# Snorkelling and breath-hold diving fatalities in New Zealand, 2007 to 2016

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**Key words**
Apnoeic hypoxia; Cardiovascular; Diving deaths; Diving incidents; Drowning; Obesity; Pulmonary oedema

**Abstract**
(Lippmann J, Lawrence C, Davis M. Snorkelling and breath-hold diving fatalities in New Zealand, 2007 to 2016. Diving and Hyperbaric Medicine. 2021 March 31;51(1):25–33. doi: 10.28920/dhm51.1.25-33. PMID: 33761538.)
**Introduction:** New Zealand's (NZ) long coastline offers a diverse underwater environment with abundant opportunities for harvesting seafood and for recreation. Fatalities from snorkelling/breath-hold diving have been reported from the 1960s through to 2006. Those from 2007 to 2016 are reported here.
**Methods:** The National Coronial Information System, the Australasian Diving Safety Foundation diving fatality database, and the Water Safety NZ "*Drownbase*" were searched and additional coronial data provided by the NZ Ministry of Justice. An anonymised database was created and analysed for multiple factors. A chain of events analysis was performed for each case.
**Results:** There were 38 snorkelling or breath-hold-related deaths in NZ, 33 men and five women. Twenty-nine were breath-hold divers involved in gathering seafood, and six 'surface snorkellers', predominantly sightseeing. Two-thirds were diving alone and/or were not being observed by anyone out of the water. Twenty-eight victims were classified as overweight or obese and 19/38 were Māori. Pre-existing health factors that may have or definitely contributed to the fatality were present in 30 cases. The most common of these were cardiac (18/38). Two divers had insulin-dependent diabetes mellitus, one each epilepsy and asthma whilst cannabis and/or alcohol were possible factors in seven deaths. Five (possibly six) deaths resulted from apnoeic hypoxia.
**Conclusions**: Overall, death from snorkelling/breath-hold diving was an uncommon event (38 in 10 years). Poor judgement was a common feature. Middle-aged Māori men with pre-existing disease feature strongly. This suggests an on-going need for appropriate water safety education within and beyond the Māori community.

## Introduction

With its 15,000 km of coastline bordered by the Tasman Sea and Pacific Ocean, New Zealand (NZ) offers an accessible and diverse underwater environment. With two main islands (North and South) and the smaller Stewart Island in the far south, NZ covers a latitudinal range of more than 12 degrees and offers a range of conditions, from sub-tropical with wide sandy beaches in the far north, to temperate waters and steep fiords in the south. The abundant marine life provides the opportunity for harvesting a variety of seafood (kai moana in Māori), which is a fundamental customary activity for Māori, and spearfishing is popular throughout NZ. Whales and dolphins are also common in some areas and provide the opportunity for close snorkelling encounters. Therefore, it is unsurprising that snorkelling and breath-hold diving are popular activities among locals and tourists, with 11% of 1,094 respondents to a 2018 online Water Safety New Zealand (WSNZ) survey of the NZ public reporting that they had snorkelled or dived during the previous year.[1]

As with any physical activity, especially in a potentially hostile environment, there is an associated risk of morbidity and mortality. Earlier reports have reviewed snorkelling-related deaths in NZ from 1961 through to 1973,[2,3] 1981–1986,[4–6] 1980–2000[7] and 2000–2006.[8] This study examines snorkelling and breath-hold diving-related deaths in NZ waters from 2007 to 2016, with the aim of identifying underlying factors and risks in order to assess and inform appropriate preventative measures.

## Methods

This was a case series of snorkelling and breath-hold diving fatalities that occurred in NZ waters from 2007 to 2016, inclusive. For inclusion in this series, a victim must have

been reported to have been wearing at least a mask and/or was breath-holding to collect food.

