Common Factors in Diving Fatalities

DAN America and DAN Europe Data

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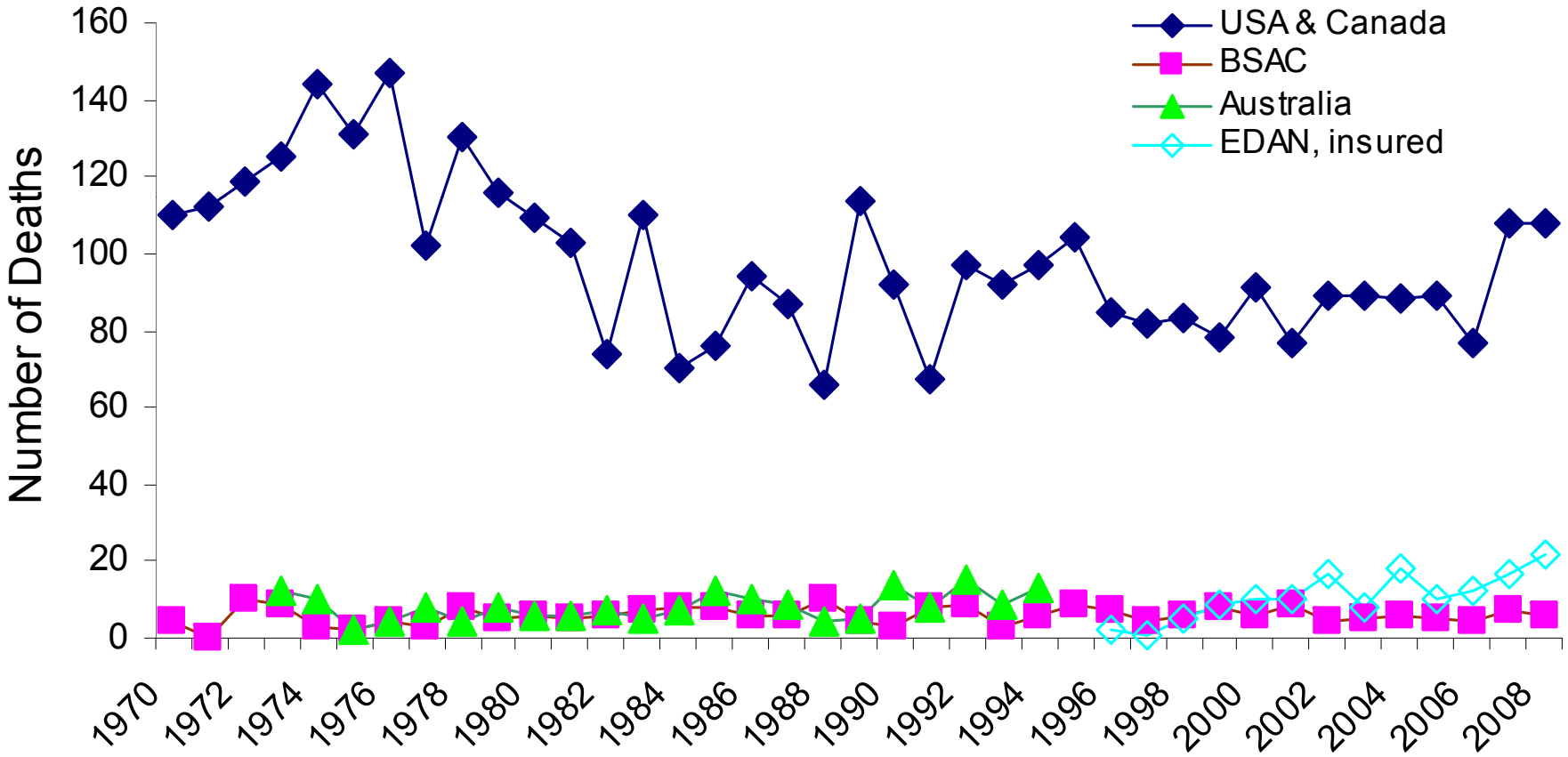
Fatality Workshop, Durham April 8-10, 2010

DIVERS ALERT NETWORK

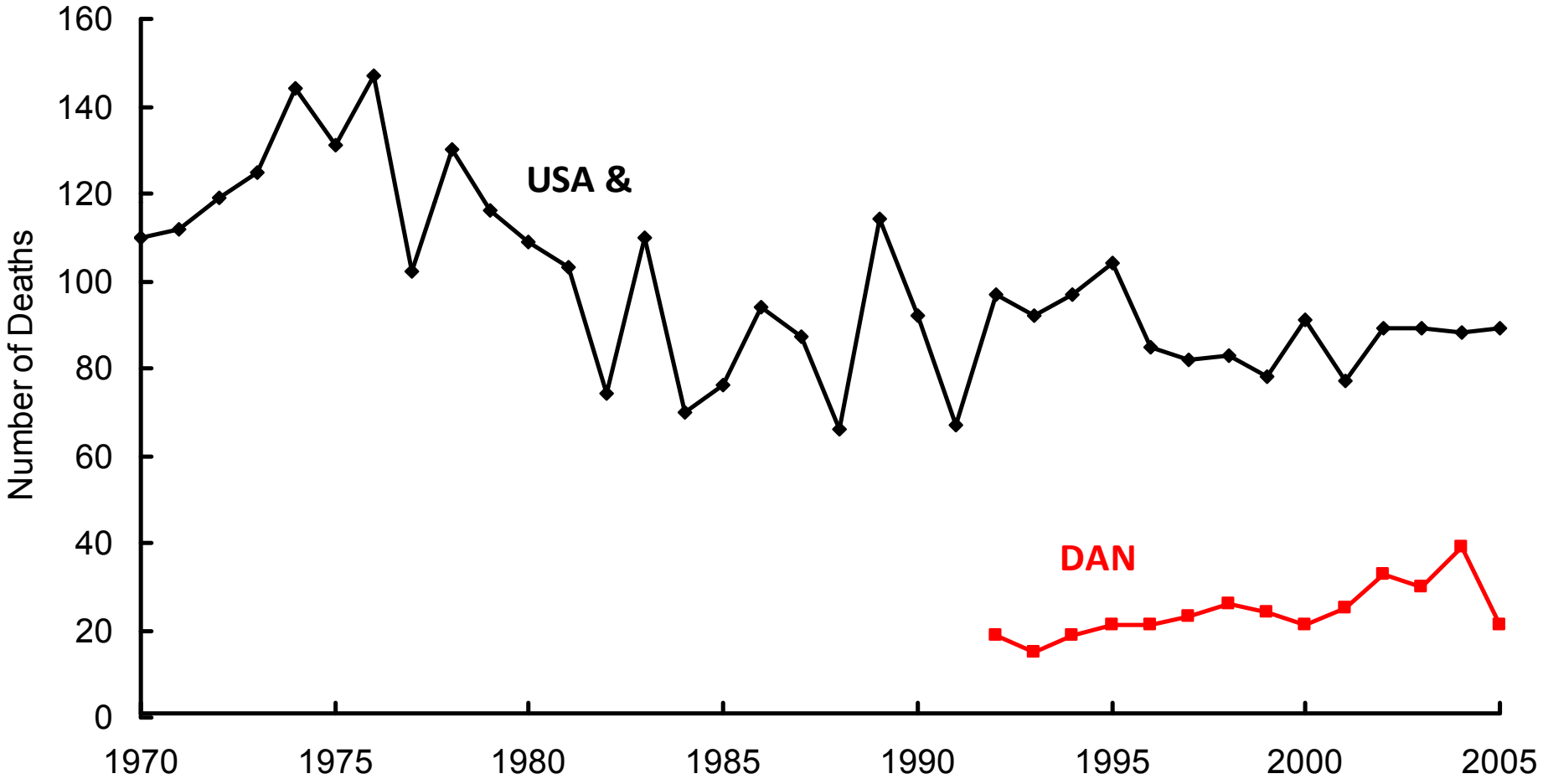
Sources

- DAN Insured Members Claims 2000-2006
  - 187 dive-related deaths
- EDAN Insured Members Claims 1996-2008
  - 144 dive-related deaths
- DAN Fatality & Injury Database 1992-2003:
  - Most common causes of deaths; 947 cases in OC diving
  - Case control study: 165 fatal and 135 non-fatal AGE case
  - Diabetes mellitus: 37 cases vs. 938 non DM cases

Annual numbers of diving fatalities



Annual Number of Diving Fatalities



Original articles

Scuba injury death rate among insured DAN members

Petar J Denoble, Neal W Pollock, Panchabi Vaithiyanathan, James L Caruso, Joel A Dovenbarger and Richard D Vann

- DAN diving accident insurance data, 2000-2006
- 1,141,367 insured member years
- 187 diving related deaths
- Sex, age, cause of death

Individual Risk Per Annum (IRPA)

- IRPA = Probability (individual is killed during one year of exposure)

- As safety performance measure:

$$\text{IRPA} = \frac{\text{Observed number of fatalities}}{\text{Total number of person-years exposed}}$$

