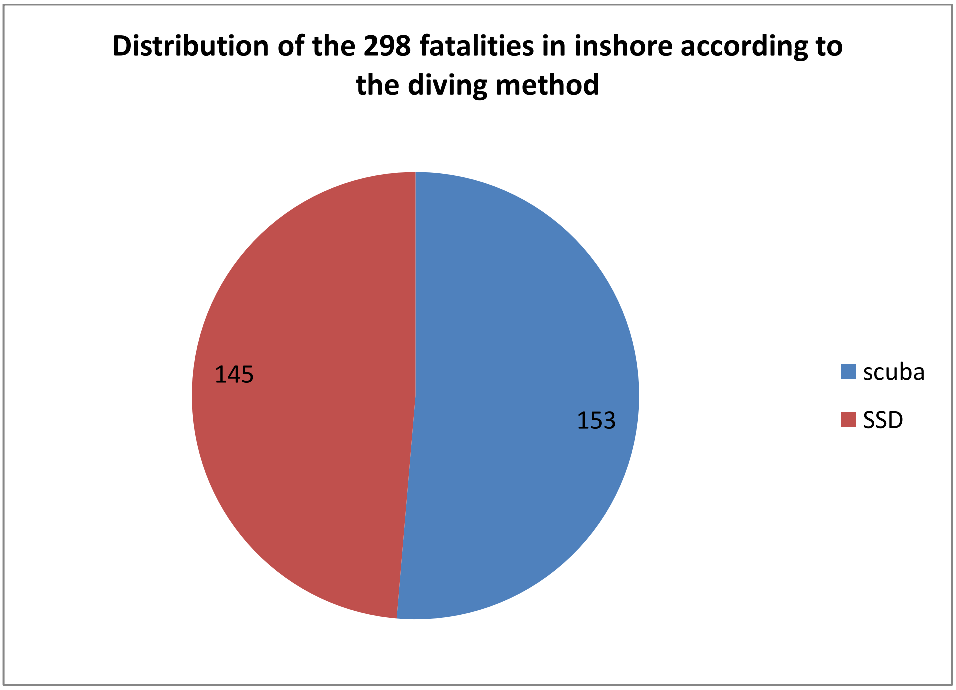


Chart n° 27:



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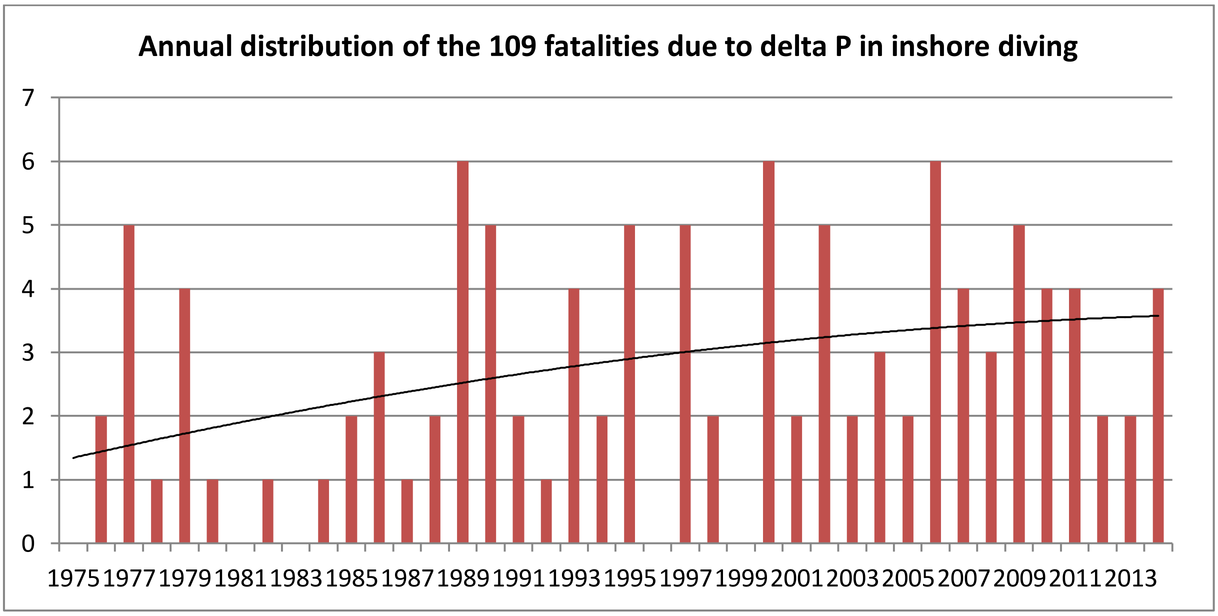
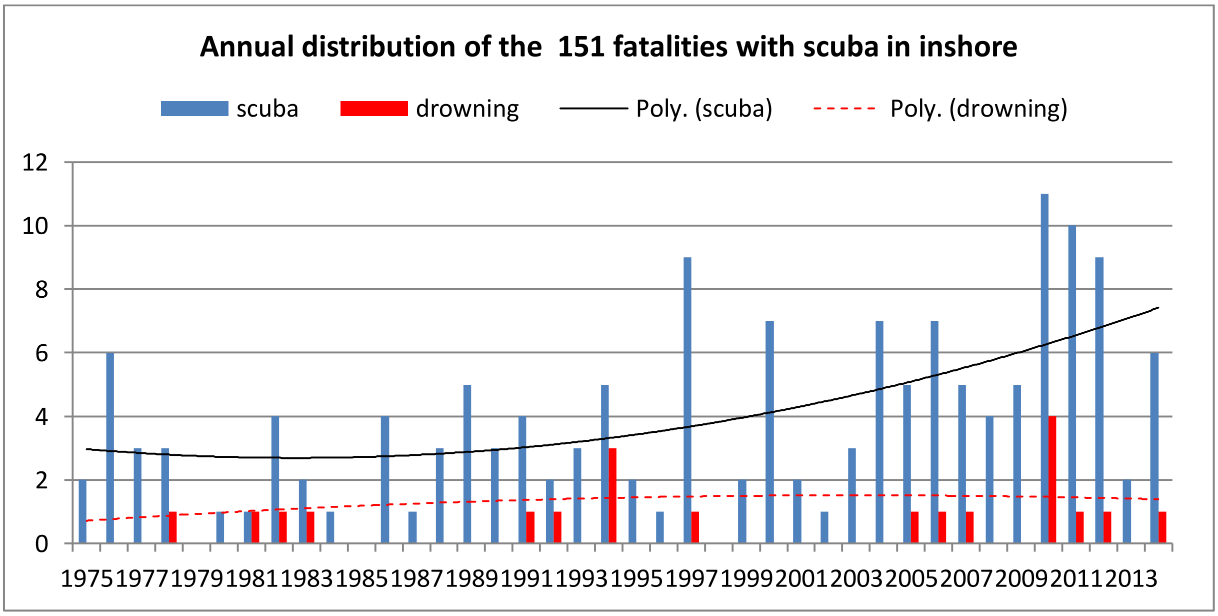


