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Underwater Cave Diving Fatalities in Florida: A Review and Analysis

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ABSTRACT: Although no formal accident data reference system exists, the cave diving deaths in Florida from 1962–1991 and 1995–July 1996 (data for 1992–1994 were unavailable) is reviewed. These cases reveal that the number of diver fatalities is cyclical in nature with a periodicity of eight years. Because we are currently only a year past the cycle low, this analysis allows predictions to be made that indicate a rise in fatalities over the next five to seven year period. This study reveals that a lack of experience and failure to follow proper safety precautions are the leading causes of fatalities in cave diving accidents. A one page accident information reporting form is proposed to aid in the initial and accurate reporting of a fatality and to standardize data collection for future research.

KEYWORDS: forensic science, forensic pathology, cave diving, fatalities

In 1968, the National Association for Cave Diving (NACD) was established to achieve safer underwater cave diving (diving in ceiling or overhead situations) through training, education, and research. As part of an ongoing research and accident prevention program, the NACD collects and maintains one of the most complete databases on cave diving fatalities. Other organizations currently responsible for the collection of diving accident and fatality data include the United States Coast Guard and the Divers Alert Network (DAN) at Duke University Medical Center, Durham, NC. Although DAN publishes a widely circulated annual report on diving accidents and fatalities, cave diving information is sometimes difficult to extract because data are condensed and compiled for statistical purposes. This study reviews cave diving fatalities occurring in Florida over a 30.5-year period and suggestions are also made as to a standardized fatality reporting form so more fatalities are accurately reported and records are more complete and consistent. This will allow for a more efficient and thorough analysis of cave diving fatalities.

Materials and Methods

To analyze data on cave diving fatalities, we reviewed an extensive database on cave diving fatalities compiled by David Desautels and made available to us by Dr. Bob Millot (University of Florida Diving Science and Safety Program). After relevant information (such as number of deaths, diver age, training level, etc.) was extracted using field searches on the existing computerized data base, we requested full medical autopsy, written investigative and toxicological reports for those cases occurring within Florida from the Florida Medical Examiner Office assigned to the district in which the death occurred. Newspaper, police, eyewitness, and family accounts were utilized whenever possible. All fatality information was categorized and entered into Quattro Pro 6.0 for record compilation. Database field code searches were used extensively to extract relevant data and a fourier spectrum analysis was performed on the total number of fatalities per year. MATLAB (The Math Works Inc.) numeric computation and visualization software's signal processing component was utilized to analyze the fatality frequency trend using standard fourier transform protocols.

Results

During 1962–July 1996 (1992–1994 data unavailable from NACD), 287 reported cave diving fatalities were recorded in Florida. The average number of deaths per year during this period was 9 (±1 SD) with the fatality number reaching its peak in 1974 with 25 deaths, and a low of only two deaths in 1982 (Fig. 1). The average age of the victims was 24.2 years with a maximum age of 54 and a minimum of 14. Only 11 female fatalities were recorded.

The fatalities reviewed listed a total of 266 cases with the official cause of death recorded as simple drowning and not as a pressure related death. Only 21 cases listed more specific causes of death on the report of autopsy (Table 1). Analysis of the 287 cases from 1962 to present revealed an eight year cyclical fluctuation in annual fatalities.

The factor contributing to the largest number of fatalities was inexperience. Diver inexperience (as reported by diving partners, friends, and relatives) contributed to at least 199 out of 287 deaths

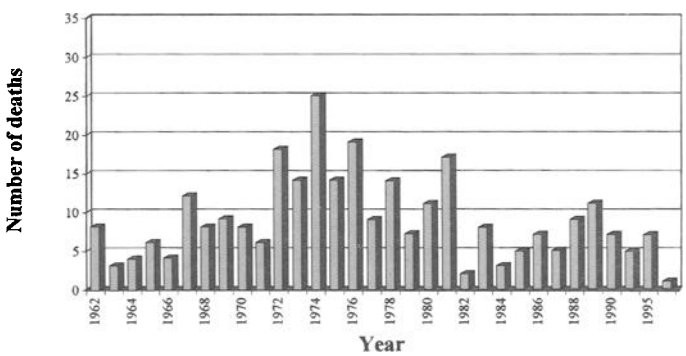

FIG. 1—*Total number of cave diving fatalities in Florida over a 30.5-year period.*