## ETHICS APPROVAL

Ethics approvals for the collection and reporting of these data were received from the Victorian Department of Justice Human Research Ethics Committee to access the National Coronial Information System (CF/18/12735),[9] the Chief Coroner, New Zealand Department of Justice, to access additional coronial records and WSNZ to access "*Drownbase*". The benefits of reviewing multiple data sources have been described previously.[10]

## SEARCH

All fatalities reported to NZ coroners since July 2007 have been added to the Australian-based National Coronial Information System (NCIS).[9] A comprehensive key word search was made of the NCIS for snorkelling-related deaths from July 2007 to December 2016. Key words included snorkel*, spear fish*, underwater fish* and breath-hold div*. Data obtained from the NCIS was matched with that listed on the Australasian Diving Safety Foundation (ADSF) diving fatality database and "*Drownbase*" to minimise the risk of over- or under-reporting. Coronial data not included on the NCIS (i.e., prior to July 2007 and for 'open' cases) were provided by the NZ Ministry of Justice.

## REVIEW PROCEDURE

The principal investigator (JL) reviewed all datasets to resolve any discrepancies between the various sources, then prepared initial incident summaries for each case, and created a protected Microsoft Excel® spreadsheet. These summaries were then independently reviewed by each of the co-investigators (CL and MD), any differences in interpretation debated, and consensus reached; CL focusing, in particular, on the reported autopsy findings. Based on these reviews, the Excel® database was finalised. A chain of events analysis (CEA) was performed for each case using a pre-prepared snorkelling CEA template, similar to one validated for scuba fatalities.[11]

Each CEA is based on the evidence in the coronial and autopsy reports. However, in some cases the authors disagreed with the interpretation of the findings, so the disabling agents and disabling injuries reported in the CEAs are based on our consensus interpretations, but the cause of death given is that of the pathologist conducting the autopsy or by the coroner where no autopsy was performed.

## OUTCOME MEASURES

A range of outcome measures were extracted. Where available, these included demographics, health factors, training and experience, dive location and conditions, buddy circumstances and oversight, dive purpose and depth, equipment used, resuscitation factors; then a possible CEA of the incident was created. Descriptive analyses based on means and standard deviations (SD) or medians and ranges, and Mann-Whitney U and $\chi^2$ tests for comparisons of age or BMI, as appropriate, were conducted using SPSS Version 25 (IBM Armonk, NY; 2017). The level of significance assumed was $P = 0.05$.

# Results

From 01 January 2007 to 31 December 2016 there were 38 identified snorkelling or breath-hold-related deaths in NZ territorial waters, 33 men and five women (Table 1). Ethnicity is documented in NZ and 19 of the 38 victims were Māori, 16 of European decent and three of Asian descent. Thirty-two victims were NZ residents and six were tourists.

Mean (SD) age was 47 (13) years, and there were no differences in age between the sexes ($P = 0.34$) or between Māori and non-Māori ($P = 0.67$). Body mass index (BMI) was available for 35 victims (mean [SD] 29.2 [5.8] $kg{\cdot}m^{-2}$) and was similar between the sexes (29.3 [6.0] for 31 men, 29.1 [4.2] for four women). Fourteen of the victims were classified as overweight (11 men and three women; BMI 25–29.9 $kg{\cdot}m^{-2}$) and 14 were obese (13 men and one woman; BMI ≥ 30 $kg{\cdot}m^{-2}$) (Table 1). The mean BMI for Māori victims was higher than that of non-Māori ($P = 0.002$).

NCIS also included two deaths abroad of NZ citizens (one in Fiji, a woman run over by a boat, and one in the Cook Islands, a man who died from an acute cardiac event) which were investigated by the authorities in NZ. These and other deaths of NZ residents and citizens abroad, not investigated by NZ authorities, were not included.

## LOCATION

Deaths occurred the length and breadth of NZ, from Stewart Island in the south to Raoul Island in the Kermadics; however, the majority (30) occurred in the warmer waters of the northern half of North Island. The fatal incident appears

**Table 1**
Body mass index (BMI) classification of 35 snorkelling fatality victims according to their ethnicity. Classification: normal (18.5–24.9); overweight (25–29.9); obese (≥ 30). There were no data for three divers. * $P = 0.02$ for the difference between Māori and non-Māori

| BMI ($kg.m^{-2}$) | Māori ($n = 16$) | European ($n = 16$) | Asian ($n = 3$) |
|---|---|---|---|
| Normal ($n$) | 2 | 2 | 3 |
| Overweight ($n$) | 3 | 11 | 0 |
| Obese ($n$) | 11 | 3 | 0 |
| Mean BMI (SD)* | 32.6 (5.9) | 27.4 (3.5) | 21.2 (0.7) |

to have occurred on the surface in 25 cases, four underwater, whilst there were no data for nine.