Chart n° 29:

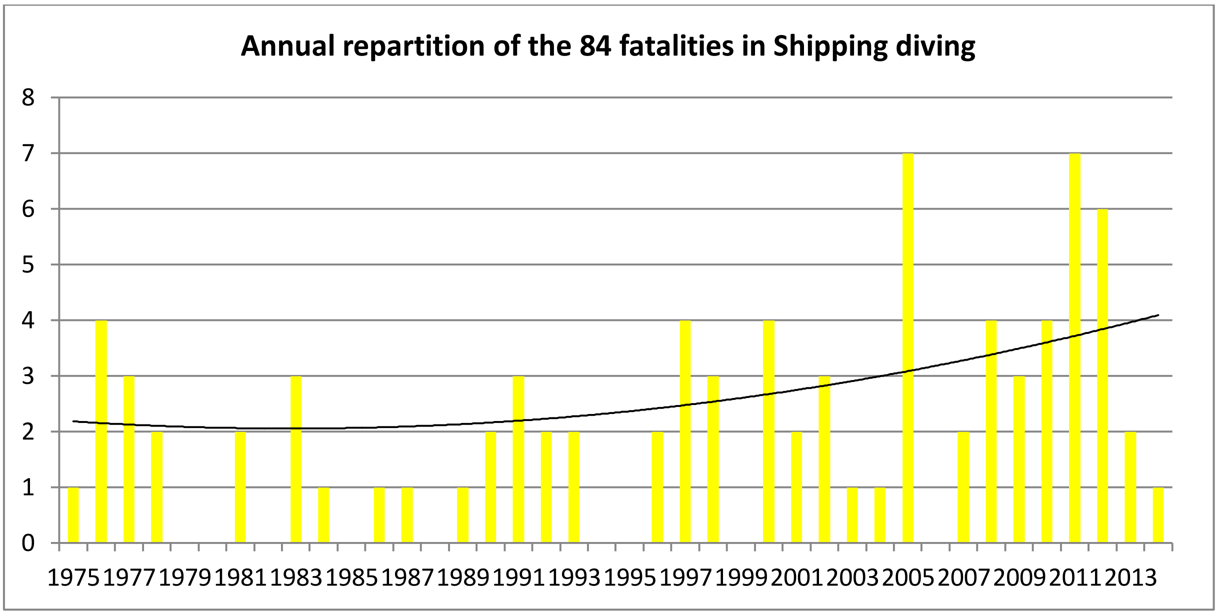


Comments

298 deaths were recorded during the period between 1975 and 2014. If we look at graph n° 19 a trend seems to be on the rise.
What is obvious in reading the various graphs is that the root cause of inshore diving deaths is accidents due to a pressure differential commonly known as Delta P.
108 accidents of this type in forty years are enormous and we notice, unfortunately, that in the course of decades the tendency remains constant.
The second cause of death (gas) is due mainly to breathing a polluted air charged with CO (bad location of the compressor suction socket).
Regarding the accidents related to underwater cutting it should be noted that only one case concerns the cutting of sheet piles. One other such accident (sheet piles) is mentioned in the USA in a video [18] published by the ADCI (Association of Diving Contractors International). However, since no date is mentioned in the video, no reference of this accident could be found, and the ADCI did not respond when contacted, this incident has not been included in these statistics.
Of the five deaths mentioned in the period 1975 - 1984, three occurred due to an oxygen flash in 1984 during an oxy-arc cutting operation in a tunnel boring machine in the region of Antwerp in Belgium where two divers and a customer representative were carbonized.
Regarding the other accidents due to cutting, they all took place during the dismantling of wrecks.
Finally, it is disconcerting to see that more than half of the inshore deaths occurred during scuba dives. Apart from other contributing causes, this diving mode drowned no less than twenty divers.
As regards the other causes of accidents, we find that, here also, they occurred randomly so none can be emphasized.

SHIPPING DIVING

Chart n° 30:



Description

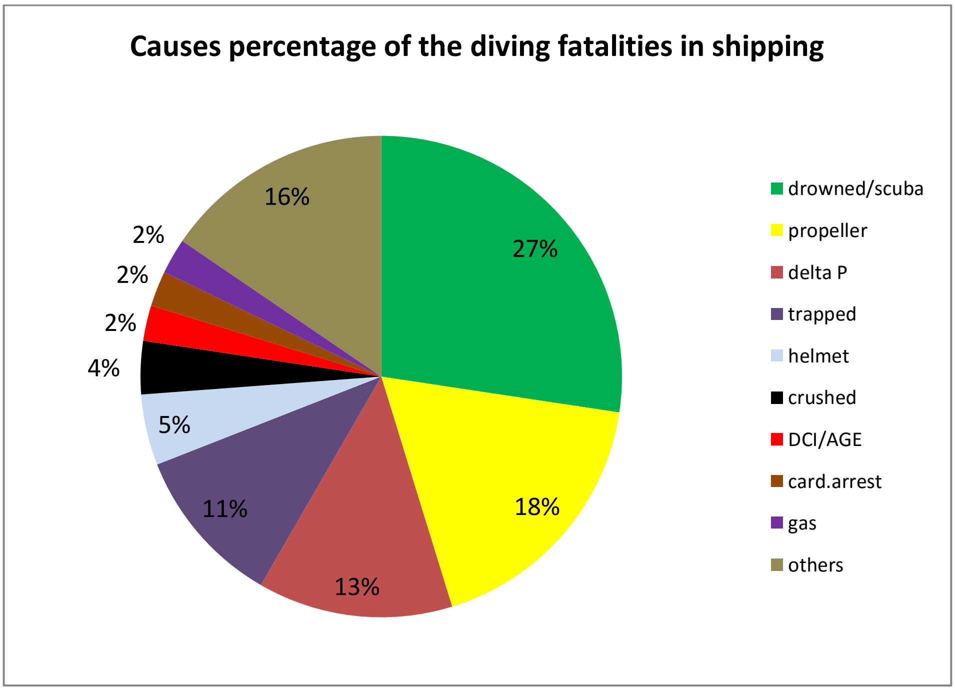
Commercial divers involved in shipping operate under boats of all sizes performing various tasks on the hull and propellers such as: hull cleaning, propeller polishing, anode replacement, thruster repair and / or replacement and detailed surveys for the classification societies, etc...
Teams are generally very mobile and must be ready to respond quickly to demands from abroad.
Working hours are often highly variable and can exceed the working time met in the other sector.

