SESSION TEN:
NEW FINDINGS ON FISHING SAFETY

Pakistani fishermen (Photo courtesy of Dr. Muhammad Khan)

QUANTIFICATION OF LOW-BACK AND SHOULDER STRESS IN COMMERCIAL CRAB FISHING OPERATIONS

Donald S. Bloswick, PhD, PE, CPE
University of Utah
Department of Mechanical Engineering
50 S. Central Campus Drive
Salt Lake City, Utah, USA
E-mail: bloswick@mech.utah.edu

Bradley Husberg, MPSH, BSN
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Safety Research, Alaska Field Station
4230 University Drive
Anchorage, Alaska, USA

Eric Blumhagen, PE
Jensen Maritime Consultants
Seattle, Washington, USA

Introduction

Musculoskeletal injuries are prevalent in the commercial fishing industry. Alaska Fisherman's Fund data for 1994-1998 indicate that nearly half of all nonfatal deck injuries in the Alaska fishing industry were strains and sprains. Trapp (1994) notes that spinal sprains and strains were the most frequent injuries in most fisheries and presents Fisherman's Fund data from 1982-1984 indicating that spinal sprains and strains account for 25.3% of the injuries to fishers in the Dungeness crab fishing industry and 18.7% of the injuries to fishers in the king crab fishing industry. Data from the Alaska Trauma Registry (ATR) indicate that approximately 5% of nonfatal injuries involving at least 24 hours of hospitalization from 1991 through 1998 could be attributed to strains and sprains (Thomas, Lincoln et al. 2001).

A possible reason for the difference between the Fisherman's Fund and the ATR data is that sprains and strains, even those requiring significant time off work, often do not result in hospitalization. It is also likely that many strains and sprains that would be reported by workers in a traditional shore-based factory are not reported by commercial fishers because of the tendency to not complain, distance to medical care, and share-based compensation plans.

Myers, Klatt, and Conway (1994) also suggest that strains and sprains, particularly related to the low back, are a leading cause of morbidity among fishers and that the application of ergonomic analysis is an important strategy to address this issue. One recommendation by Working Group IV (Prevention of Non-Fatal Work-Related Injuries) from the Second National Fishing Industry Safety and Health Workshop in 1997 is that ergonomic assessments should be performed to address nonfatal injuries among fishers (Klatt and Conway 2000). Fulmer and Buchholz (2000) emphasize that ergonomic training in the fishing industry should convey an understanding of the relationship between work performed and the risk of musculoskeletal injury. It has also been proposed that if deck crews were to condition themselves physically for their activities, there might be fewer related injuries (Jarris 2000).

Biomechanical analysis

Five major factors associated with the risk of musculoskeletal injury at the back and shoulder are—

> The magnitude and direction of the load or force on the hands.
> The posture assumed during materials-handling activities (including twisting of the torso and horizontal distance of the load out from the torso).
> The frequency of the force application.
> The duration of the activity.
> Static postures.

In this paper, stresses associated with the magnitude of the load and posture of the body will be investigated for several tasks commonly required during on-deck crab-fishing operations.

Two concepts must be understood to appreciate the impact of the work environment on musculoskeletal stress at the back and shoulder. These are

moment and ***compressive force.*** A moment (or torque) is defined as the effect of a force acting some distance from the point of rotation. The quantification of moment is force magnitude times distance from point of rotation. Compressive force is the force actually pushing bones together at the joint. In the case of the low back, a major risk factor is the total compressive force pushing the vertebrae together in the lower part of the back. This compressive force results from upper body weight and posture and magnitude and direction of the load and force in the hands. The effect of twisting the torso when exerting force with the hands, while less understood than compressive force, appears to increase the risk of injury to the low back. In the case of shoulders, a major risk factor is the moment or torque about the shoulder joint and the posture of the shoulder.

Whole-body biomechanical modeling is a type of ergonomic analysis that quantifies stress on the back and shoulder when a worker exerts forces on an external object with his or her hands. This paper presents biomechanical analyses of several on-deck crab-fishing operations. Inputs to the model include worker posture, worker anthropometry (body weight and height), and hand-force magnitude and direction. Outputs include low-back compressive force and shoulder moment (torque), which are primary measures of injury potential at these two joints. This quantification allows a comparison of musculoskeletal stress to generally accepted norms and facilitates recommendations for task or procedure redesign to reduce this stress.

Back compressive forces of 770 pounds are generally thought to present risk to some workers, and back compressive forces of 1,430 pounds are generally thought to present significant risk to most workers. No established limits are available for shoulder stress; therefore, shoulder moment is often presented as the approximate percentage of males who can be expected to have the strength required to perform a noted task. When this value approaches 100%, the task can be expected to present shoulder stress to many workers. In addition to the computer-based analysis, user-friendly hand-calculation methods to estimate back compressive force and shoulder moment can be requested from the first author.