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TABLE 1—*Official cause of death listed on report of autopsy.*

	Drowning	Asphyxiation	Air Embolism	Nitrogen Narcosis	Oxygen Toxicity	Aspiration
Number of Cases:	266	10	6	2	2	1

(information on diver experience was not available for 88 cases). Diver panic was a contributing factor in 50 deaths. No correlation was found between inexperience and panic. It was anticipated that incidences of panic would occur most frequently during early exposures to the cave environment. However, only 11 deaths occurred during training sessions in cave settings and only 3 deaths were caused by panic situations during training. Of the 287 fatalities reviewed, 270 were not certified cave divers. Of the 17 fatalities among certified cave divers, only two deaths were attributed to equipment failure, and one for failure to use properly functioning equipment correctly. No less than 93 fatalities were individuals certified for open water diving only.

The second leading contributing factor was failure to use a guideline. In 180 cases, divers failed to follow the common safety practice of utilizing guidelines. However, information on the use of guidelines was not available in 107 cases, and thus could prove to be the true leading cause of cave diving fatalities. Deaths in 58 of these cases were attributed to simply becoming lost and disoriented within the cave system without a guideline to indicate an exit path. Loss of contact with an established guideline resulted in the death of 15 cave divers. Separation from the line usually occurs in zero visibility conditions produced when divers disturb bottom sediment or 'silt' while navigating the cave system. In these conditions, even a momentary loss of contact with the line, or with a partner in contact with the line, can result in disorientation and panic. During panic situations, air usage increases and thus diminishes the time available for the diver to regain orientation before exhausting the air reserve. For obvious reasons, diver orientation within the cave system can be aided with the use of lights. However, 117 recovered victims were not utilizing lights during their dive whereas 124 had only one light in use. A total of 26 victims carried two lights, the number recommended by the NACD for cavern diving and only 7 individuals had the recommended number of three lights for cave diving.

Our study cases also revealed that cave fatalities do not frequently occur on long or deep dives. However, all dives within the overhead environment of a cave system are classified as "technical dives" and are beyond the limits of divers without the proper certification. In cases in which depth and distance information was available, 216 (81.5%) of the fatalities occurred in water ≤30 m in depth, (Fig. 2) and 167 (57%) were within the first 30 m from cave opening (Fig. 3). Although having a dive partner increases safety in the event of an accident through such practices as buddy breathing, 167 deaths occurred in dives with multiple individuals (Table 2). However, no reliable data are available to estimate the total number of successful multiple participant dives versus dives undertaken solo.

The one page NACD accident statistics information form (Fig. 4) was created by Dr. Millot and is less daunting than the four page diving fatality reporting form published by the DAN. This form includes all information needed to formally record the fatality, classify the cause of death, and provide enough detail about the accident so that more in-depth inquiries can be directed to the proper investigating officials.

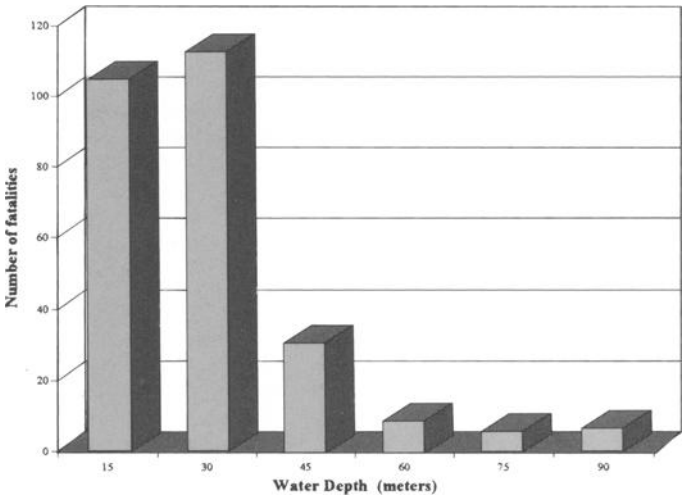

FIG. 2—*Depth at which accident occurred in cases in which information was recorded.*