## ACTIVITY AND SETTING

All but three of the 38 fatalities occurred during private activities. Twenty-four were harvesting seafood (recreationally), another four were spearfishing, and six were sightseeing; two of these on commercial dolphin-watching tours and another on a commercial sightseeing tour. In a double fatality, one victim died while trying to rescue his friend who was unconscious on the seabed; another died attempting the body recovery of a scuba diver in shallow water. The activity was unknown in two cases. Based on the reported activities at the time, it seems reasonable to consider 29 as breath-hold divers as they were involved in hunting or harvesting seafood, whilst seven were designated as 'surface snorkellers', generally sightseeing. There was insufficient information on two individuals. Five freedivers succumbed to apnoeic hypoxia, whilst a sixth possibly did so.

## HEALTH ISSUES

Pre-existing health factors that may have or definitely contributed to the fatality were present in 30 of the 38 cases. The most common of these pre-existing conditions were cardiac (18/38), particularly moderate to severe ischaemic heart disease (9) and left ventricular hypertrophy (13). Fourteen victims were classified as obese (BMI ≥ 30 $kg \cdot m^{-2}$), of whom nine also had known cardiac disease. Of the 16 victims who identified as Māori for whom the BMI could be calculated, 11 were obese. Two divers had insulin-dependent diabetes mellitus, whilst epilepsy (poorly controlled) or asthma contributed to two deaths. Medications being taken were reported in 14 victims, whilst the remainder were either reported to not be on any medication or there was no information. In only three deaths might prescription medicines have been relevant to the incident; multiple drug interactions likely contributing to cardiac arrhythmia in one, non-therapeutic levels of anti-epileptics in another and the third had an elevated clozapine level. Alcohol and/or cannabis was a likely factor in seven divers, including two who suffered apnoeic hypoxia.

## TRAINING AND EXPERIENCE

Whether victims had received any training was not reported for 28 of the 38 victims. However, two victims were known to be untrained, one was snorkel-trained, six had scuba training and one had been a commercial paua (abalone) diver. The level of experience was not indicated in 12 cases. Nineteen victims were reported to have been 'experienced', six to have had some experience and one no experience, although no objective measures of experience were provided. In the majority of cases, the diver's swimming ability was not documented.

## BUDDY AND OBSERVER CIRCUMSTANCES

Twenty-five of the 38 victims were alone at the time of the incident. Thirteen had set out solo, and another 12 had separated from their buddy or group before the incident. Four became separated during the incident, and nine had not separated. Twenty-three victims were not being observed or supervised by anyone out of the water. Up to 13 were being watched from the boat or shore, and there was no information on supervision in two cases.

## ENVIRONMENT

Sea conditions (currents and/or surface swell/waves) may have contributed to 15 incidents. The depth of water where the victims were snorkelling was not reported in 15 of the 38 cases. However, in the 23 incidents where it was recorded, the median depth was 3 metres' seawater (msw) (range 1–22.5 msw). Twenty-six of the incidents were reported to have occurred at the surface, five underwater (at unknown depths) and where the incident occurred was unknown in seven cases.

## EQUIPMENT

The reports varied in detail about exactly what equipment was worn by the victims. However, at least 30 were recorded as having worn masks, at least 25 had snorkels, at least 25 wore fins, and at least 29 wore wetsuits. Overall, at least 21 of the snorkellers were recorded to have been wearing mask, snorkel, fins and wetsuit. One victim had none of these but was included as he was breath-hold diving for seafood.