Biomechanical modeling of crab-fishing operations

Lifting/lowering
When lifting or lowering a given load, the force in the erector spinae muscle and resulting compressive force can be reduced by keeping the torso as up-

Figure 1: On-deck lifting task bending at waist

right as reasonable and comfortable. A crab-fishing task in which the torso is flexed is shown in Figure 1.

For this study, it was hypothesized that most on-deck lifting loads were 100 pounds or less (for example, two boxes of bait). Remember that a compressive force of 770 pounds is thought to present a risk for some workers and a compressive force of 1,430 pounds is thought to present a significant risk for most workers.

Figures 2 and 3 represent the output of a computer-based biomechanical model for a lift with the torso flexed (stoop) and more upright (squat) with a load of 100 pounds. Figure 4 compares compressive force on the back for a stoop lift and squat lift with hand loads of 25, 50, 100, and 150 pounds. As can be seen, low-back compressive forces are lower when lifting with the torso upright than when lifting with the torso flexed forward.
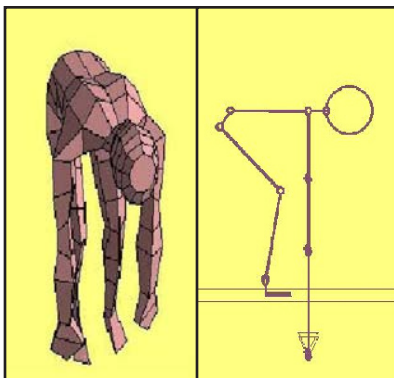

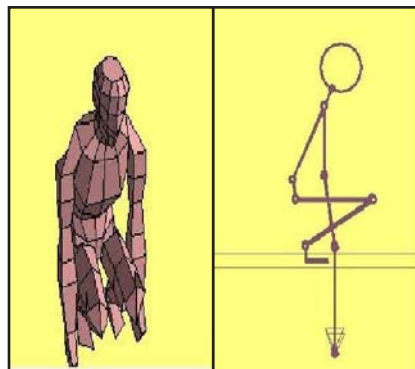*Figure 2: Biomechanical representation of a lifting task with torso flexed (stoop).*

Figure 3: Biomechanical representation of a liftimg task with torso more upright (squat).
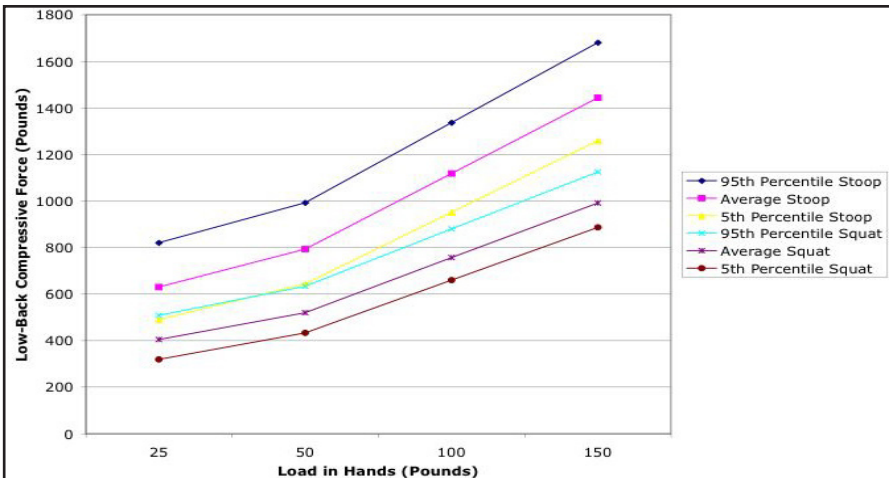
Figure 4: Low-back compressive force for stoop and squat lifting with loads of 25, 50, 200, and 150 pounds
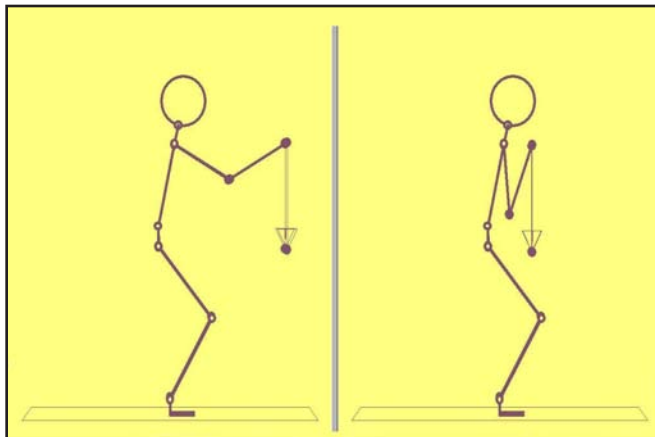

Figure 5: Biomechanical representation of a lifting task with load held out from body and with load held close to body