DAN Membership IRPA

$$IRPA = \frac{187}{1{,}141{,}367} = 163 * 10^{-6}$$

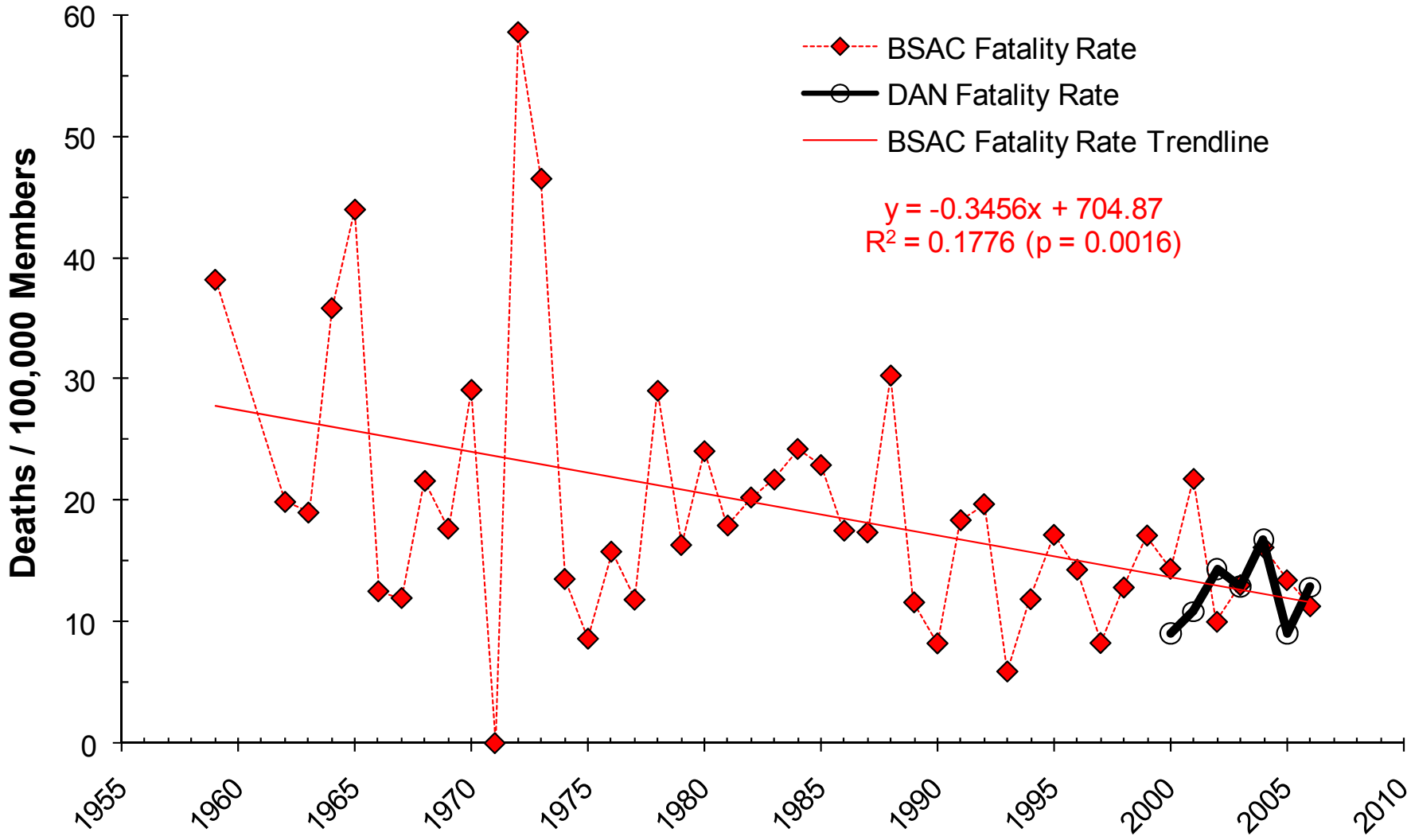
1 in 6000 or 0.016%

Individual Risk Per Annum (IRPA)

Industry sector	Annual risk	Annual risk
Recreational diving*	1 in 6,000	163×10^{-6}
Jogging	1 in 7,700	130×10^{-6}
Mining and quarrying	1 in 9,200	109×10^{-6}
Construction	1 in 17,000	59×10^{-6}
Agriculture, hunting	1 in 17,200	58×10^{-6}
Fatalities to self-employed	1 in 50,000	20×10^{-6}
Manufacturing industry	1 in 77,000	13×10^{-6}
Fatalities to employees	1 in 125,000	8×10^{-6}
Service industry	1 in 333,000	3×10^{-6}

Data from "Reducing risks, protecting people" (HSE 2001)
** DAN membership data*

BSAC & DAN Fatality Rates



Scuba injury death rates

Group	Denominator	Time period	Rate (95%CI)	
			per 100,000 divers	per 100,000 dives
Cave Divers, GB	Measured	1957-1979		138
Cave Divers, GB	Measured	1980-2006		24.6
USA	Estimated	1986	3.4 to 4.2	
USA	Estimated	1989	16.7	0.8 to 1.6
Orkney, Scotland	Measured	1999-2000		4
Australia	Estimated	1989	34 (1 in 3000)	1.7 to 3.4
Victoria, Australia	Tank fill count	1992-1996		2.5
Australia	Survey	2000-2006	3.57 (1 in 28,000)	0.57
BC, Canada	Tank fill count	1999-2000		2.04
Japan	Tank fill count		(8.8-33.8)	1.0 to 2.4
BSAC	Measured	2000-2006	14.4 (10.5-19.7)	
DAN Insured	Measured	2000-2006	16.4 (1 in 6000) (14.2-18.9)	0.7*

**estimated based on 25 dives/diver/year*

Acceptable Risk

Activities with a fatality risk greater than $1 \cdot 10^{-3}$ deaths/year to the general public are generally not acceptable.

- Cars $3 \cdot 10^{-3}$ deaths/person-year
- Falls $1 \cdot 10^{-4}$ deaths/person-year
- Fires $4 \cdot 10^{-5}$ deaths/person-year
- Drowning $4 \cdot 10^{-5}$ deaths/person-year
- Firearms $1 \cdot 10^{-5}$ deaths/person-year
- Poisoning $1 \cdot 10^{-5}$ deaths/person-year
- Lightning $8 \cdot 10^{-7}$ deaths/person-year