Thirty-one of the 38 victims were known to have been wearing weight belts when they set out and 21 of these were still wearing their belt when found. The amount of weights worn was only recorded in seven cases, ranging from 2.5 kg to approximately 18 kg (the latter reported by police to be approximately 9 kg over-weighted). One victim used an inflated tyre tube for support whilst 32 of the victims did not use a specific buoyancy aid, such as an adjustable buoyancy life jacket. There was no information in the other five cases.

## RESCUE AND RESUSCITATION

Rescue attempts were made in 22 of the 38 cases, the remainder being body recoveries, whilst one diver was never found. Of the 29 cases where such information was available, some form of in-water resuscitation (presumably rescue breathing) was reported to have been attempted on only one victim. In the 36 cases with available information, basic life support (BLS) was performed on 22 victims on boat or shore. In the remaining incidents, BLS was not performed because of delays in recovering the victim's body or the body was not available. There were only five reports indicating that a defibrillator was used during resuscitation attempts. Four were in a hospital or paramedic setting, and

**Table 2**

Chain of events analysis for 38 snorkellers and breath-hold divers in New Zealand waters; CAD – coronary artery disease; COPD – chronic obstructive pulmonary disease; cerv. spond – cervical spondylosis; IDDM – insulin-dependent diabetes mellitus; IHD – ischaemic heart disease; IPO – immersion pulmonary oedema, NR – not recorded

| Case | Sex | Age | BMI | Predisposing factor | Trigger | Disabling agent | Disabling condition | Cause of death |
|---|---|---|---|---|---|---|---|---|
| 1 | M | 38 | 24.9 | Activity; Planning (solo) | Extended apnoea | Apnoeic hypoxia | Asphyxia | Drowning |
| 2 | M | 57 | 33.8 | Health (obesity); Planning (solo) | Unknown | Unknown | Unknown | Drowning |
| 3 | F | 47 | NR | Health (cardiac); Equipment (snorkel)? | Environment (immersion) Aspiration? | Medical (cardiac) | Cardiac (Ischaemic and rheumatic valvular heart disease) | Cardiac |
| 4 | M | 51 | 19.4 | Health (cardiac) | Exertion | Medical (cardiac)? Buoyancy? | Cardiac (arrhythmia?) | Drowning |
| 5 | M | 49 | 28.0 | Health (asthma, cardiac) | Exertion Environment (immersion) | Medical (asthma, cardiac?) | Cardiac | Asthma |
| 6 | M | 70 | 34.0 | Health (cardiac, obesity) | Unknown | Medical (cardiac?) | Unknown | Drowning |
| 7 | M | 26 | 21.6 | Health (alcohol) | Unknown | Unknown | Asphyxia | Drowning |
| 8 | M | 59 | 39.9 | Health (cardiac, obesity, COPD) | Environment (immersion)? | Medical (arrhythmia?) | Cardiac (arrhythmia?) | Cardiac |
| 9 | M | 70 | 27.1 | Health (IDDM, neuropathic disease) | Unknown | Unknown | Asphyxia? Cardiac (arrhythmia?) | Drowning |
| 10 | M | 55 | 30.4 | Health (cardiac, obesity); Planning (solo) Equipment (weight belt, no fins) | Diver error OR Environment (conditions) | Buoyancy (overweighted) | Asphyxia | Drowning |
| 11 | F | 27 | 34.9 | Health (obesity, drug combination) | Unknown | Medical (arrhythmia?) | Cardiac (arrhythmia?) | Cardiac |
| 12 | F | 56 | 25.1 | Health (cardiac); Organisational (supervision); Equipment (no oxygen) | Environment (immersion) Aspiration? | Medical | IPO | IPO |
| 13 | M | 58 | 31.8 | Health (obesity, sarcoidosis) | Environment (immersion) Aspiration? | Medical? Aspiration? | Cardiac (arrhythmia?) Asphyxia? | Drowning |
| 14 | M | 51 | 30.0 | Health (cardiac, obesity) | Environment (conditions, immersion?) | Medical (IHD) | Cardiac (arrhythmia?) | Cardiac? |
| 15 | M | 42 | 33.9 | Health (obesity); Equipment (no fins) Planning (conditions) | Environment (conditions) | Environment (adverse conditions) | Asphyxia | Drowning |
| 16 | M | 58 | 27.7 | Health (cardiac) | Unknown | Unknown | Cardiac (arrhythmia?) | Drowning |
| 17 | M | 24 | 25.2 | Activity | Extended apnoea | Apnoeic hypoxia | Asphyxia | Drowning |
| 18 | F | 58 | 29.4 | Health (cardiac) | Environment (conditions, immersion?) | Environment (immersion) Medical (cardiac)? | IPO? Cardiac? | Drowning? |