For a given load, the force in the erector spinae muscle and resulting compressive force can also be reduced by keeping the load close to the body. Figure 5 contains biomechanical representations of a lift task with the load far from and close to the body. Figures 6 and 7 illustrate the compressive force and the percentage of males with the shoulder strength to perform "close lifts" and "far lifts" with load of 25, 50, 100, and 150 pounds. These figures show that the low-back compressive forces are lower and the percentage of male workers who would have the shoulder strength to perform the task is higher when the load is lifted close to the body than when it is lifted held out in front of the body.
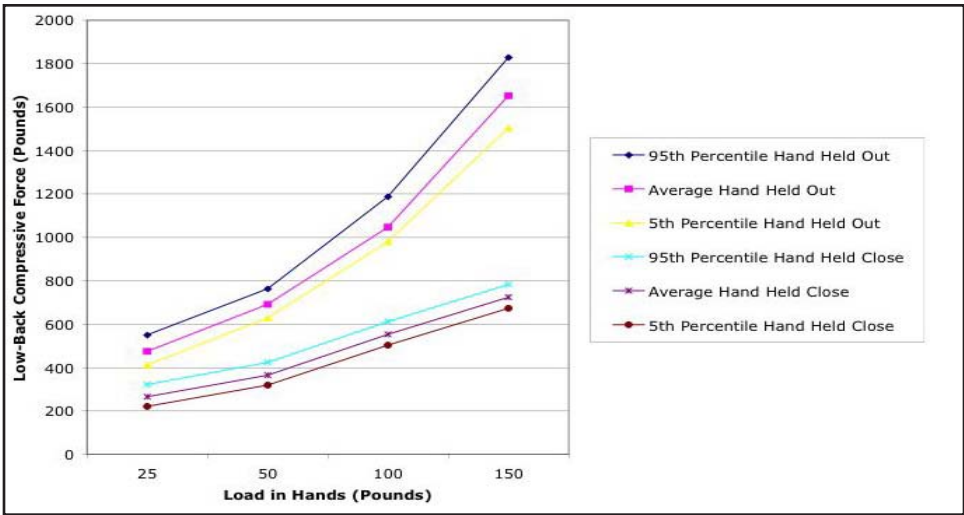
Figure 6: Low-back compressive force for lifting task when load is held out from body and when load is held close to body at loads of 25, 50, 100, and 150 pounds
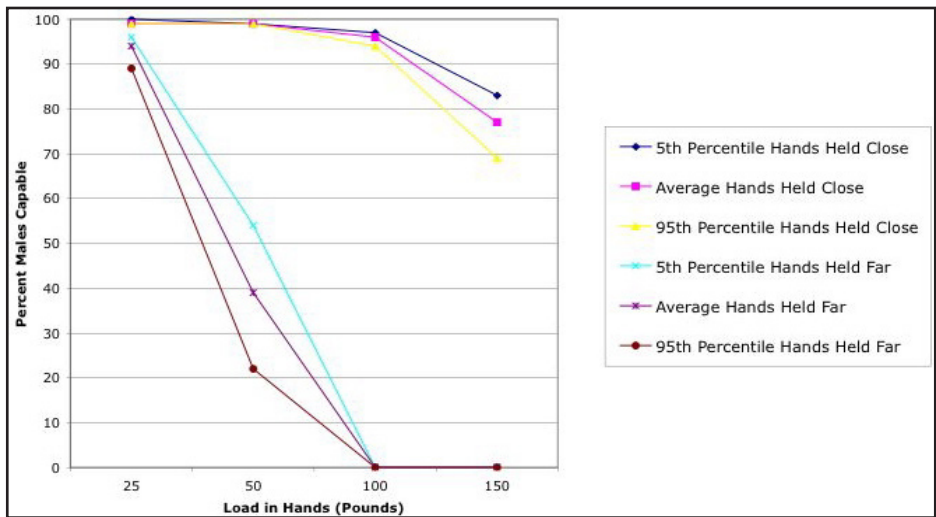

Figure 7: Percentage of male workers with shoulder strength to perform a lifting task when load is held out from body and when load is held close to body with loads of 25, 50, 100, and 150 pounds

For each posture, the three plotted lines represent the compressive force for the 5th, 50th, and 95th percentile male, which approximately represent the smaller/weaker, average, and larger/stronger person. Data for the 95th percentile (larger/stronger male) are included to recognize the fact that commercial fishermen may tend to be stronger and better conditioned than the average industrial population.