Scuba diving $1.6*10^{-4}$

Criteria for Acceptable Risk in the Netherlands

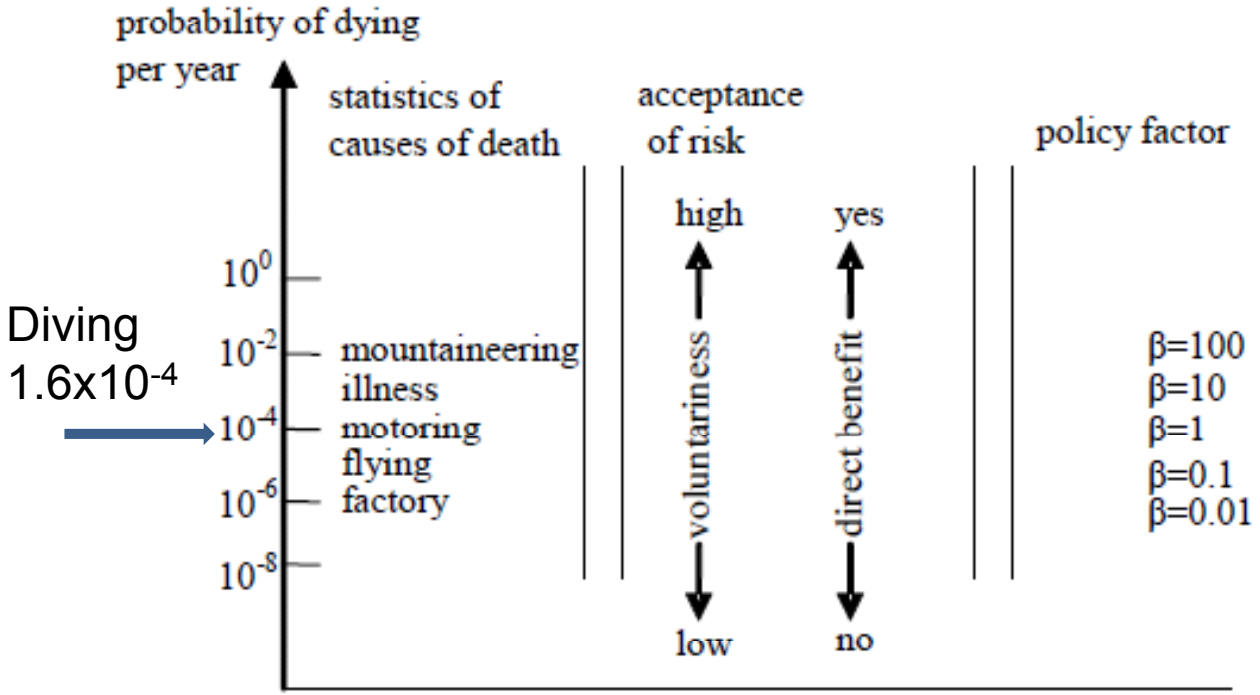
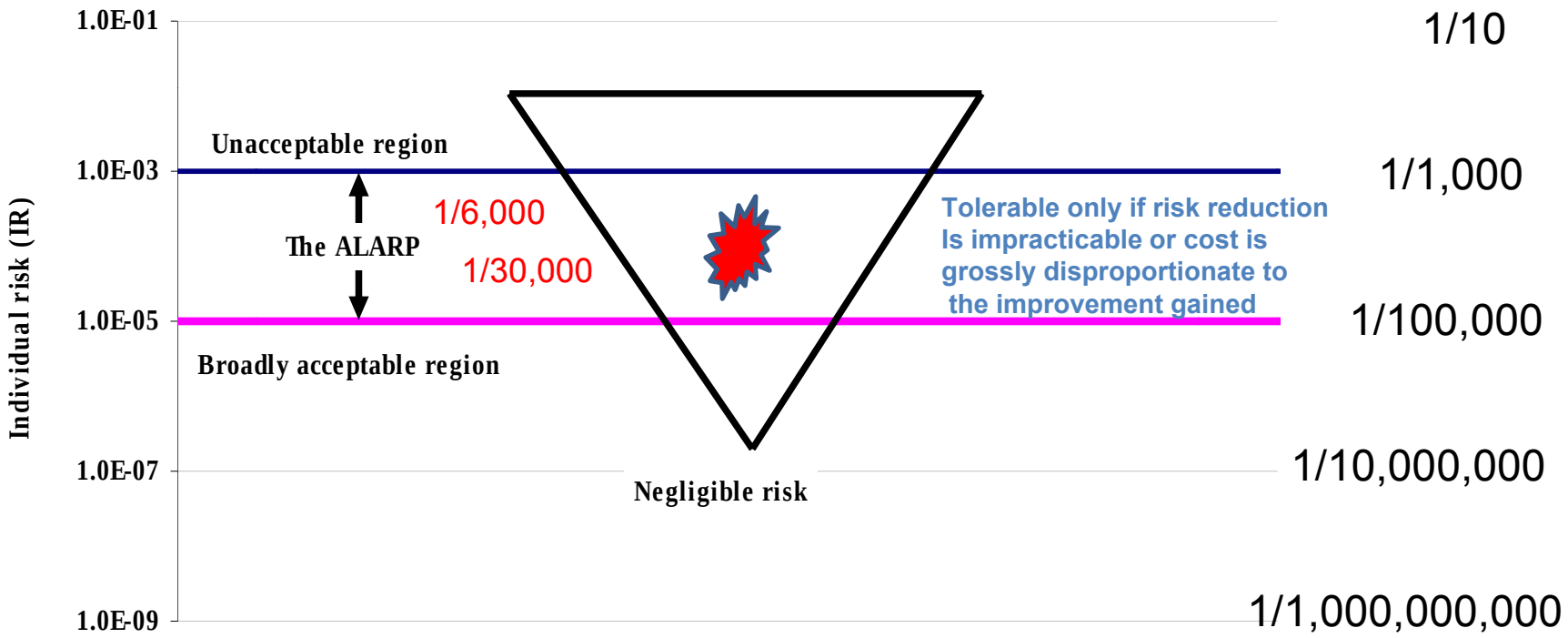


Figure 3 *personal risk in Western countries, deduced from the statistics of causes of death and the number of participants per activity.*

J.K. Vrijlinga, P.H.A.J.M. van Geldera & S.J. Ouwerkerka
Delft University of Technology

ALARP

- As Low As Reasonable Practicable (ALRAP)



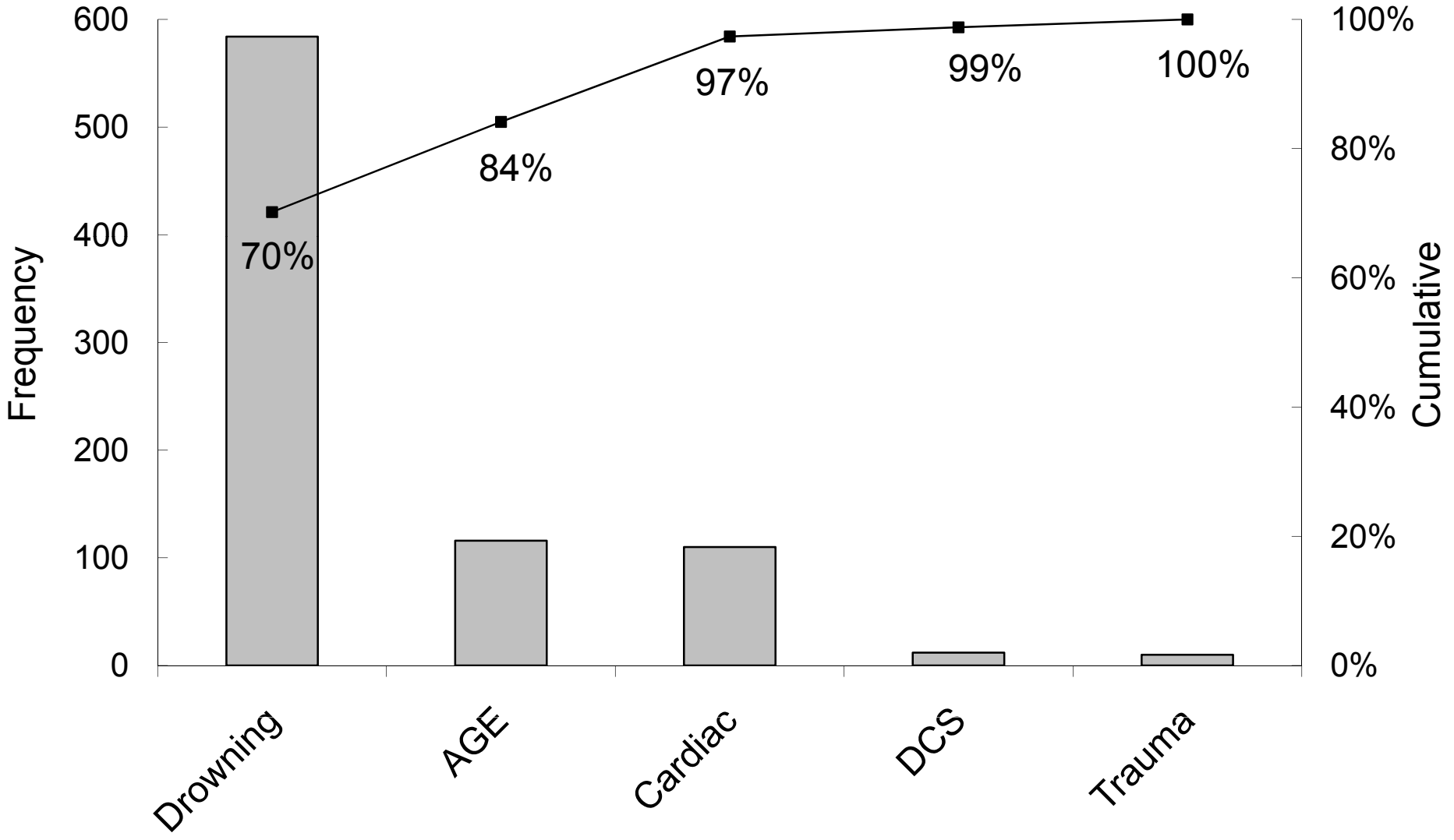
UHM 2008, Vol. 35, No. 6 – Causes of Recreational Diving Fatalities

Common causes of open-circuit recreational diving fatalities.