**Table 2 continued.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 19 | M | 30 | NR | Planning (conditions)<br>Equipment (overweighted) | Environment (conditions)<br>Other (Cramp) | Buoyancy<br>(overweighted) | Asphyxia | Drowning |
| 20 | M | 25 | 21.7 | Inexperience, poor skills | Unknown | Unknown | Asphyxia | Drowning |
| 21 | M | 52 | 26.5 | Activity | Extended apnoea | Apnoeic hypoxia | Asphyxia | Drowning |
| 22 | M | 53 | 27.1 | Planning (solo)<br>Health (migraine)? | Unknown | Unknown | Asphyxia | Drowning |
| 23 | M | 33 | 20.4 | Planning (solo)<br>Equipment (no fins or knife) | Environment (entrapment) | Buoyancy | Asphyxia | Drowning |
| 24 | M | 53 | 29.3 | Health (cardiac); Other (drug toxicity);<br>Planning (no buddy system) | Unknown; Clozapine toxicity? | Unknown<br>Medical (cardiac)? | Asphyxia?<br>Cardiac<br>(arrhythmia?) | Drowning |
| 25 | M | 43 | 36.0 | Health (obesity, cardiac) | Exertion | Medical (cardiac)? | Cardiac<br>(arrhythmia?) | Drowning |
| 26 | F | 64 | 27.1 | Health (cervical spondylosis) | Other (light-headedness)? | Medical (cerv. spond.)? | Medical (stroke) | Cerebral<br>ischaemia |
| 27 | M | 41 | 36.7 | Health (epilepsy, obesity, cardiac)<br>Equipment (no mask, snorkel, fins) | Environment (immersion)?<br>Breath-holding? | Medical (seizure;<br>cardiac?) | Asphyxia | Drowning |
| 28 | M | 33 | 39.0 | Health (cardiac, obesity) | Environment (immersion) | Medical (cardiac)? | Cardiac<br>(arrhythmia?)<br>Asphyxia? | Cardiac |
| 29 | M | 56 | 20.9 | Health (alcohol)<br>Planning (alcohol) | Environment (conditions)? | Environment<br>(conditions)?<br>Buoyancy? | Asphyxia | Drowning |
| 30 | M | 25 | NR | Planning (solo) | Unknown<br>Extended apnoea? | Unknown<br>Apnoeic hypoxia? | Asphyxia | Drowning |
| 31 | M | 42 | 25.8 | Planning (solo)<br>Health (cannabis, smoker)? | Aspiration? | Unknown | Asphyxia | Drowning |
| 32 | M | 53 | 42.4 | Health (cardiac, obesity); Planning<br>(conditions); Equipment (no fins) | Environment (current) | Environment<br>(conditions)?<br>Head trauma? | Asphyxia?<br>Cardiac? | Drowning |
| 33 | M | 37 | 27.8 | Health (cannabis)? | Unknown | Unknown | Asphyxia | Drowning |
| 34 | M | 31 | 23 | Planning (night + alcohol)<br>Equipment (overweighted) | Diver error (?intoxicated);Extended<br>apnoea; Buoyancy (overweighted) | Apnoeic hypoxia | Asphyxia | Drowning |
| 35 | M | 55 | 27.1 | Health (alcohol); Planning (night)<br>Equipment (overweighted) | Diver error (alcohol); extended apnoea;<br>Buoyancy (overweighted) | Apnoeic hypoxia | Asphyxia | Drowning |
| 36 | M | 62 | 35.8 | Health (diabetes, hypertension,<br>cardiac, obesity) | Environment (immersion)<br>Exertion? | Medical (cardiac) | Cardiac | Cardiac |
| 37 | M | 46 | 29.9 | Health (issue from previous dive,<br>hypertension, cardiac); Planning (solo) | Unknown | Unknown<br>Medical? | Cardiac | Drowning |
| 38 | M | 44 | 30.0 | Health (undiagnosed CAD, cannabis);<br>Planning (solo, conditions); Equipment | Environment (conditions); Exertion;<br>Stress (likely) | Medical (CAD)<br>Environment | Cardiac? Asphyxia? | Drowning |