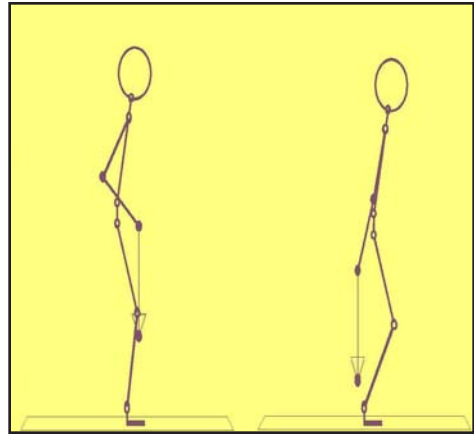Figure 8: Opening crab pot door with hands behind torso

Figure 9: Biomechanical representation of lifting with hands in front of and behind torso
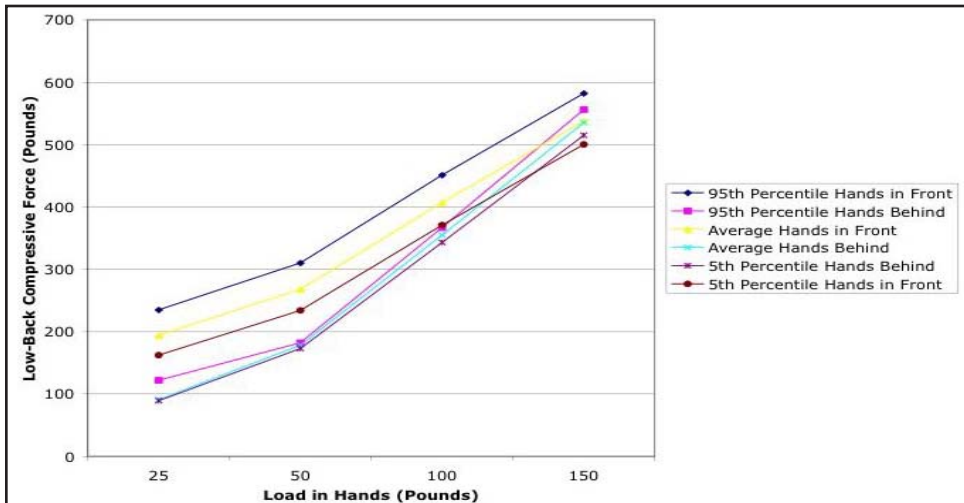
Figure 10: Low-back compressive force when hands are in front of torso and behind torso with loads of 25, 50, 100, and 150 pounds

Low-back compressive force during lifting and lowering can be minimized by locating the hands absolutely as close as possible to the low back. A crab-fishing task in which this is commonly done is shown in Figure 8. Figure 9 contains biomechanical representations of a lift task with the hands in front of and behind the body. Figure 10 compares the compressive force on the back with the hands in front of and behind the body with hand forces of 25, 50, 100, and 150 pounds. This figure shows that the low-back compressive forces are lower when lifting with the hands behind the body than when lifting with the hands in front of the body, even when the hands are right in front of the body.
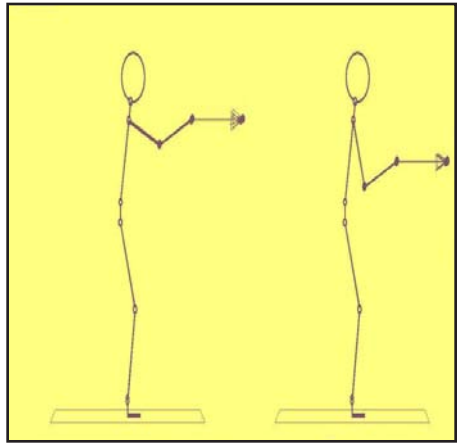
Figure 11: Biomechanical representation of pulling task with hands above waist and close to waist

Push/pull

The generation of pushing and pulling forces also results in external moments that must be resisted by the muscles of the body. For a given push or pull force, the low-back compressive force can be reduced by task design and/ or work practices that orient force direction as close as possible to the waist. This reduces the external moment and torso muscle force and, consequently, the low-back compressive force. Figure 11 contains biomechanical representations of a pull task with the force far from and close to the waist. Figure 12 compares compressive force on the back with force far from and close to the waist for pulls with hand forces of 25, 50, 100, and 150 pounds. These forces are representative of the push and pull forces often exerted during crab-fishing operations. For example, pushing or pulling a crab pot weighing 750

Figure 12: Comparison of compressive force on back with force far from and close to waist