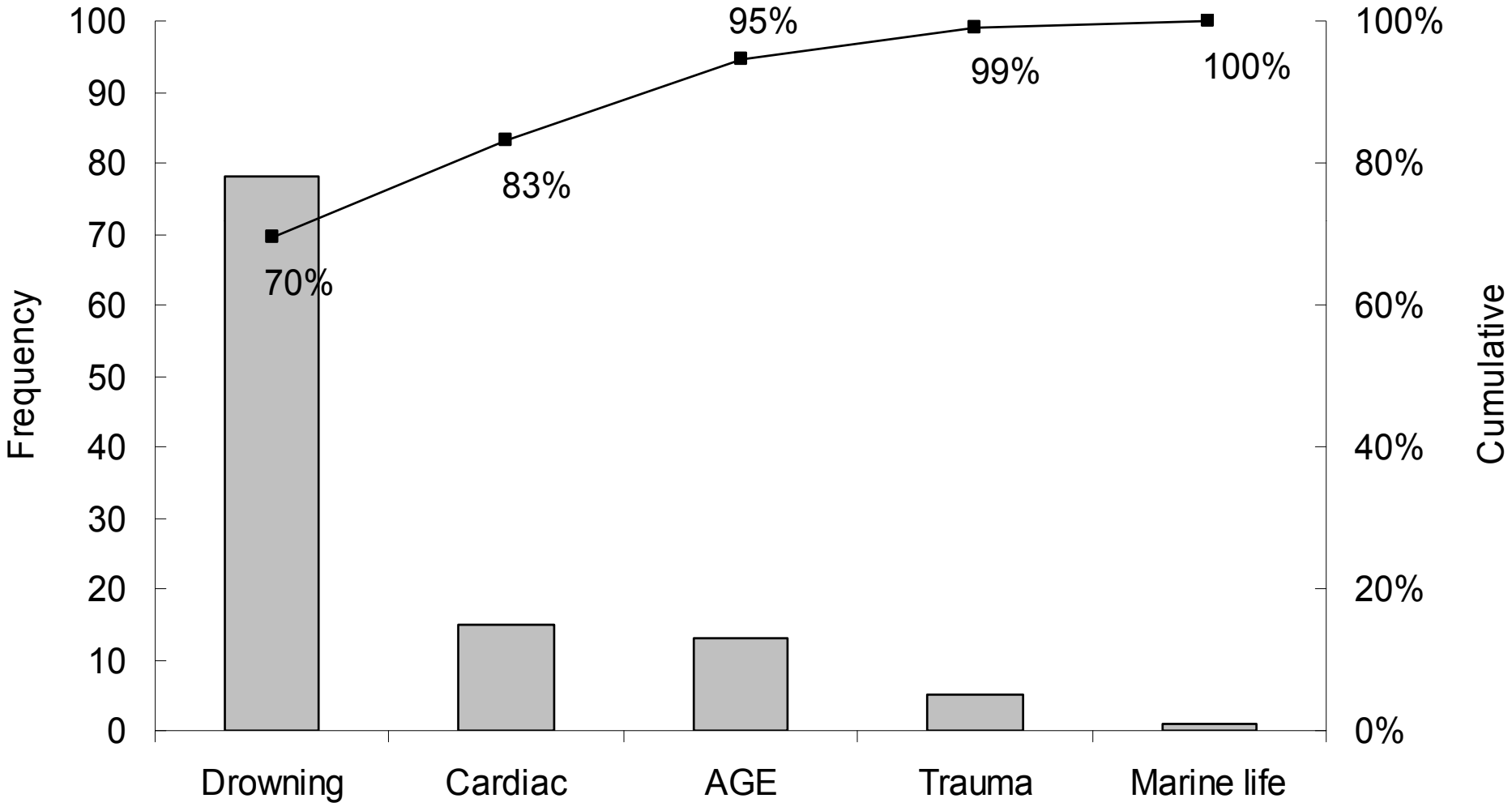
P. J. DENOBLE[1], J. L. CARUSO[1,2,3], G. de L. DEAR,[1,2], C. F. PIEPER.[4], and R. D. VANN[1,2]

- 947 Open-Circuit Deaths from 1992-2003
  - 70% family interviews
  - 60% autopsy findings
  - 52% witness reports
  - <52% investigative reports
  - 28% equipment testing
  - 22% breathing gas analysis

Cause of Death
(DAN America, n=814)



Cause of Death (EDAN, n=112)



Titanic

Cause Map

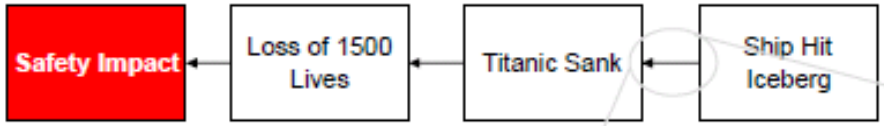
Cause Mapping is a visual, systems-based approach that focuses on fundamental cause-and effect relationships supported with evidence. The three basic steps of Cause Mapping are shown here.

CAUSE MAPPING

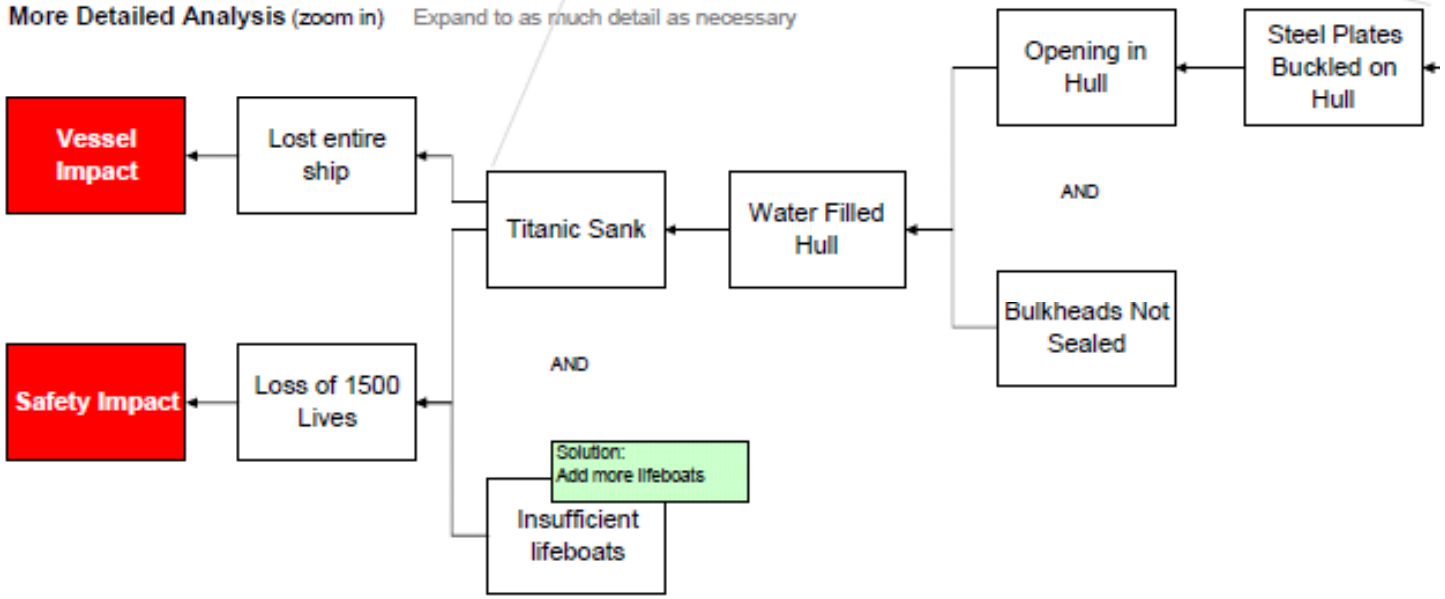
Problem Solving • Incident Investigation • Root Cause Analysis

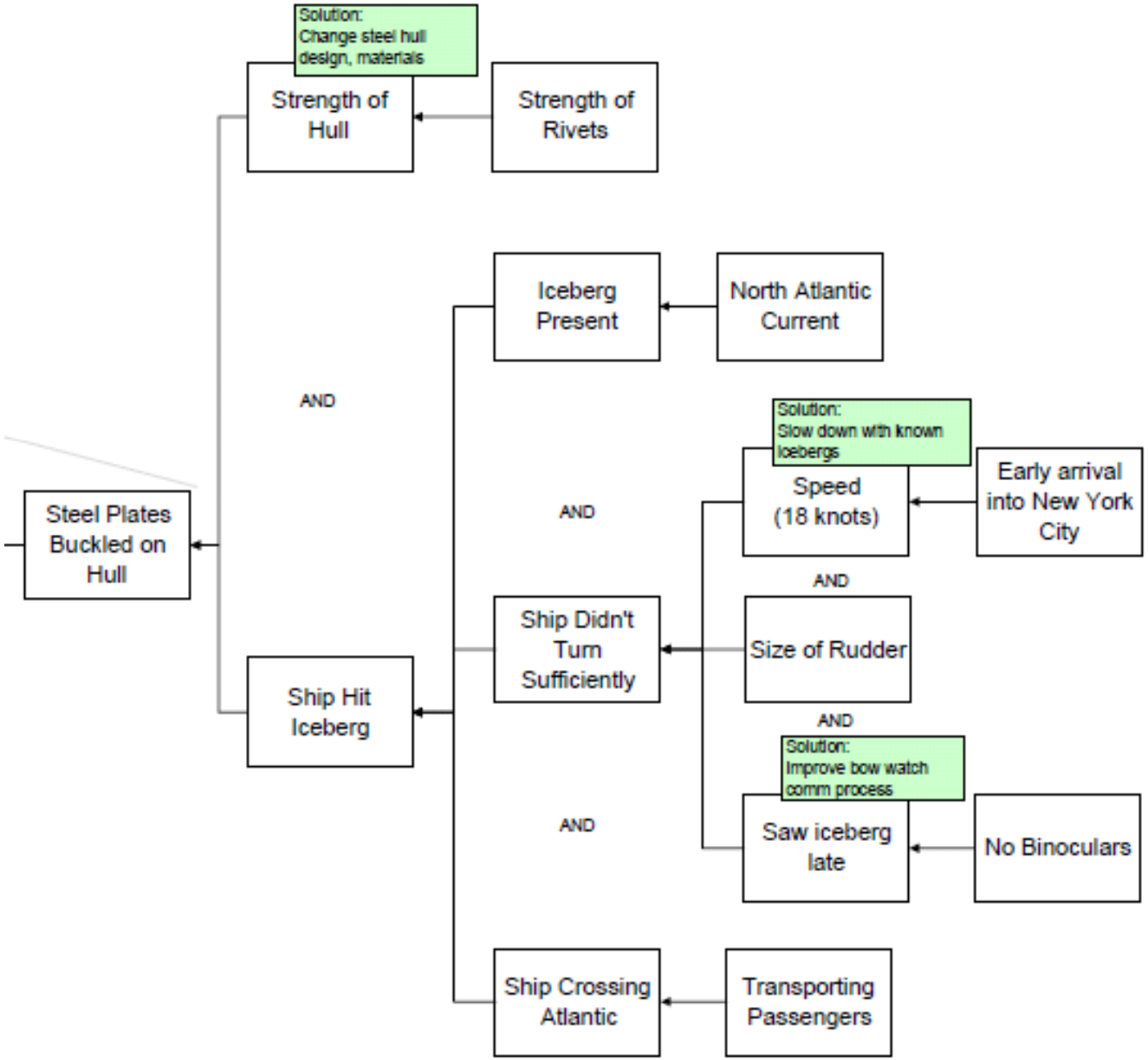
Step 1	Problem	What's the Problem?
Step 2	Analysis	Why did it happen?
Step 3	Solutions	What will be done?