the other involved the use of a lifesaving club's defibrillator by an off-duty paramedic.

CHAIN OF EVENTS ANALYIS

Sixty-three possible or likely predisposing factors to the 38 incidents were identified, these included health-related (30), poor planning (14) and equipment-related (10). No triggers could be identified in 10 incidents and 44 possible or likely triggers were identified in the remaining 28 cases. The commonest of these were environmental (19), which included the cardiovascular effects of immersion *per se*, poor conditions and entrapment. Extended apnoea was implicated as the likely trigger in five incidents and a possible trigger in a sixth. Thirty-six possible or likely disabling agents were identified in 31 incidents, the main being medical (17), apnoeic hypoxia (6), and buoyancy problems (5). No disabling conditions (DC) could be identified with confidence in two cases. In another six cases the DC was unclear but likely to be either asphyxia or cardiac. In one case, the DC was likely to be either cardiac or immersion pulmonary oedema (IPO). The DCs identified in the remaining 30 cases were asphyxia (17), cardiac (10), stroke (1) and IPO (1). A possible chain of events analysis for each case is presented in Table 2.

AUTOPSY FINDINGS AND CAUSE OF DEATH

In two cases either no autopsy was done or the body was decomposed. Pulmonary oedema was a common finding (30/36). There were 15 medical conditions which likely acted as disabling agents mostly cardiac, with left ventricular hypertrophy in more than a third (13/36) of cases, moderate to severe ischaemic heart disease in nine and two cases of known valvular heart disease. Significant cardiac disease was found at autopsy in 20/36 (Table 3).

The cause of death was recorded as drowning in 29 cases and cardiac in five. There was one case of IPO which showed left ventricular hypertrophy and contraction band necrosis, a histological feature indicative of stressed myocardium from various causes and which has been reported in IPO.[12] In one case there was cervical spondylitis that was postulated to have caused brain stem ischaemia. Cause of death was undetermined in two cases.

**Table 3**

Autopsy findings of 38 snorkelling deaths (multiple abnormalities found with many, e.g., coronary atherosclerosis and left ventricular hypertrophy); * heart weight over normal range for BMI; † severe coronary artery disease > 75% vessel occlusion; ‡ moderate coronary artery disease between 50–75% occlusion; CoD – cause of death; -ve – negative

| Conditions identified at autopsy | Divers ($n$ = 38) |
|---|---|
| Pulmonary oedema fluid | 30 |
| Left ventricular hypertrophy | 13 |
| Cardiomegaly* | 10 |
| Severe coronary artery disease† | 8 |
| Moderate coronary artery disease‡ | 6 |
| Significant drug effect | 7 |
| Elevated alcohol | 4 |
| Cardiac fibrosis | 7 |
| Cardiomyopathy | 4 |
| Genetic tests for long QT (all -ve) | 4 |
| Significant valvular heart disease | 2 |
| Asthma/chronic lung disease | 2 |
| Sarcoidosis of heart/lungs | 1 |
| Too decomposed to ascertain CoD | 1 |
| No autopsy | 1 |

## Discussion

Historically, NZ has had a high prevalence of unintentional (accidental) drownings, with the tenth highest death rate out of 32 Organisation for Economic Co-operation and Development (OECD) countries.[13] Over 2007–2016, the reported average annual preventable drowning death rate was 89 per 100,000 population, with snorkelling and breath-hold diving deaths from drowning ($n$ = 29) representing only approximately 3% of these, similar to previous reviews.[7,8] From 1980 to 2005, there were a total of 74 snorkelling and breath-hold fatalities (average 3, range 1–6 per year);[7,8] so the rate covered in this report (4, range 1–9 per year) is similar despite an approximately 60% increase in the NZ population over that time.