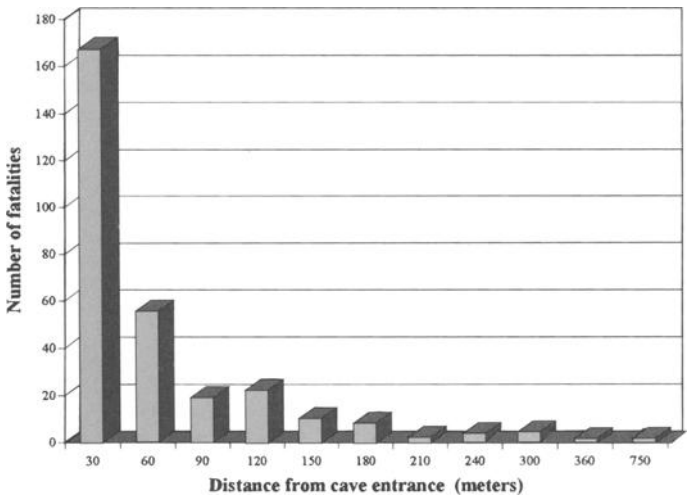

FIG. 3—*Distance of body from cave entrance in cases in which information was recorded.*

TABLE 2—*Fatalities as compared with number individuals in dive group.*

	Individuals Per Dive Group			
	1	2	3	4
Fatality Number:	120	122	33	12

NACD Accident Statistics Information

Please complete the areas to which you have specific knowledge. If information is unavailable, please mark as either unavailable or unknown.

Date_____ **Time**_____ **Number of Victims**_____

Victim(s):

1. **Name**_____ **Age**_____ **Sex**_____ **Address:**_____
Certifications: (Open water/Cave)_____ **Date Certified**_____ **Experience (hrs)**_____
Abe Davis/Wakulla award_____ Physical condition_____ Injuries_____ Medications_____
Conditions of dive: Solo_____ Team_____ Lost_____ Careless_____ Panic_____

2. **Name**_____ **Age**_____ **Sex**_____ **Address:**_____
Certifications: (Open water/Cave)_____ **Date Certified**_____ **Experience (hrs)**_____
Abe Davis/Wakulla award_____ Physical condition_____ Injuries_____ Medications_____
Conditions of dive: Solo_____ Team_____ Lost_____ Careless_____ Panic_____

Accident Site: (Type)
River_____ Spring_____ Sink_____ Cave_____ Lake_____ Ocean_____ Other_____
Name of site: _____ State_____ County_____ Country_____
Dive Conditions: Currents_____ Silt_____ Restrictions_____ Depth of accident_____ Distance from surface_____
Accident Details:
Time of accident_____ Time of recovery_____ Reported by_____ Recovery by_____
Survivors_____
Accident Analysis factors: 1. Training_____ 2. Guidelines_____ 3. 2/3s air rule_____ 4. Depth_____ 5. Lights_____

Cause of accident: Equipment failure- YES_____ NO_____ (If yes, check all that apply below)
Regulator_____ Buoyancy control_____ Light failure_____ Suit problems_____ Scooter_____ Valve_____
Line reel_____ Weights_____ Computer Error_____ "O" ring failure_____ Narcosis/HPNS_____
Water conditions___ Entanglement_____ Training deficit_____ Carelessness_____ Buddy Separation_____
Seizure/anoxia_____ Gas error/confusion_____ Companion error_____ Site collapse_____ On/off line _____
Diver physical condition_____ Gas Planning (out of air)_____ Directional Confusion_____