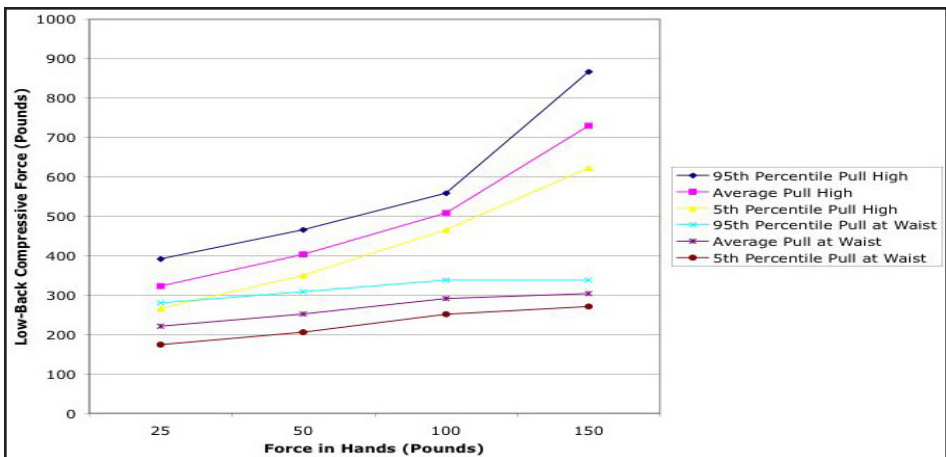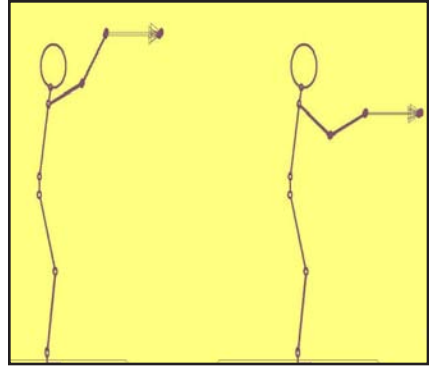Figure 13: Pull on rope with hands above shoulder and close to shoulder

Figure 14: Biomechanical representation of task with hands above shoulder

pounds on a boat deck with a coefficient of friction of 0.2 would require a pushing force of approximately 160 pounds. The coefficient of friction is the percentage (0.2 = 20%) of load weight that must be exerted horizontally to slide the load. (It should be noted that a worker would have to have his/her feet braced to generate this force without sliding on a deck with a coefficient of friction of 0.2.) It is hypothesized that push/pull forces would seldom, if ever, exceed 175 pounds.

As can be seen in Figure 12, low-back compressive forces are lower when pulling with the line of action of the force close to the waist than when pulling with the lines of action of the force above the waist. The comparative results for a push would be the same.

A major risk factor for shoulder injury is the moment or torque about the shoulder joint that results from the posture and magnitude and direction of the load/force in the hands. For a given push or pull force, the shoulder moment can be reduced by task design and/or work practices that orient the force direction through the shoulder. For example, in Figure 13, a crab-fishing operation is shown where the line of action of the pull force is exerted above the shoulder and where the line of action of the pull force is closer to the shoulder. Figure 14 contains biomechanical representations of these two tasks.

Figure 15 illustrates the percentage of males having the shoulder strength to perform pull tasks with the force close to the shoulder and above the shoulder using hand forces of 25, 50, 75, and 100 pounds. It can be seen that
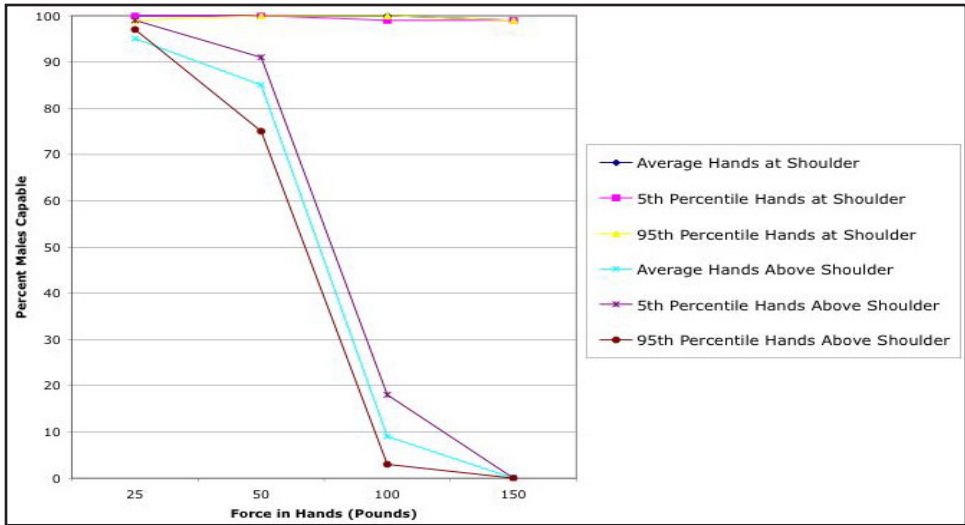
Figure 15: Percentage of male workers with shoulder strength to perform pulling task with hands above shoulders and with hands close to shoulders at forces of 25, 50, 100, and 150 pounds

the percentage of male workers who can be expected to have the strength required to perform the task is considerably higher when the line of action of the pull force is through the shoulder than when it is overhead.

As might be expected, workers often develop work practices that optimize overall stress on the body, but do not minimize stress on any one joint. An example of this is positioning the hands approximately half-way between the low back and the shoulder when pulling or pushing so that neither the back nor the shoulders are highly stressed.

Summary and recommendations

Biomechanical modeling can be used to estimate the musculoskeletal stress in commercial crab-fishing activities. The output of the biomechanical model is an objective method to identify equipment, task, and procedural and design recommendations that can be made to reduce stress to acceptable levels.