Diving modes used in shipping diving are:

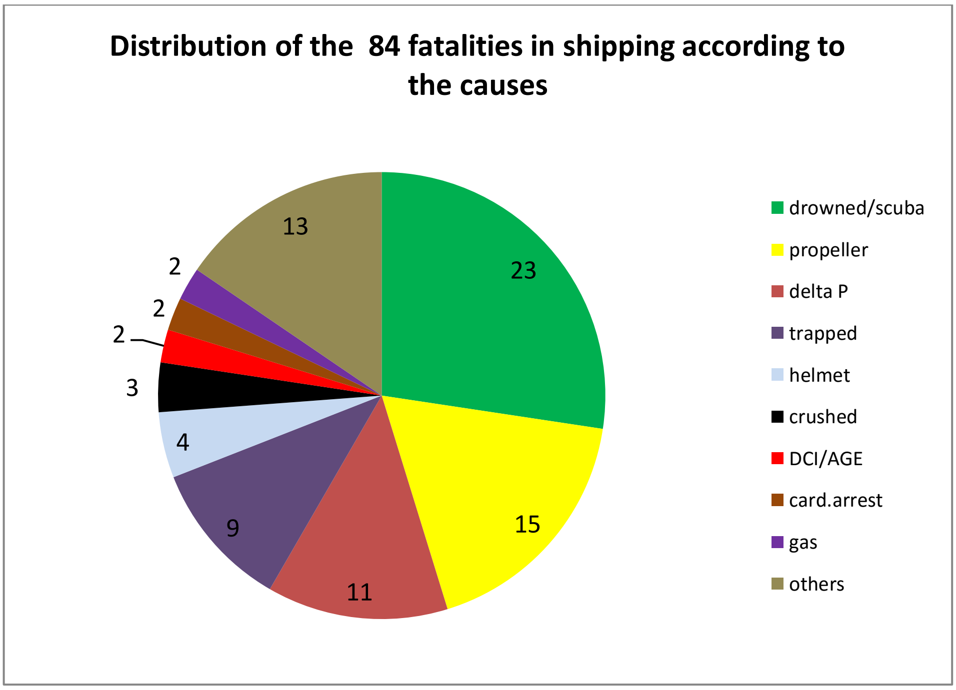
- Scuba diving.
- Surface demand.

The statistics in this section concern the fatal diving accidents that occurred during work under boats.

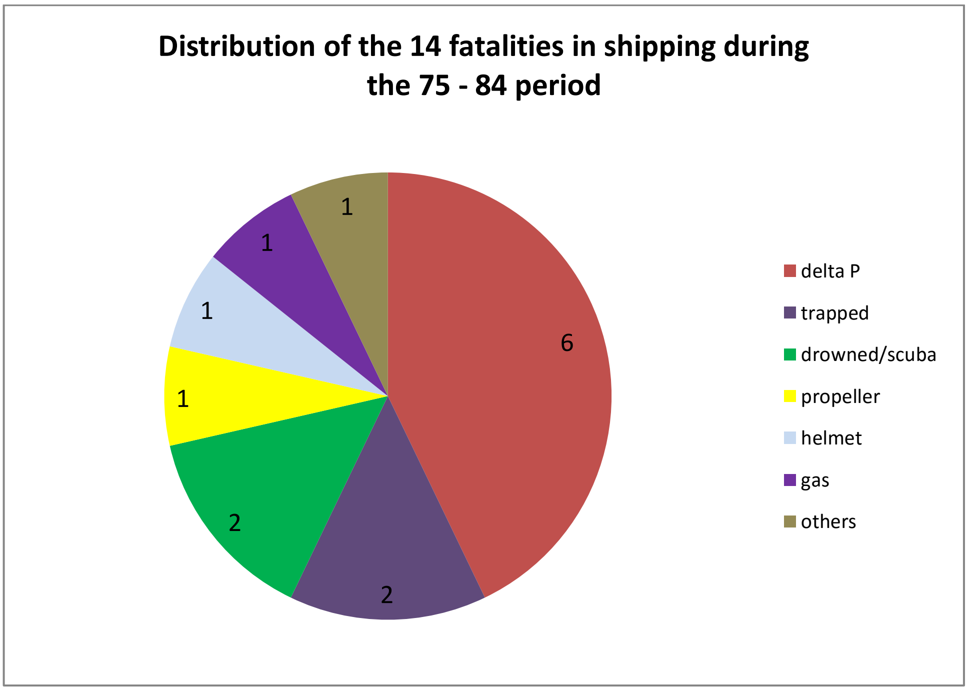
Graph n° 31:



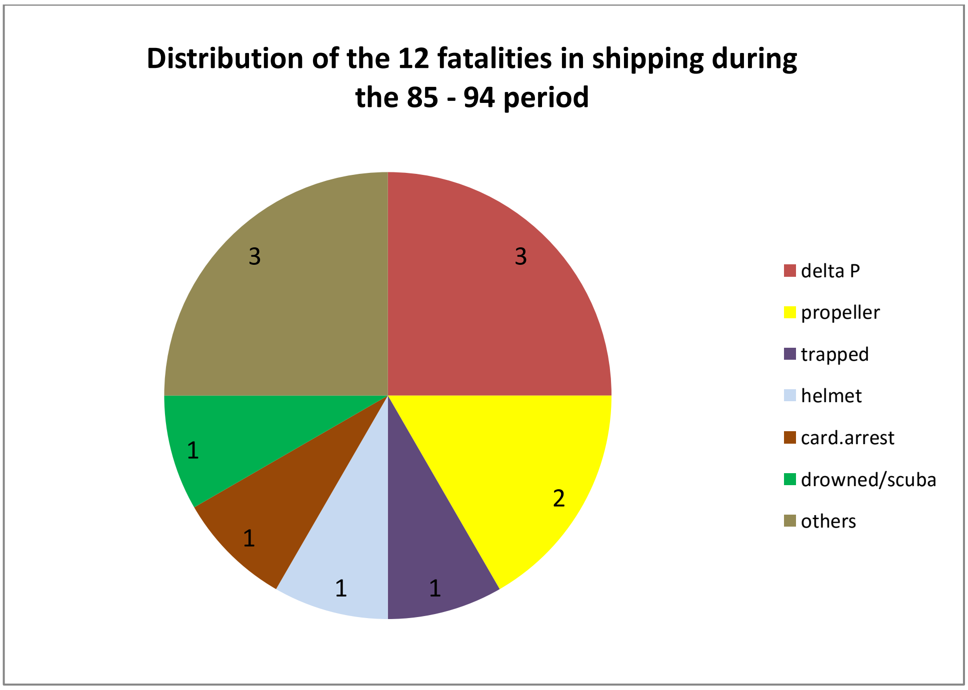
Graph n° 32:



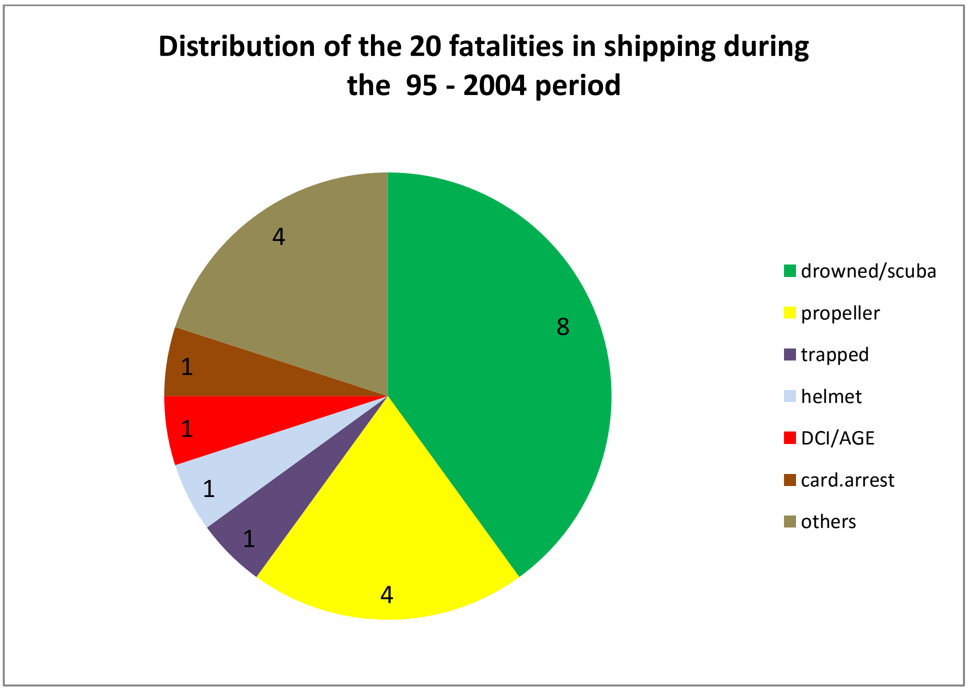
Graph n° 33:



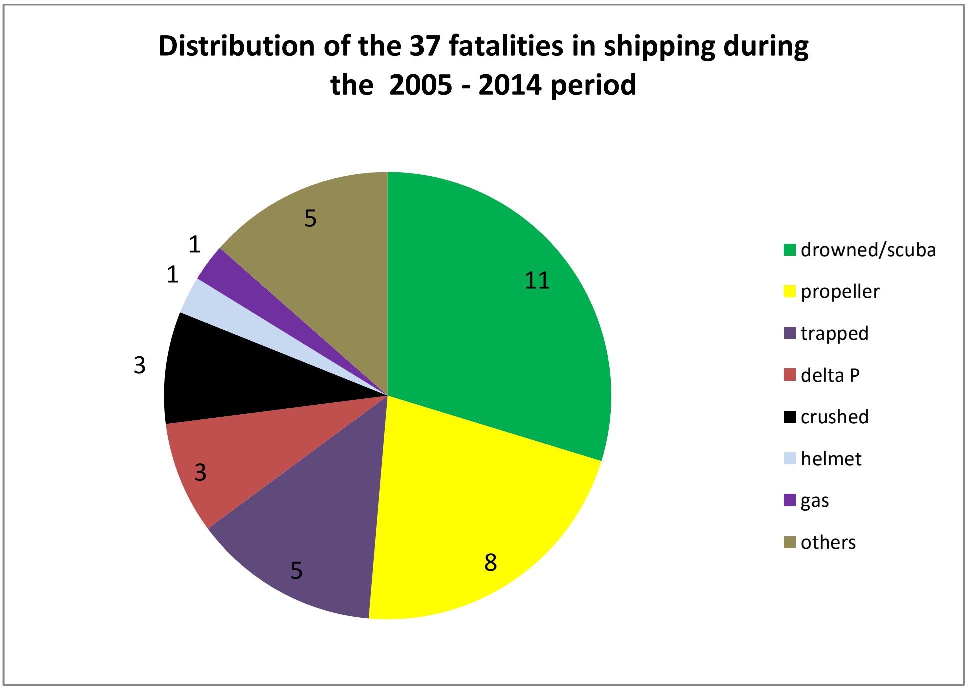
Graph n° 34:



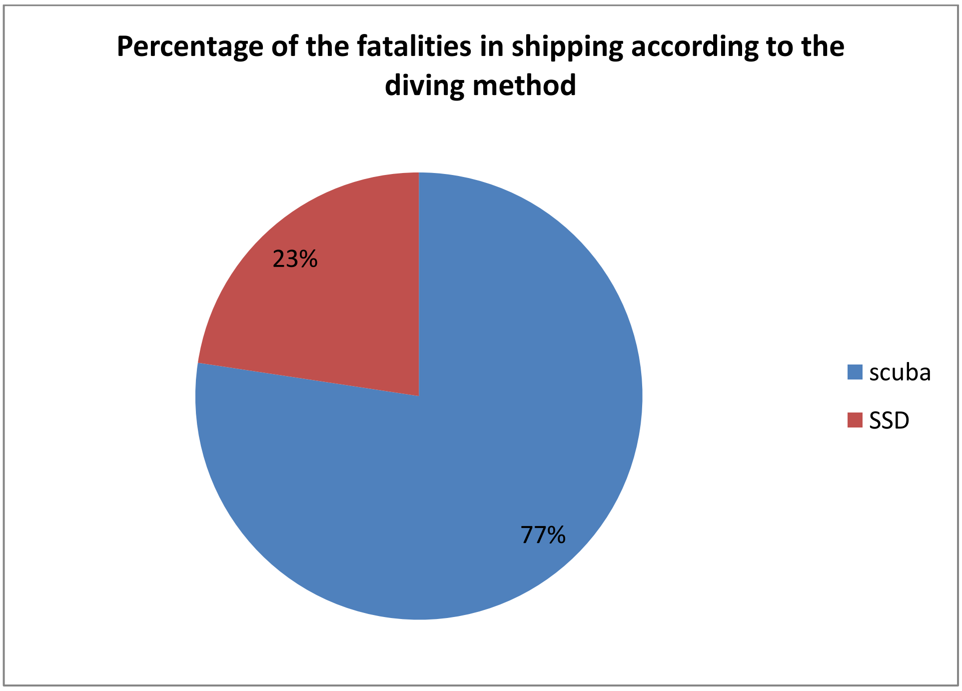
Graph n° 35:



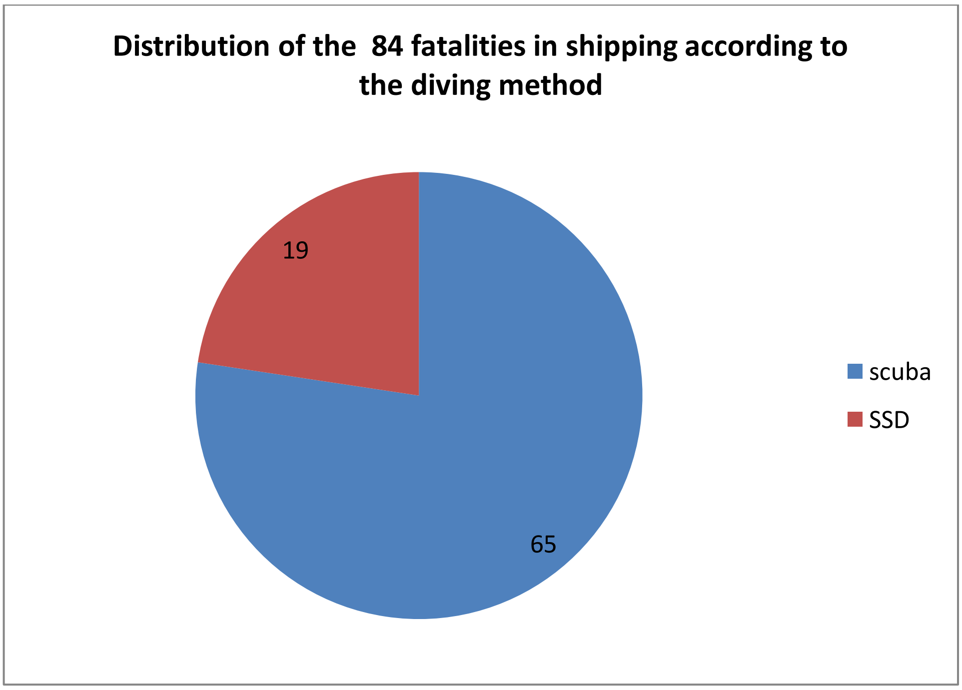
Graph n° 36:



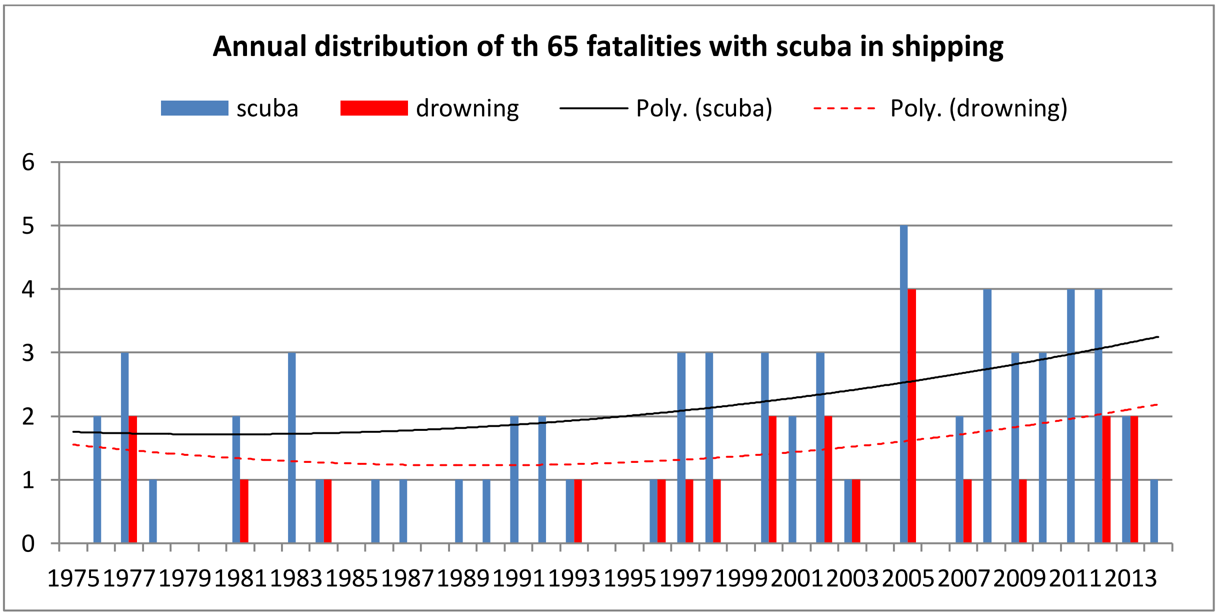
Graph n° 37:



Graph n° 38:



Graph n° 39:

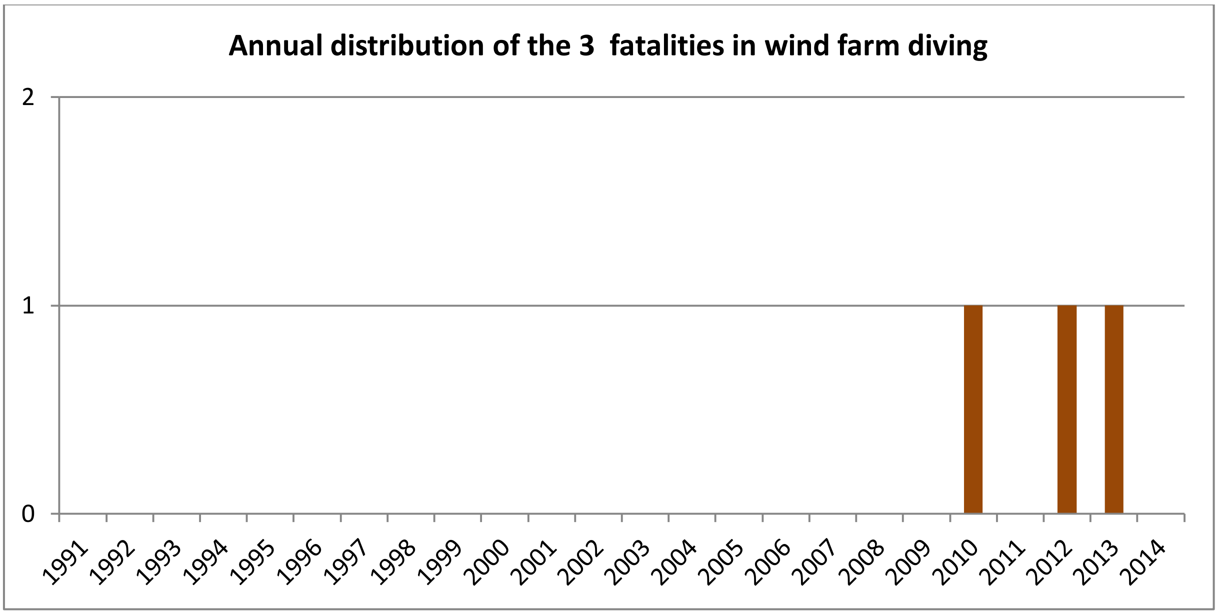


Comments

The first cause of death in shipping diving is due to drowning, which can be justified by the fact that many operations were and are still made in scuba diving.
It is followed by accidents related to the unexpected start of the propeller.
Accidents due to delta P are also high enough in this diving sector.