Basic Lev

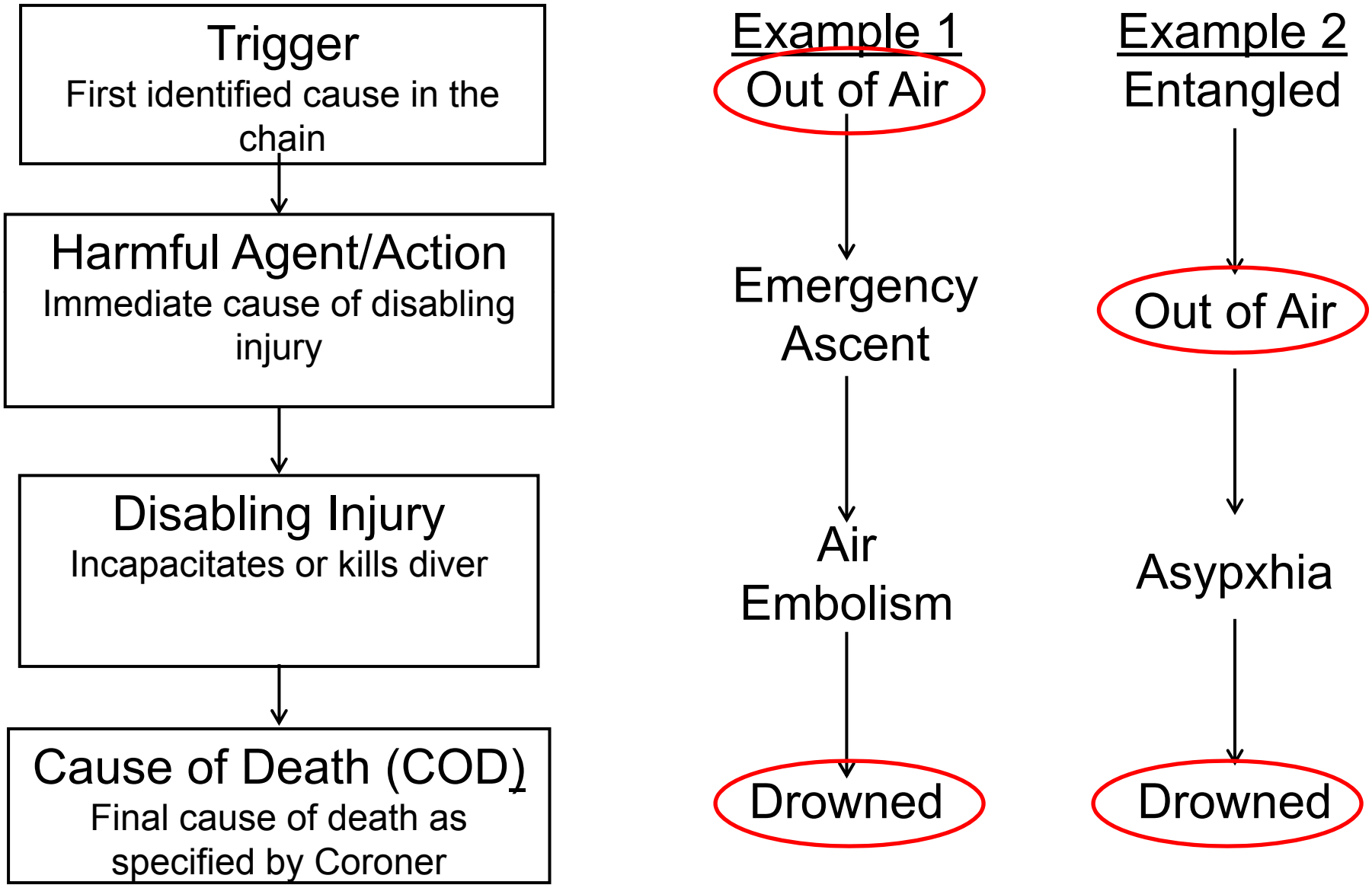


More Detailed Analysis (zoom in) Expand to as much detail as necessary




Solution:
Change steel hull design, materials
Strength of Hull
Strength of Rivets
Iceberg Present
North Atlantic Current
AND
Solution:
Slow down with known icebergs
Speed (18 knots)
Early arrival into New York City
AND
Steel Plates Buckled on Hull
Ship Didn't Turn Sufficiently
Size of Rudder
AND
Ship Hit Iceberg
Solution:
Improve bow watch comm process
AND
Saw iceberg late
No Binoculars
Ship Crossing Atlantic
Transporting Passengers