Stresses on the low back can be reduced by designing lifting and lowering tasks and work practices so that (1) the torso remains as upright as possible and (2) the hands are held close to the body. For tasks involving the generation of horizontal forces, both pushes and pulls result in less low-back stress when the line of action of the force is approximately at waist level. Lifting "behind the back" results in less low-back stress than lifting in front. Shoul-

der stress can be reduced by designing pulling tasks and using work practices so that the line of action of the force is approximately at shoulder level. An overall optimization of back and shoulder stress results when the line of action of the push or pull force is approximately at chest level.

In conclusion, while on-deck operations during crab fishing may require considerable hand force to lift, lower, push, or pull objects, musculoskeletal stress and the resulting risk of injury can be minimized if care is given to correct body posture.

Information in this paper can be used to assess the stresses and forces experienced by fishermen performing these or similar tasks in other commercial fishing operations. Future recommendations include collaboration between fishermen and fishing companies to obtain specific measurements of these tasks. The authors are willing to work with any of those parties who might be interested.

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EFFECTS OF COLD WATER IMMERSION ARE DEADLY
BE PREPARED!

Shane K. Neifer
Occupational Safety Officer
Fishing Team Leader
Prevention Division
Workers' Compensation Board of BC
4450 Lakelse Ave.
Terrace, BC, Canada
E-mail: sneifer1@wcb.bc.ca

Introduction

On 9 October 1999, the fishing vessel *Nopsa*, a 16.8-metre (55-foot) black cod longline trap vessel, was near the end of a 3-week trip. It was located on the Bowie Seamount, approximately 90 nautical miles west of the Queen Charlotte Islands on British Columbia's north coast. There was a crew of five on board, and after much bad weather the seas were finally calm. At approximately 2155 hours, the crew had 30 of the string of 60 traps on board. The current trap was somewhat heavier than the previous traps, and two of the deckhands were having trouble stacking it on top of the other traps on deck.

On the second attempt, the trap fell to the deck, causing the two deckhands to scramble to safety. One man moved to the center of the vessel, and the other moved to the starboard rail. The crew member who had moved to the rail of the vessel misjudged his location and slipped forward of the guardrail securing the trap storage area and fell headfirst into the water. He was not wearing personal floatation protection. Although the initial response from the crew was laughter, they quickly realized that the deckhand was in distress and began rescue attempts. The crew member was recovered on board within 9 minutes of entering the water; however, he was unconscious by this time and attempts to revive him were unsuccessful. During rescue attempts, a variety of lines and floating objects were thrown well within reach of the

man overboard, but he made no attempt to grab onto any of them and aid in his own rescue. He was able only to continue to cry out for help. The water temperature was between 10° and 11 °Celsius (50° and 52 °Fahrenheit).

On 08 November 2001, the fishing vessel *Golden Dragon*, a 10.7-metre (35-foot) single-pot crab-fishing vessel was in Hecate Straits approximately 34 nautical miles southwest of Prince Rupert on British Columbia's north coast. At approximately 2300 hours, the crew of three were pulling pots at the south end of their line of gear. The winds were from the south and south-west at 12 to 20 knots, making for less-than-ideal but not impossible fishing conditions. The vessel began to roll and pitch, requiring the crew to ensure that everything on deck was well secured. The crew was in the process of emptying crabs from, and re-baiting, the pot on deck when the vessel took a port turn. The crew had been pulling traps on the starboard side leaving the buoy line in the water during the process. The buoy line became caught in the propeller during the port turn, and as the line came tight, it started to pull the partially processed trap off the setting table. One of the crewmen reached to secure the trap as it was prematurely sliding over the side of the boat and was pulled into the water with the trap. As he entered the water, he released the trap and remained at the surface. As in the previously discussed incident, various lines and floating objects were thrown well within reach of the man in the water, but he made no attempts to aid in his own rescue. The stricken crewman was finally recovered on board after approximately 12 minutes in the water. The crewman was unconscious and attempts to revive him were unsuccessful. None of the crew were wearing floatation devices. The water temperature was 9 °Celsius (48 °Fahrenheit).

Both of the above-mentioned incidents were recorded by on-board video equipment used for fisheries management. The video evidence provides a running clock and GPS location data as well as vessel speed and direction.

On 20 September 2000, the fishing vessel *Ocean Jade*, a 15.2-metre (50-foot) salmon troller was at anchor for the evening in Pocket Inlet on the west side of the Queen Charlotte Islands on British Columbia's north coast. A crewman fell overboard and was unable to pull himself back on board the vessel. Attempts to regain entry, with the vessel master's assistance, were un-successful, and the crewman began to panic. The master of the vessel, sens-ing that his crewman was in very real danger of drowning, also entered the water. Neither person was then able to gain re-entry onto the vessel. The master attempted to swim to his brother's vessel that was anchored some 200

metres (650 feet) away. The master did not arrive at his brother's vessel, and his body has never been recovered. The crewman who had initially fallen into the water was recovered almost 10 hours later beside the boat he had fallen from. Although he was severely hypothermic, he survived his ordeal. The water temperature was 12 °Celsius (54 °Fahrenheit). Neither crewman was wearing personal floatation protection.