Equipment status: - Was victim using equipment- YES_____ NO_____ (If yes check all that apply below)
Owned_____ Borrowed_____ Rented_____ New_____ Used_____ Weights_____ Mask_____ Fins_____
Snorkel_____ Knife_____ Compass_____ Reel_____ Line_____ Markers_____ Lights (number)_____
PSI gauge____ Computer_____ Watch_____ Wet suit____ Dry suit____ Tables_____ Buoyancy device _____
Regulator(s)___ functional_____ marked_____ Lights Operational_____
Cylinder configuration_____ Size_____ Rebreather_____
Tank Valve: H/Y_____ Dual Manifold_____ Vol. remaining - doubles_____
Side mount_____ Vol. per cylinder_____ Stage bottles_____ Travel Gas_____ Vol. remaining_____
Deco Gas_____

Recovery person: Name:_____ Ph#_____
Autopsy Performed: YES_____ NO_____ (If yes, please complete below)
Name of Pathologist(s)_____
Where performed (County, city, institution)_____
Please request complete report of medical autopsy, all written investigative reports, and toxicological results be sent to the address below.
Investigating law enforcement agency _____ Officer name_____
Additional comments:_____

Name of person(s) completing form:_____ **PH#**_____

Please complete this form and send it to the address below for any dive accident in which you are involved, or which occurs close enough for you to obtain the needed information. Include any local news articles. If on-site, draw location and site map on back.

National Association for Cave Diving, Inc.
Accident Report, P.O. Box 14492, Gainesville, FL 32604
Questions and comments may be sent via e-mail to: **kens@ufl.edu**

FIG. 4—*NACD accident information reporting form.*

Discussion

Cave diving has one of the lowest fatality rates of the eight major dive activities recognized by DAN. These categories are sightseeing, wreck diving, instructional diving (those under instruction), teaching (instructors themselves), spearfishing, night diving, photography, and cave diving. Although it is impossible to obtain accurate data on the total number of individuals participating in this sport during the time period reviewed, we examine the leading causes of fatalities and make predictions as to future trends based on past fatality patterns. Because standardized accident report forms were sparse in reviewed case files, information gathered on cave diving accidents and fatalities was frequently incomplete, inaccurate, and haphazard. The abundance of incomplete reports made complete analysis of factors such as circumstances leading to the fatality difficult or impossible in many cases.

Most dive organizations rely on active members, subscription services, phone contacts, and witnesses to report accidents and fatalities. However, many cave diving deaths may go unreported as data collection methods, fatality report forms, and accident information reports frequently change. Once reported to the NACD or DAN, these organizations request full medical autopsy and written investigative reports from the medical examiners, coroners, and law enforcement agencies. Unfortunately, many of the medical reports are of limited use as most classify the cause of death simply as "drowning" (1) when in fact drowning may be secondary to air embolism, nitrogen narcosis, and oxygen toxicity (2). An additional complication concerns the evolution of diving training standards during this time. Although more classes are being offered by businesses so that more products can be marketed to help assure financial success, such an environment allows divers to be classified as "advanced" with as little as 5 h of dive exposure.

Although the technique for reporting cave diving fatalities is relatively informal and the responsibility for data collection has frequently changed hands, an extensive database has been amassed by the commendable efforts of the NACD. Despite a lack of standardized reporting and the incomplete and disorganized state of many records, valuable information is obtainable from existing records and written accounts.

The leading cause of cave diving accidents in the cave environment is inexperience. Although diving in overhead situations is clearly beyond the skill level of open water recreational divers, the NACD reports (through witness accounts) that many such divers typically plan on entering the cave system "just a little bit". Lured by the clear and pristine water, they are often unaware of the blinding wall of silt and sediment stirred into the water by their swim fins. Upon turning to exit they find that their view is obstructed and they are unable to retrace their path. Recovery divers report that victims seem to have become disoriented while attempting to feel their way out, or continued to swim deeper into the cave in search of another exit. In either case, air reserves often exhaust themselves before they are able to locate an exit because divers often fail to allow enough emergency air for unexpected underwater delays. Such an error is typically fatal in the cave environment. The NACD states the false feeling of safety provided by only going in "just a little bit" probably accounts for the high percentage of fatalities within the first 30 m feet of overhead as silting and disorientation can be rapid and unexpectedly overwhelming for the inexperienced diver.