WIND FARMS DIVING

Chart n° 40:



Description

The first offshore wind turbines were installed off Denmark in 1991 that is to say the dives in this sector are relatively recent.
As dives are made at sea, they are similar to those of offshore diving, but the nature of the work is generally limited to obstacle removal works, J tube clearing and jetting, cable pulling through I and J tubes, rock armour and / or protection mats placement, CCTV or routine inspections, assistance in cable laying operations.

Diving modes used in wind farms diving are:

- Surface demand.
- Wet bell.
- Scuba diving.

The statistics in this section concern the fatal diving accidents which occurred on diving support vessels or on wind farm facilities.

Chart n° 41:

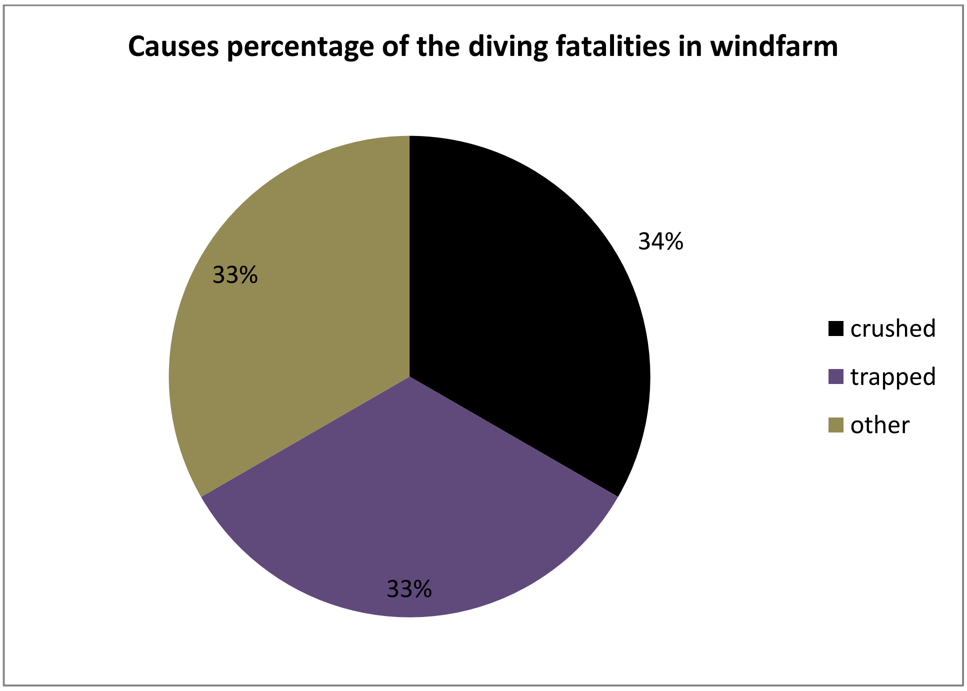


Chart n° 42:

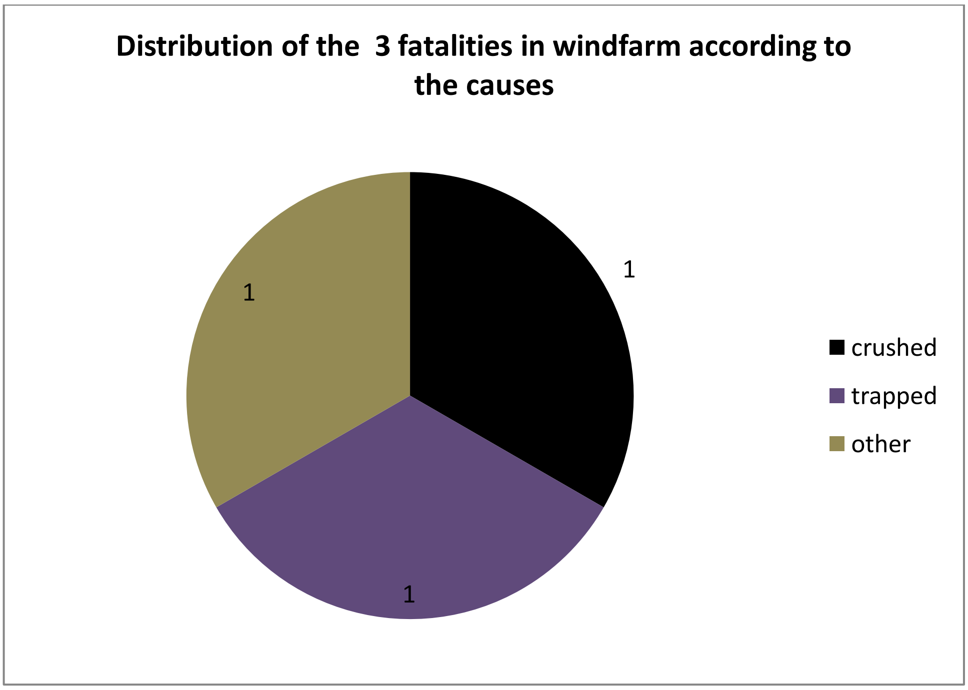


Chart n° 43:

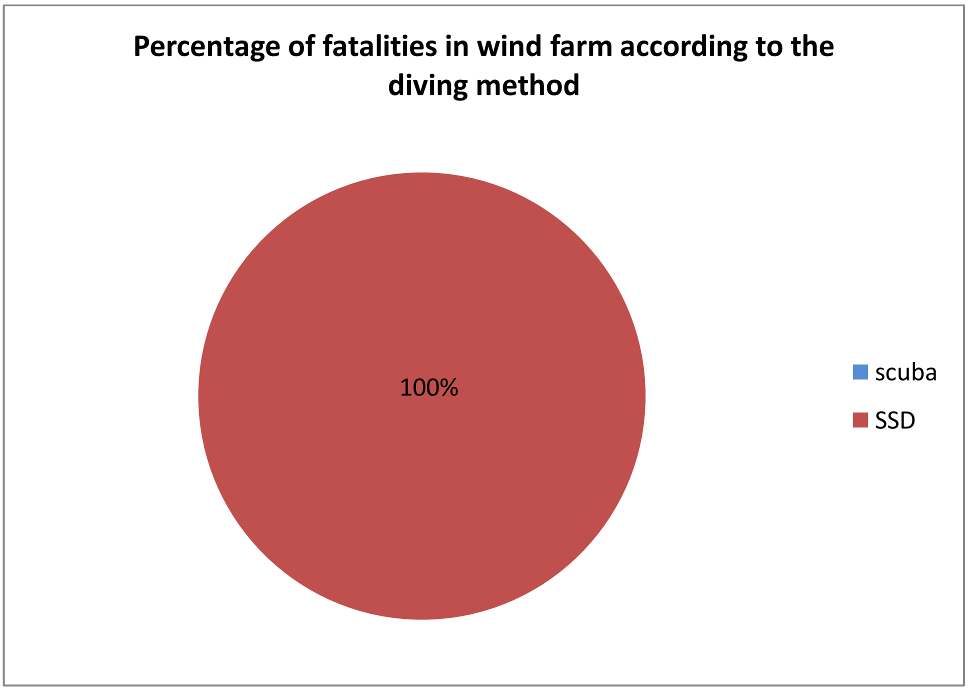
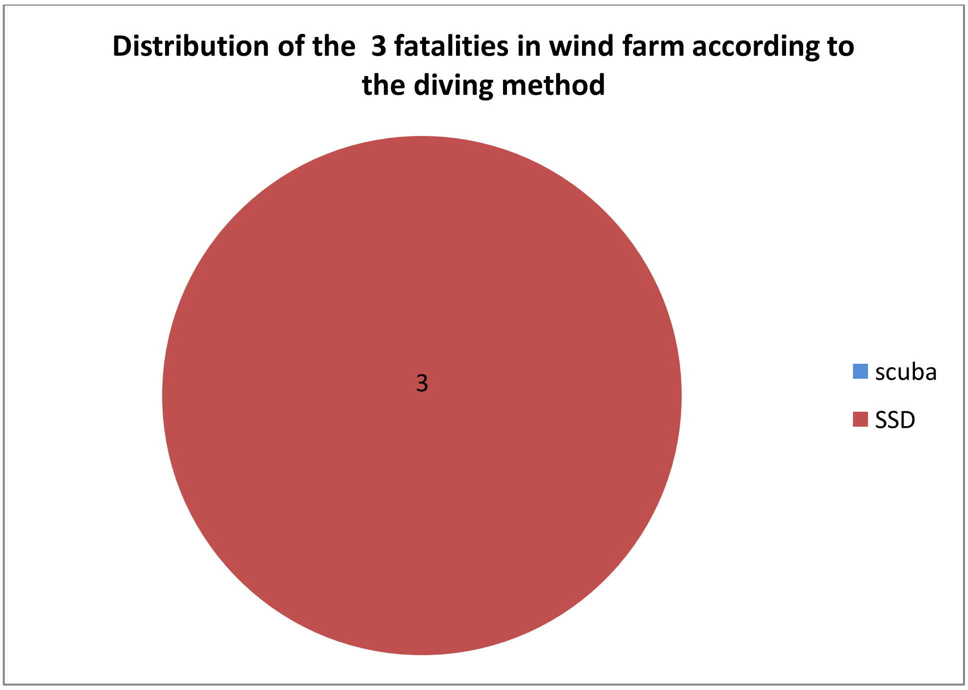


Chart n° 44:

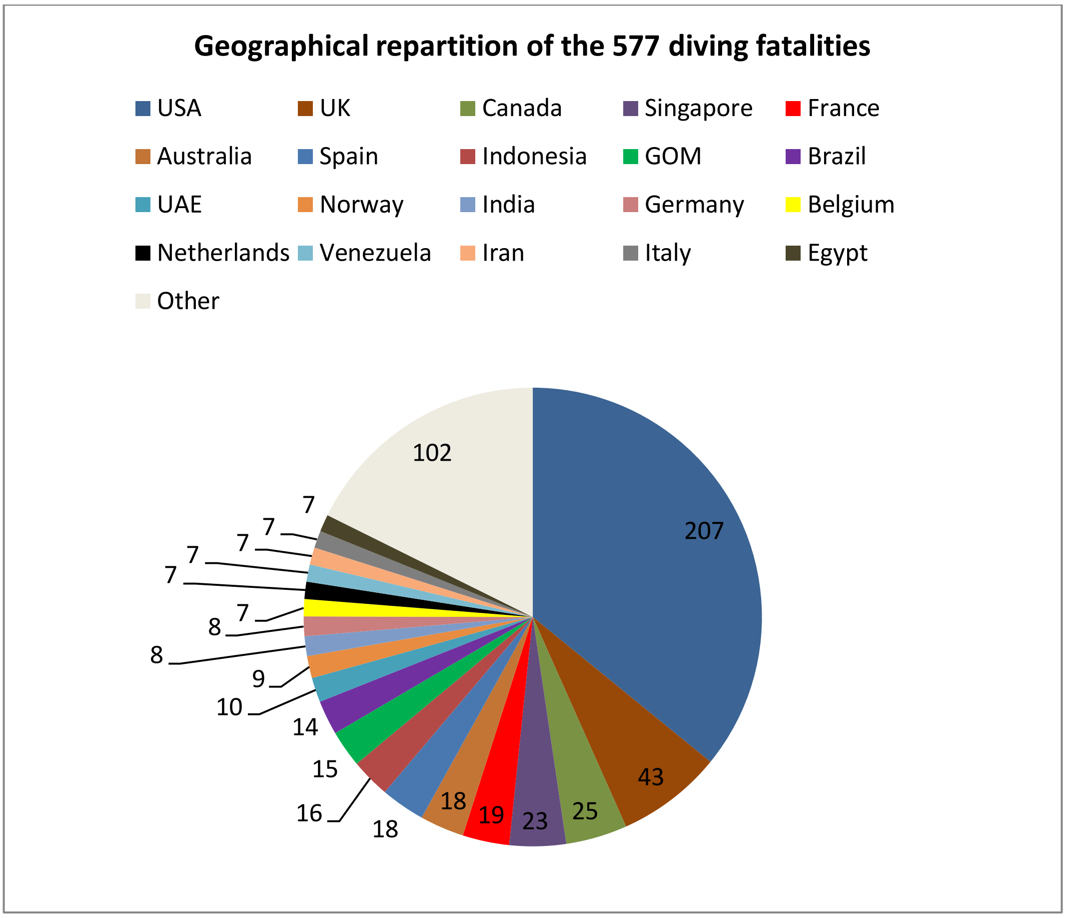


Comments

Only three deaths have occurred since the start of this type of work.
Is it because the volume of hours spent underwater is significantly lower than in other sectors and / or that from the outset, adequate safety precautions have been implemented and respected?
It is probably a combination of the two and only the future will tell.