In another incident, which occurred on 27 March 2002, two fishery technicians were conducting eulachon research in the Skeena River on British Columbia's north coast. Although the portion of the Skeena River on which the technicians were working is not considered "tidal," it is influenced by the tides at the mouth of the river. The water rises and falls on-cycle as water levels change further down the river. The technicians had walked out to an island in the river at low water to conduct part of their survey. When they attempted to return, they found that the river was now too deep to cross back to the mainland. In their initial attempt to recross the river, both men filled their chest waders. The technicians returned to the island cold and wet to wait the 5 hours before the river would be low enough to cross. They had no survival gear and were not equipped to start a fire. After some discussion and against the advice of his partner, one of the technicians decided to swim across the channel. The narrowest part of the channel at that time was approximately 90 metres (300 feet) across. Their truck was parked on the far side of the channel next to the highway running alongside the river. Being in good physical condition and a good swimmer, the technician felt confident he could cross the river to the vehicle and go for help. He removed his chest waders, draped them across his shoulder and began to swim. His partner watched him make excellent progress and decided to also attempt the swim. He later reported that the water was so cold that it hurt too much to continue the crossing, so he returned to the island to monitor the progress of his partner. The swimmer reached within 3 metres (10 feet) of the far shore, at which time he simply sank and subsequently drowned in about 1 meter (3 feet) of water. The river water temperature ranged between 0° and 1 °Celsius (32° and 34 °Fahrenheit). The pathologist reported the incident as a "simple drowning." The author questioned a possible relationship between the drowning and the water temperature. The coroner, however, confirmed the pathologist's diagnosis that there was no evidence of hypothermia, and in fact the event was a "simple drowning."

These four summaries of actual incidents investigated by the author lead him to believe that stating that the casualties simply "drown" was incomplete. He

felt that exploring and understanding the physiological aspects of immersion could lead to development of initiatives to reduce or prevent the continued occurrence of this type of accident.

Problem

The significant issue that stood out to the author in the four examples above was that the victims all seemed to "give up" very quickly. In two of the cases, the casualties appeared unwilling to aid in their own rescue, and in the other two, the casualties were observed to be swimming strongly and then just appeared to sink or went missing before arriving at their destinations.

The leading cause of fatalities in British Columbia's commercial fisheries is drowning. Over 85% of all fishing fatalities from the period 1991 to 2001 on Canada's West Coast were the result of drowning. This includes individuals who entered the water, were not recovered, and are presumed drown.

The Workers' Compensation Board (WCB) of British Columbia investigates all occupational fatalities within its jurisdiction that occur in the province to determine causes of the accident. Once the accident cause is known, then the WCB further investigates to determine (1) if there are preventative measures to develop and/or (2) if there were compliance issues that led to the accident. In British Columbia, although the number of people fishing for a living has decreased significantly over the last decade, fishing still remains one of the most lethal occupations under the jurisdiction of the WCB. Figure 1 illustrates participation levels, total injuries claimed, and total fatalities over the 11-year period reviewed.

It is clear from Figure 1 that injury claims in the fishing industry are being reduced, although not as quickly as participation levels are dropping. Unfortunately, the number of fatalities is not following the same marked downward trend. Figure 2 breaks out the significant types of accidents that have resulted in death within the fishing industry. Eighty-six percent of these deaths, including those missing and presumed drowned (50 of the 58 that occurred from 1991 to 2001) were from drowning. Thus, it becomes important to determine what issues underlie this statistic. Only then can work begin to reduce the number of drowning fatalities within the fishing industry.
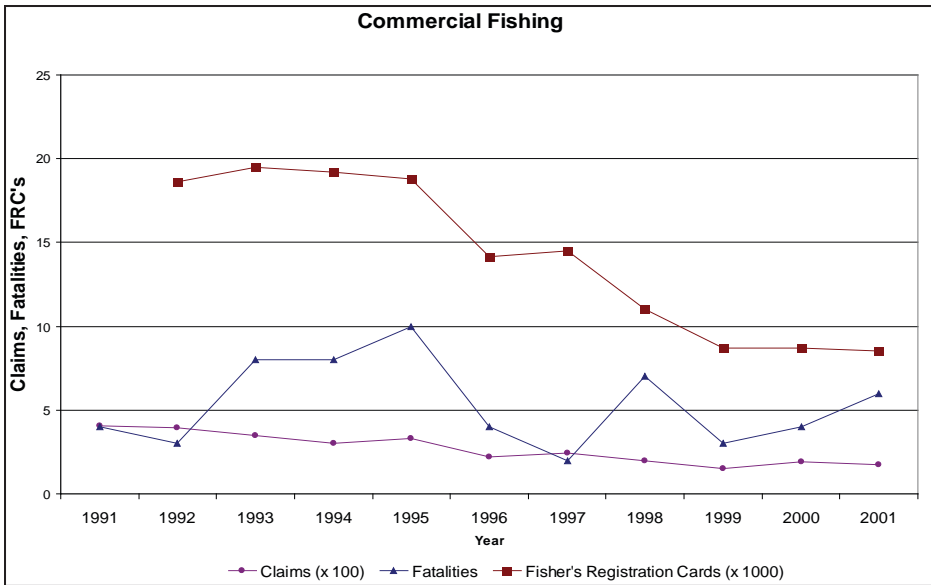
Figure 1: Injury claims, fatalities, and participation in British Columbia's commercial fisheries, 1991 to 2001 (Source: Workers' Compensation Board of BC, Fisheries and Oceans Canada)