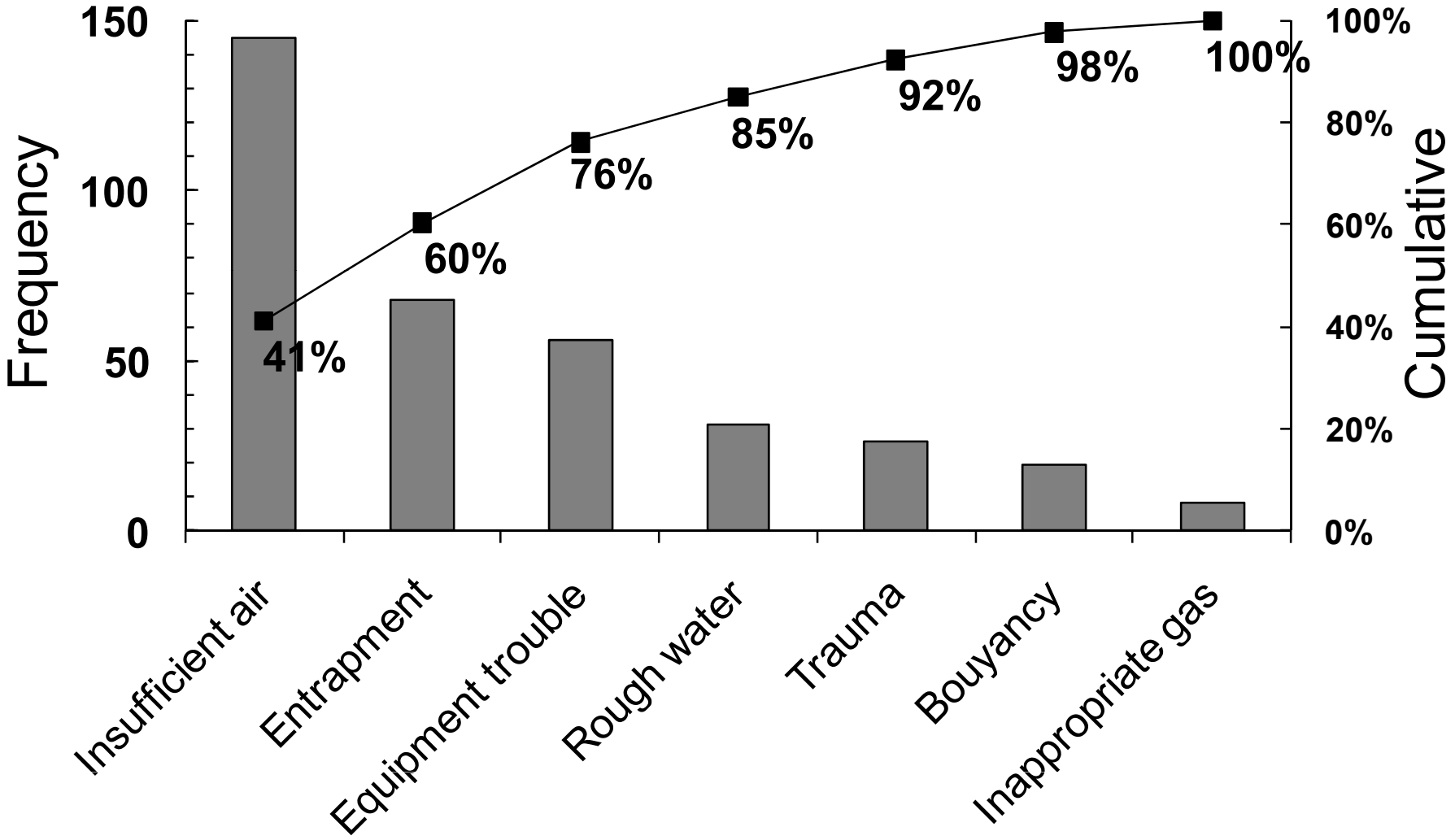
Root Cause Analysis of Diving Deaths



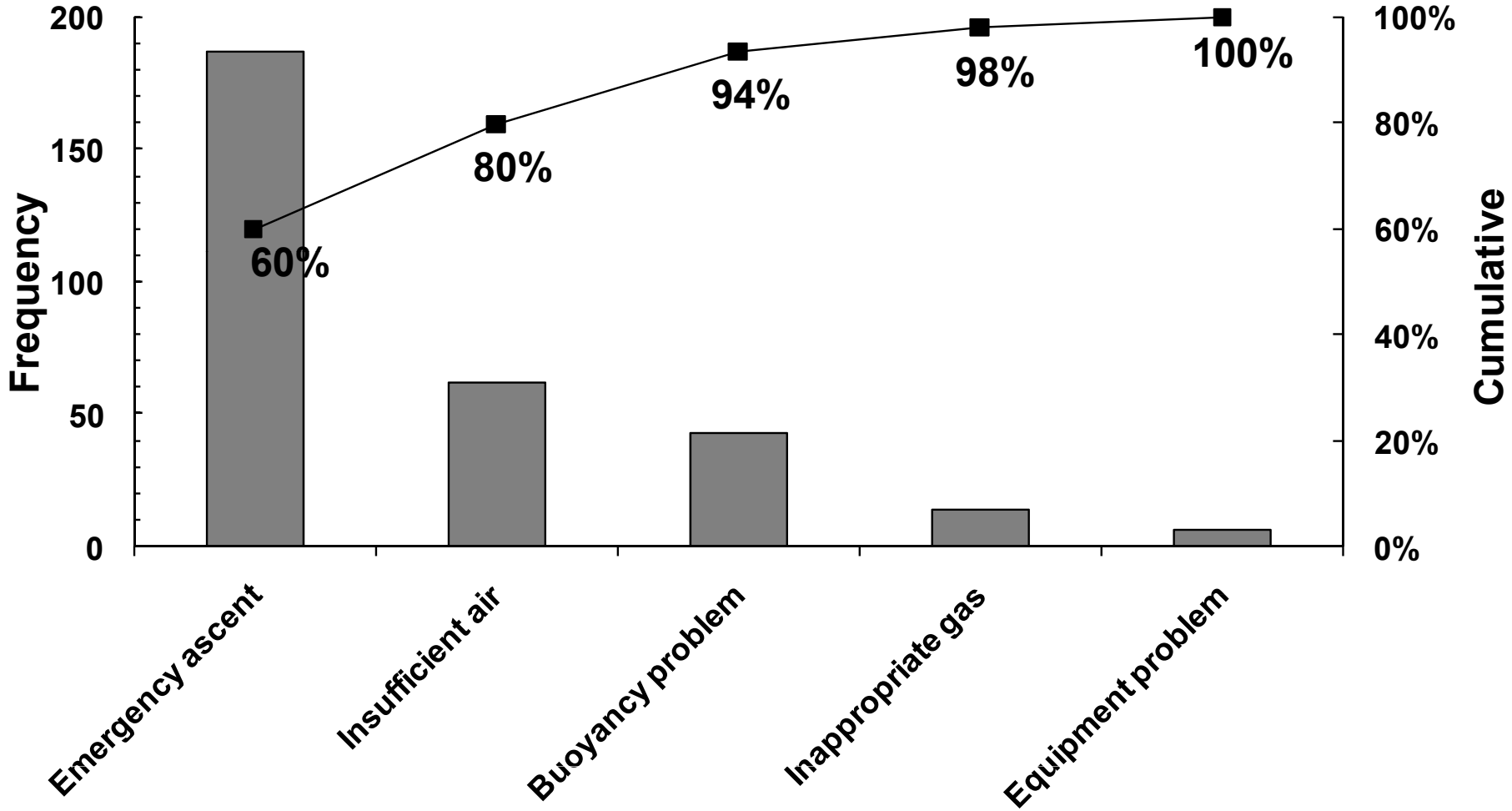
Root Causes

Causes	Frequency	Role	
		Disabling Agent	Trigger
Complication of a pre-existing disease	**389**	169	24
Buoyancy	293	43	18
Emergency ascent	289	**187**	
Water movements	217		31
Gas supply problem	199	62	**145**
Equipment problem	109	6	56
Entrapment/Entanglement	75	61	68
Injury	40	38	26
Wrong gas	14	8	
Lost/separated	13		13
Total	N/A	574	381

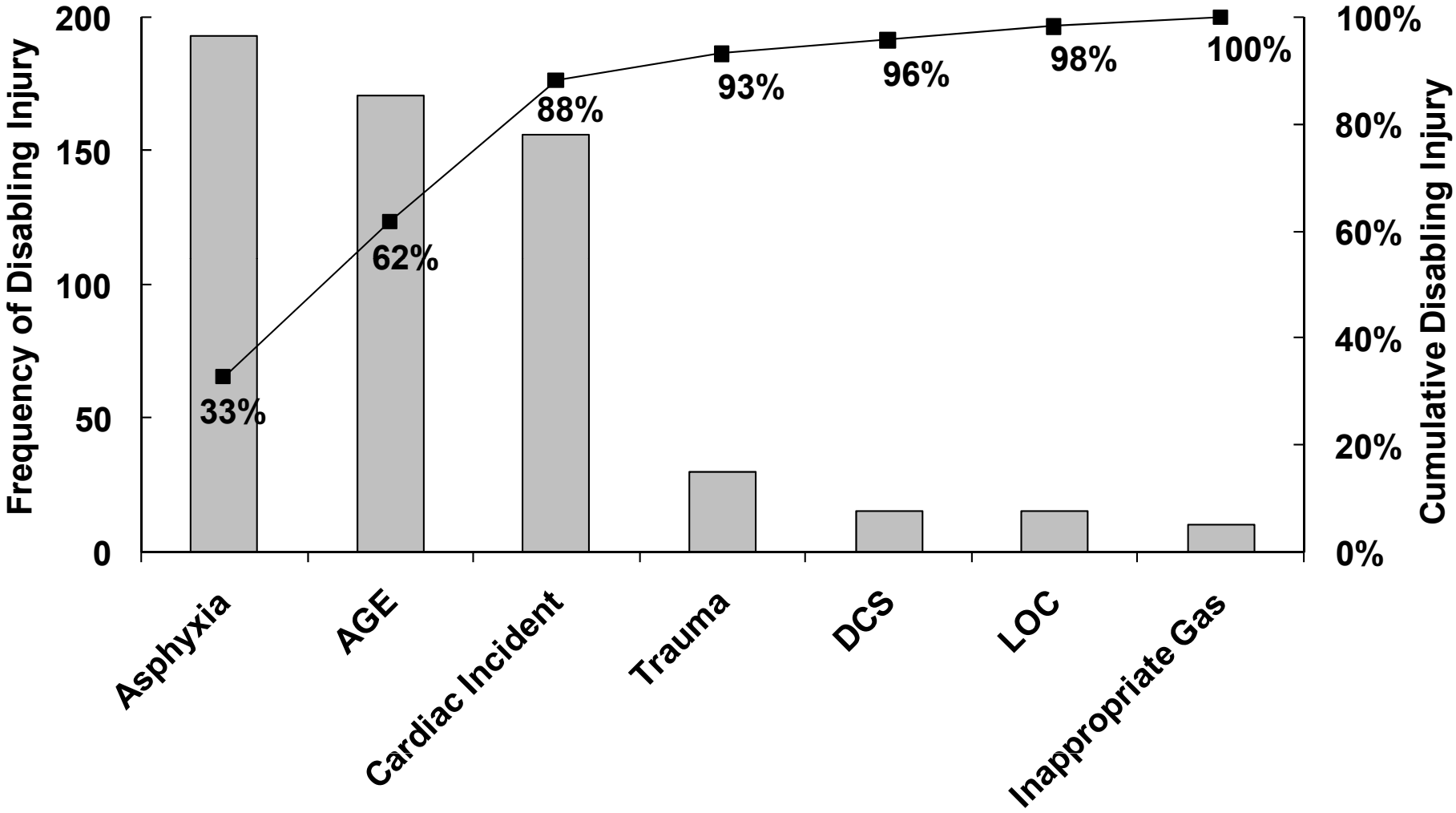
Triggers (n=346)



Disabling Agents (n=332)



Disabling Injuries (n=590)



Triggers by Disabling Injury

	Disabling Injuries		
Trigger	Asphyxia	AGE	Cardiac
Insufficient gas	32%	**63%**	
Entrapment	**40%**	9%	
Equipment trouble	15%	17%	
Rough water	11%		

Rarely identified

Disabling Agent by Disabling Injury

	Primary Disabling Injuries		
Disabling Agent	Asphyxia	AGE	Cardiac
Emergency ascent	13%	**97%**	
Insufficient gas	**62%**		
Buoyancy trouble	17%		
Rough water	11%		