Analyse

Chart n° 45:



577 fatalities in 40 years in the commercial diving industry is about 14.42 accidents per year. Is it high or is it low?
It’s difficult to answer this question without knowing the total number of commercial divers who were exposed to these risks.
As can be seen on the last chart, all the accidents used in this survey came from data reported in no fewer than 64 countries.
As shown, the US seems to pay the highest price in this business. This does not necessarily mean that it is there that it is the most risky to work, but rather than it is in America that we find the highest density of commercial divers and it is also there that we find a greater transparency which can result in perceived higher numbers.
Extrapolating the annual death rate per 100,000 equivalent divers to 75 and 100 could be an attempt to say that the annual average number of divers who were active in the world during these four decades should be between 11900 and 15867 [19].
But is this calculation reliable, that's the question and it is not so easy to answer to it.
What is certain, on the other hand, by reading this survey, is that a large number of accidents could have been avoided if correct risk analyses had been made before diving.

If we look at graph n° 6 to 8, we can see that a large number of accidents (252) occurred in scuba diving.
For 56 of these accidents the main cause of death was drowning and for the other 196 cases, death generally occurred as a result of a combination of factors but where the end was also drowning.
All these divers would probably not have been saved, but many of them would probably not have died if they had dived with an umbilical.

Another cause which bewilders by the high number of deaths it generates is accidents due to the differences of pressure (delta P).
Three sectors are concerned by it, but especially inshore diving speaks loudest with its high number of accidents.
The risk of suffering a delta P there is much higher than in other sectors because the work situations where this risk exists are quite numerous (locks and culverts, sluice gates, installation and sealing of cofferdams, leak search, work in dams, desilting (vacuum / pump / airlift/ etc.).
Work under boats also presents this kind of risk due to the presence of numerous hull intakes.
In these two sectors quite a lot of accidents would have been avoided if the dangerous area had been correctly localized and/or correctly locked out.
Facing delta P a commercial diver does not have much of a chance to get out alive and that's why a good study of the situation should ABSOLUTELY be performed before diving.
If in doubt, preventive detection measures must be carried out to define the power of the delta P which will then allow taking appropriate action to stop, reduce or otherwise isolate and prohibit the diving area.
Two interesting documents [20, 21] on this subject and a video [22] are available and it would be good that they were read and seen by all diving supervisors.

Accidents related to underwater cutting have also made a lot of victims. In each case (except two) the cause of death was due to the explosion of a gas pocket (hydrogen / oxygen) generated by the burning of (an) electrode(s) or from the residual gas of a burning torch.
Whatever the structure to be cut, it is good to remember that before starting to cut it is important and vital to determine whether the gasses can freely come to the surface or whether there is a risk that they remain confined or are deflected in a specific area.
As we can see, this risk exists particularly in the cutting of wrecks, and it is therefore essential before starting this type of work to go through the ship's plans (if available) and look as well at its position on the bottom to find out where residual gas will tend to be trapped.
One of the few situations in which electrical cutting (or gas cutting) exhibits substantially no risk of explosion occurs when cutting a structure in open water and when no material is present on the back of the cut; thus allowing gas to freely rise to the surface.
In all other cases, the risk is more or less present and must be taken into consideration.
One of the most effective ways to avoid the concentration of gas at a given location when cutting in an enclosed space is the realization of a preventive evacuation window.

In many cases, the cutting of these windows can be carried out using cutting electrodes but in certain circumstances (presence of decomposition gas or other hydrocarbons) this method may prove to be highly dangerous and even fatal.
In this case the vent holes will be created by using a non-sparking tool (drill with reduced RPM).
The second method of evacuating explosive gases when cutting is by way of venting with compressed air.
This method is also used when some material (concrete, sand, clay, etc.) is present on the back of the metal structure.
For this method to be effective, it is essential that the over-pressure surplus of the explosive gas and air can escape freely to the surface.
Ventilation with compressed air must nevertheless be carried out prudently and in all cases one must prevent pressure used for the ventilation becoming too high and thus increasing the volume of any existing cavity.
If during the risk analysis it is found that despite the completion of the drain holes and / or the ventilation, a risk is still present that more than a few cubic centimetres of explosive gas could remain trapped, then it is better to opt for a another cutting method.
Through another survey [23] it has been seen that commercial divers are not always correctly trained to use this cutting technique and thus not always aware about the hazards.

Entanglement is also a major cause of accidents and demonstrates the importance of properly managing the umbilical and ensuring it remains clear at all times so that the commercial diver can free himself immediately in case of problems.

Crushing accidents are often bound to communication problems between the surface and the diver and / or incorrect positioning of this last when a load is lowered.
It is good to remember that in case of load manoeuvres under water, the orders are given by the diver.
For two accidents the divers were killed by the cave-in of a trench. It is good to remember that even under water the sloping and benching rules need to be applied.

Accidents related to the loss of the helmet (or band mask) seem to indicate that they were not set up correctly. While it is true that in the past the neck clamp of a particular helmet had a tendency to open easily if it was not closed properly and / or if the safety pin was not fixed, that risk no longer exists with the new locking systems and therefore logically this cause of accident is expected to decrease in the future.
Regarding accidents due to the voluntary removal of the helmet they relate more specifically to commercial divers who dived without a bailout and ditch in a last effort to stay alive. This ditching technique is still taught in some training centres.

To finish, what can we say about the propeller-related accidents?
Hearing an engine start and seeing a propeller beginning to turn on, what a horrible death for a commercial diver.
ALL the accidents listed here concerning this type of hazard could have been avoided if good communication between the diving team and the ship’s crew and particularly the senior

engineer had been put in place to make sure that the main engines were shut down and that the brakes were on.
Ditto for the umbilical fouled in the propeller of a boat passing nearby, they could have been avoided if the warning signs on the dive sites were properly marked (flag A, navigation panel) and diving work reported to the harbour master.

Conclusion

In conclusion, we can say that commercial diving is effectively a risky business that can lead to the death of commercial divers.
The number of fatal accidents might yet be reduced if for each diving project and before each dive a correct and serious risk assessment was conducted, but also and especially if we abandon or severely restrict the use of scuba diving.

REMEMBER

COMMERCIAL DIVING IS HAZARDOUS

IF THE RISK OR DANGER CANNOT BE CONTROLLED THEN DO NOT DIVE

DIVE SAFE

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Divers population in 2014 = Number of accidents / death rate per 100.000 / 40

577 / 0.00075 / 40 = 19233

577 / 0.00100 / 40 = 14425

Divers population in 1975 = 2014 population – 35% **

19233 – 35% = 12501

14425 – 35% = 9376

Average:

(19233 + 12501) / 2 = 15867

(14425 + 9376) / 2 = 11900

** 35 % is the average increase of workers in several construction sectors during four decades.

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