As in the previous NZ reports,[7,8] most victims were male, although there appeared to be an increase in women dying (5/38 compared to 1/74). The average age has slowly increased from 34 years pre-2000 to 47 years in the present study. A similar increase in the age of snorkelling and breath-hold diving fatalities is seen in Australian data from the same period.[14] In many respects, it is difficult to compare the NZ studies since the quality of the data was limited in earlier reports. With respect to Australian fatalities, the patterns of diving and the people involved are different; predominantly food gathering in NZ compared to more-elderly tourists, inexperienced in snorkelling, visiting the Great Barrier Reef on commercial charter boats in Australia.[14–16] The increase in ages likely accounts for the higher incidence of cardiac deaths in the Australian cohorts.

One feature common to NZ and Australia is the relatively low numbers of breath-hold divers dying as a result of apnoeic hypoxia; 22 of 175 (12.5%) in Australia[14] and five (possibly six) of 37 in NZ. However, although relatively few, deaths from apnoeic hypoxia are often easily preventable by avoiding pre-dive hyperventilation and the pushing of breath-hold limits, as well as having close oversight by a

buddy who can perform a rapid rescue (the 'one up, one down' principle).

A large proportion of victims in this and other studies had pre-existing medical problems, especially cardiac disease and obesity, either known or identified at autopsy, which were likely contributory factors to their death.[7,15,16] This reflects that immersion *per se* and the physical challenges of being in the ocean, with waves and currents to contend with, are demanding and should never be taken lightly. When this is combined with commonly reported poor assessments of sea conditions and/or poor diving practices, particularly solo diving or separation from diving 'buddies', a potentially dangerous situation is created. A particular example of poor diving practices was that in none of the cases in which hypoxic apnoea was the likely cause of death was the diver practicing the 'one up, one down' safety routine. Although, compared to previous NZ studies,[3,7,8] the quality of information in the NCIS reports has improved considerably, there remain deficiencies such as in the recording of the equipment used, including the amount of weight carried. It appears a number of victims may not have been wearing swim fins, a concern identified in a previous NZ study.[7]

Māori, predominantly middle-aged men, consistently feature strongly in these studies (30/74 between 1980 and 2005[7,8] and 19/38 in the present study; overall 44%). Fifteen per cent of the NZ population were registered as Māori in 2010 so they are disproportionately represented in these data and in all other water safety statistics. However, adult Māori are more likely than other parts of the NZ community to participate in gathering seafood, which has a strong cultural tradition. Nevertheless, the frequent lack of proper equipment, especially swim fins, poor diving practices and poor judgement relating to individuals' health and physical capabilities and the sea conditions reflect a clear need for improved education within Māori communities. The same concerns were raised in two previous NZ studies.[7,8] Water Safety New Zealand and the NZ Police National Dive Squad have a number of on-going national programmes to promote water safety, including some specifically aimed at the Māori community. The data from this and a forthcoming report on NZ scuba-related deaths over the same period (2007 to 2016) will contribute towards these programmes. A recent large grant from the Accident Compensation Corporation will help to facilitate these educational endeavours.

In aquatic incidents it is important to get the victim onto a solid platform as soon as possible for assessment and commencement of resuscitation. BLS was not attempted, mainly due to considerable retrieval delays in up to 40% of these incidents, higher than in a comparable Australian series (29%).[17] This is likely largely a consequence of the higher prevalence of solo snorkelling in the NZ cohort (32% versus 26%) and the smaller proportion involved in a supervised activity (8% versus 37%). There was sparse information about resuscitation, including complications, use of supplemental oxygen and on-site defibrillation. Given the generally non-organised nature of snorkelling and breath-holding diving in NZ, it is likely such adjuncts were rarely available. However, such information is worth recording for later research into improving outcomes from future incidents.