A second leading cause of cave diving accidents was failure to use a guideline. Surprisingly, this did not always result from a lack of experience. The NACD has determined that many experienced divers choose not to utilize the safety factor that a guide line can provide because they feel it is not adventuresome enough, and in search of adventure they enter cave systems without a line. Other NACD safety recommendations that were violated included the use of underwater lights. Most diving organizations suggest that individuals cave diving should carry three cave diving approved lighting devices. In 117 deaths, victims were reported as not having lights in use. Whether lighting devices were not used or were lost by the divers during terminal events and were subsequently not recovered is unknown. In contrast, only 33 victims were found to have carried the recommended number (three or more) of lights.

Strict adherence to safety recommendations may prove to be of utmost importance if past fatality trends are to be altered. A fourier spectrum analysis was conducted on the total number of fatalities per year. This analysis revealed an eight year cyclic trend in which the number of fatalities can be expected to rise during the next five to seven year period as we are currently about one year past the cycle trough. Although the cause of this trend is not clear, it was possible to predict, based on the fourier spectrum analysis, that the overall number of fatalities will again be on the rise unless the past trend is unexpectedly broken. The authors and the NACD recommend a continuance of formalized training and education courses, along with a vigilant adherence to safety recommendations in order to halt the possible future rise in fatalities that our analysis predicts.

The NACD attributes the predicted fatality rise as being due to the growing popularity of mixed gas, or nitrox diving which will attract inexperienced and uncertified divers. The NACD is concerned that this new technology may also result in an increase in the fatality number of trained divers as they have a tendency to operate to the limits of such technology. Breathing custom gas mixes allows divers to descend to greater depths for longer periods of time than previously attainable; however, it adds a level of technical complexity to the dive profile that allows little room for error. According to the NACD, the increased technical skills required to accomplish this type of dive is undoubtedly beyond the skill level and physical capability of many who will attempt mixed gas dives, and dives such as these will almost certainly become another major category of cave diving fatalities.

The current and future proliferation of mixed gas dives requires that the pathologist closely follow approved autopsy procedures (2) to properly define the cause of death and be prepared to classify the cause beyond a simple drowning accident. Formerly, drowning was defined as a simple "asphyxial" death, but is now considered a complex series of physiological and biochemical disturbances (1,4). Although 'asphyxia' constitutes a major portion of such events, the inadequacies of past 'drowning' definitions is detailed by other authors (3). Additionally, pressure related causes must be differentiated from complications arising from the gas mixture itself. Where possible, the pathologists should have the composition of the diver's air supply analyzed by experienced persons and include their findings in the report of autopsy and in written investigative reports.

The proposal of a one page reporting form is intended to be less time consuming and intimidating to complete than previous forms. Hopefully, its brevity will encourage more legal investigators to report the fatality, thus improving the accuracy of basic and essential information. Such information includes victim name, date of death, county, city, and precise geographic location death occurred. Currently, this critical information is frequently missing or inaccurate in initial fatality reports which makes collection of additional data extremely time consuming and difficult. Once

accurate initial information is received by the agency responsible for data collection, they may contact the proper authority and make specific and detailed information requests. In many cases, the information requests received by legal investigators are vague and the information requested may need to be compiled by several different specialists (i.e., medical examiners, police, toxicology laboratories, and recovery divers). Once provided with accurate basic case information and specific informational requests, the task of record retrieval should be less time consuming for the legal investigator to accomplish, so the pertinent information can be forwarded with little delay and minimal data loss.

Acknowledgments

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