Rarely identified

Odds Ratios for Root Causes & Intrinsic Factors

	Asphyxia	AGE	Cardiac
Entrapment	**≥30**		
Emergency ascent		**≥30**	
Cardiovascular Disease			**≥30**
Insufficient gas	16		
Age > 40 years			6
Equipment trouble	5		
Rough water	4		
Female	2		
Depth < 80 fsw		2	

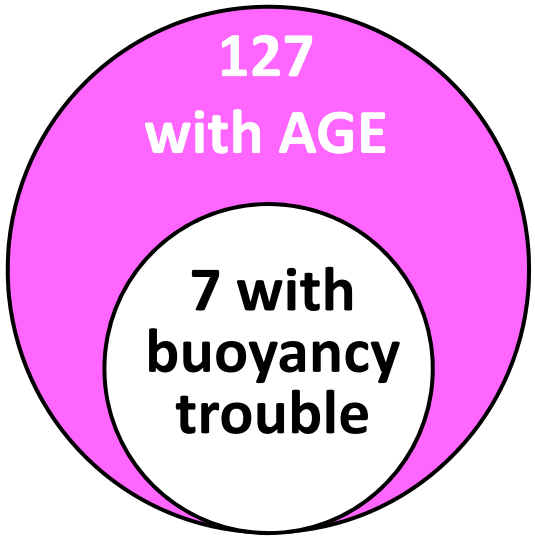
Cardiac Incidents (n=156)

- Body Mass Index
  - Cardiac incidents: 30.5 kg/m^2
  - AGE: 28.7
  - Asphyxia: 27.8
- 60% of victims of cardiac incidents noted dyspnea, fatigue, distress, chest pain, or felt ill
- 56% had autopsy reports & usually evidence of CVD but not myocardial damage

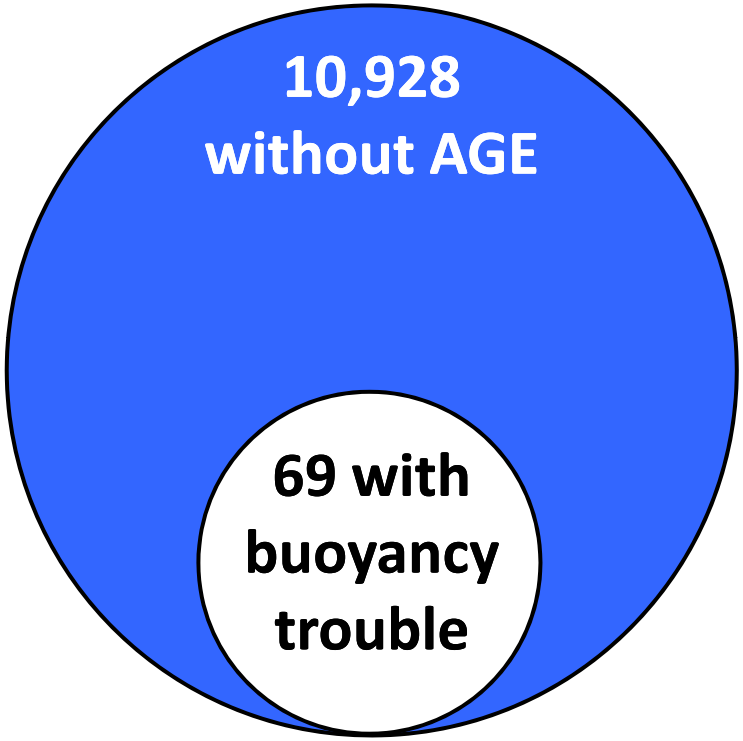
Case Control Study: Risk Factors for Fatal & Non-Fatal AGE, 2005

- What factors influence the risk of death?
  - Demographic
  - Experience
  - Medical history
  - Dive profile
  - Dive conditions
  - Dive problems

Buoyancy Trouble & Non-Fatal AGE



Odds of buoyancy trouble with AGE = 7/(127-7) = 0.06



Odds of buoyancy trouble without AGE = 69/(10,928-69) = 0.0064

Odds Ratio (OR) of non-fatal AGE for divers with buoyancy trouble = 0.06/0.0064 = 9.2

AGE Findings

- ~12% of all injuries were fatal
- ~6% of non-fatal injuries were AGE
- Over half of all AGE were fatal
- Sex, CVD, diabetes & asthma not AGE risk factors
- Greater AGE risk for divers in 1st year of certification & on 1st dive of day

AGE Findings

- AGE risk decreases with experience
- Dive problems appear strong risk factors although diagnostic bias is a problem
  - Rapid ascent, gas supply, buoyancy
- Factors associated with AGE death
  - Higher risk: obesity, increasing age, use of helium, increasing maximum depth
  - Lower risk: healthy BMI

Pulmonary Barotrauma in Divers During Emergency Free Ascent Training: Review of 124 Cases

Pierre Lafère , Peter Germonpré ,and Costantino Balestra

- Risk of PBT during training dives 100-400 x
- During ascent training dives 500-1500x
- Most Belgian sport diver federations have modified their ascent training protocols since 2006
  - Since then, no cases of PBT related to ascent training

Aviat Space Environ Med 2009; 80: 371 – 5 .

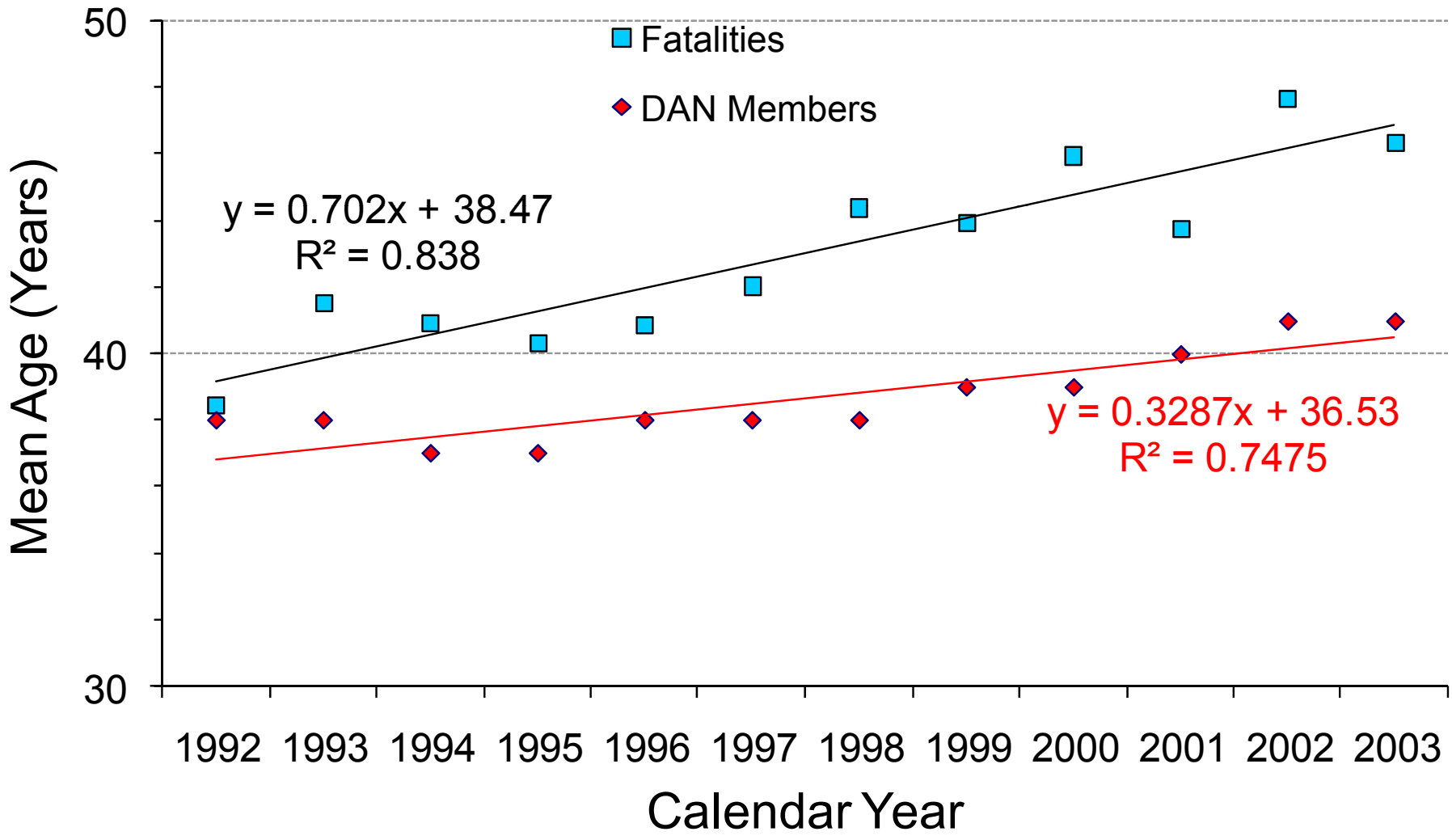
Diabetes & Fatalities

- Review DAN Fatality Database 1992-2004
- Total 975 fatalities
  - 938 Non-DM (96.2%)
  - 37 with DM (3.8%)
- Variables: divers characteristic, accident scenario, disabling conditions
- Age and dive depth tested with t-test for independent samples
- Contrasts tested with Chi squared analysis
  - Significance accepted at $p<0.05$