## CAUSE OF DEATH

Pulmonary oedema was recorded at autopsy in the majority of cases but is not particularly discriminating as it is present in drowning, drowning following a cardiac event, cardiac events and IPO. Its absence can suggest a cardiac event. In determining the cause of death at autopsy where there is evidence of significant heart disease and evidence of drowning it can be very difficult to tell whether:

- a cardiac arrhythmia preceded drowning due to a loss of consciousness (i.e., secondary drowning);
- the heart disease accelerated death due to drowning; or
- the heart disease played no direct role in the drowning.

Left ventricular hypertrophy is an independent predictor of sudden cardiac death, probably owing to cardiac arrhythmia, and its role in drowning is likely similar to that of severe ischaemic heart disease.[18] Cardiac pathology is commonly seen in snorkellers who die and seems to be important in causation of such fatalities.[14,19]

Careful description of the heart and lungs in autopsy reports is helpful.[20,21] Useful information includes:

- height and weight of the individual and heart weight relative to BMI or body weight;
- thickness of the right and left ventricles and maximum diameter of the left ventricle;
- degree of occlusion of the coronary arteries by atherosclerosis (macroscopic and microscopic);
- description of the heart valves;
- whether the lungs were over-expanded and presence of pulmonary oedema in the upper airway;
- histology, including cardiac fibrosis and contraction band necrosis; and
- results of toxicology.

Imaging of the body may be useful for examination of the sinuses for water but, unlike in scuba divers, is not necessary for detection of intravascular gas.

The diagnosis of drowning at autopsy is a diagnosis of exclusion in the appropriate circumstances. There was a significant number of Māori in this group. It is likely in the future that there may be more objections to autopsy of Māori victims on cultural grounds, which may obscure the role of heart disease, hypertension and obesity in these deaths.

## LIMITATIONS

Even using multiple sources, it is possible that some fatalities were not recorded due to limitations in recording and NCIS searches. One additional case from 2016, which

was not identified in the databases or search, was later found incidentally, whilst several cases that were initially documented by authorities as snorkelling or breath-hold divers proved not to be so and were excluded. In previous studies,[2,7,8] a few cases in which the cause of death was not recorded as 'drowning', and not documented in WSNZ's Drownbase, may have been missed, but the current search was wider than those.

Information from immersion incidents is notoriously patchy and incomplete; especially when unwitnessed. However, in the majority of cases in this series, the coronial and autopsy reports were quite detailed and provided good insight into what happened. Health records were often deficient, so there is a strong subjective element to determining what personal factors contributing to a death were important. The CEA attempts to identify the predominant features of each case, but there always remains an element of uncertainty. Nevertheless, some clear lessons can be learned, such as the high frequencies of pre-existing deleterious medical conditions, the contribution of environmental conditions and/or poor diving practices and the disproportionate number of Māori.

## Conclusions

Overall, death from snorkelling/breath-hold diving in NZ between 2007 and 2016 was an uncommon event (38 in 10 years), largely associated with seafood gathering, whilst only five (possibly six) deaths resulted from apnoeic hypoxia. Poor judgement was a common feature. Obese, middle-aged Māori men with pre-existing disease, particularly cardiac, feature strongly. This suggests, as it did two decades ago, an ongoing need for continued water safety education and appropriate medical surveillance of prospective aquatic participants both within and beyond the Māori community. There is also an ongoing need to remind all breath-hold divers of the potential for apnoeic hypoxia with extended breath-holding, with or without hyperventilation, and the benefit of having a vigilant buddy on-hand in the event of unconsciousness.

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### Acknowledgements

National Coronial Information Service; Office of the New Zealand Chief Coroner, Ministry of Justice, New Zealand; Coronial Services Unit, Ministry of Justice, New Zealand and Water Safety New Zealand for their assistance in the provision and ready access to coronial and other records. Senior Sergeant Bruce Adams of the NZ National Police Diving Squad is thanked for his advice and preliminary assistance.

**Conflicts of interest and funding**

John Lippmann is the Chairman of the Australasian Diving Safety Foundation. This study was supported by a grant from the Australasian Diving Safety Foundation.

**Submitted:** 14 August 2020
**Accepted after revision:** 30 October 2020



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