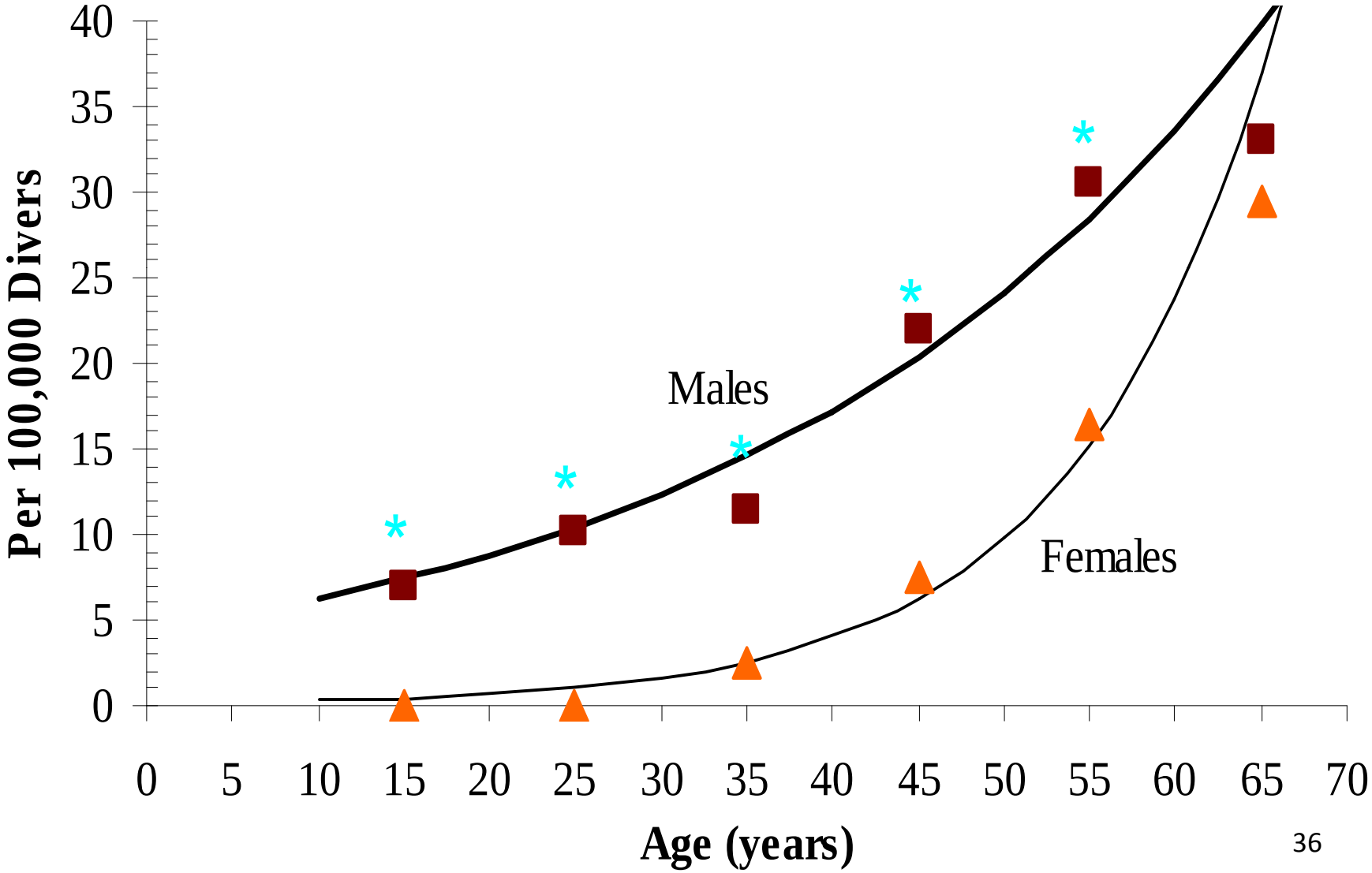
Adverse Events Preceding Deaths

Condition	% of Decedents		Statistics
	DM	Non-DM	
Cardiac	**40.5**	**15.9**	**p<0.001**
Unknown	27.0	37.8	NS
AGE	10.8	17.9	NS
Drowning	10.8	20.5	NS
Unexplained LOC*	**10.8**	**1.3**	**p<0.001**
Trauma	0	3.5	NS
DCS	0	1.8	NS
Wrong gas	0	1.3	NS

Mean Age
DAN Members and Fatalities

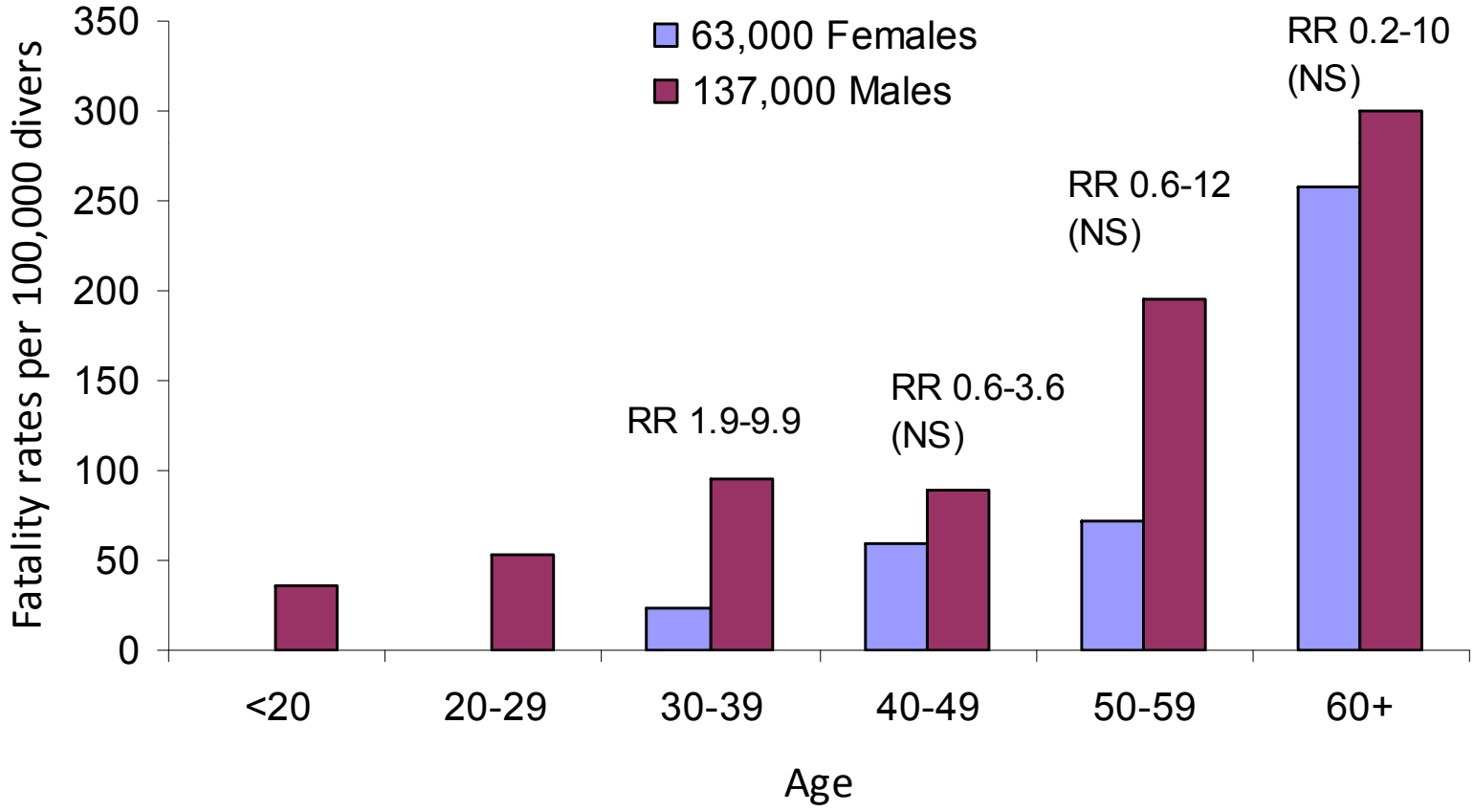


DAN Fatality Rates by Age



EDAN Insured Members

200,000 insured years, 141 deaths



Age & Cause Specific Relative Risk

Disabling Injury	<50 years n=788,489	≥50 years n=352,878	RR
Cardiac	5*	29	12.9
AGE	8	14	3.9
Asphyxia	15	17	2.5
Total	50	79	3.5

* Number of deaths

Conclusions

- Death while diving by insured DAN members occurs at rate of 1 in 6000 divers per year.

- Most common causes are gas supply problems, emergency ascent, cardiac health issues, entrapment/entanglement, and buoyancy issues.

- Risk of death while diving increases with age.