Methods

A formal statistical analysis was not within the scope of this report. Rather a review of WCB records involving fishing industry fatalities from drowning and a minimal review of the literature pertinent to cold water immersion were undertaken. Inquires were made to colleagues at the Canadian Coast Guard, Transport Canada, and the Transportation Safety Board concerning their records involving cold water immersion and any literature on the topic. The Transport Canada publication *Survival in Cold Waters* (TP 13833) proved to be an invaluable resource. It can be downloaded from marine publications at the Transport Canada Website (www.tc.gc.ca) (Brooks 2003). Transport Canada commissioned *Survival in Cold Waters* in response to a drowning incident in the Great Lakes in 2000. The report was authored by Dr. Chris J. Brooks of Survival Systems Limited in Dartmouth, Nova Scotia. In this report, Dr. Brooks describes four stages of physiological response by human beings to immersion in cold water.

The author contacted Dr. Brooks to discuss drowning incidents in British Columbia's fishing industry in relation to the stages of cold water immersion. Dr. Brooks then undertook a retrospective analysis of the WCB's investigations into workplace drowning fatalities from 1976 to 2002.

*Figure 2: Accident types leading to fatal injuries in British Columbia's commercial
fisheries, 1991 to 2001 (Source: Workers' Compensation Board of British Columbia)*

Another text was also reviewed. *Essentials of Sea Survival* (2002), authored
by Drs. Frank Golden and Michael Tipton, documents historical data
through to modern science on the effects of and protection from cold water
immersion.

Results

Cold water is defined as water below 25 °Celsius (77 °Farenheit), but sig-
nificant effects of cold water immersion peak in water below 15 °Celsius (59
°Farenheit). As stated earlier, there are four stages involved in cold water im-
mersion. Stage 1, cold shock or initial immersion, can lead to death within
the first 5 minutes. Stage 2, swimming failure or short-term immersion,
which can be deadly from 3 to 30 minutes after entering the water. Stage 3,
hypothermia or long-term immersion, can take effect and be fatal within 30
minutes. Stage 4, post-rescue collapse, involves fatalities occurring during
or after rescue. Outlines of the four stages, as described by Drs. Brooks,
Golden, and Tipton, are provided below.

Stage 1- Cold shock
Cold shock occurs immediately upon immersion in cold water. It is a short-
lived event, lasting only 3 to 5 minutes. It is the human's physiological

response to sudden cold water immersion. It often leads to panic, which can result in quick drowning. These uncontrollable responses are as follows:

- A large inspiratory gasp immediately upon immersion.
- A four-fold increase in respiratory rate.
- A reduced breath-hold capability.
- A large increase in heart rate.
- A large increase in blood pressure.
- Onset of decreased peripheral dexterity.

The initial inspiratory gasp and increase in ventilation rate can lead to involuntary aspiration of water if the victim's head is below the surface, resulting in quick drowning. The hydrostatic pressure of the water coupled with vasoconstriction of the periphery and increased heart rate quickly increase blood pressure and can lead to heart failure. Heart failure can be fatal on its own, but often just aids in the drowning process. A person's ability to breath hold in cold water is reduced by up to 85%. In air, the average breath-hold capability is just over 1 minute. In cold water, breath-hold capability can be as little as 10 seconds (Golden 2002, p. 63). The effects of stage 1 can easily lead to panic as the person struggles to breathe. In many cases, the result is that the person in the water is unable to function well enough to aid in their own rescue. They may well be unable to grab a line or life ring that has been deployed directly to them as they panic and because the cold water has cooled peripheral muscles, causing loss of dexterity. The human body will adjust to the effects of cold shock quickly. The key is to not inhale water into the lungs and spiral into complete panic within these first 5 minutes. It takes only 150 mL of water in the lungs to drown. Staying afloat by using a personal flotation device, immersion suit, or lifejacket would significantly increase the chance of survival during stage 1 cold shock.

Stage 2 – Swimming failure
Swimming failure lasts from 3 to 30 minutes in cold water. In this stage, the casualty has survived initial immersion and has decided to attempt swimming to rescue. The physiological responses are as follows:

- Breath-hold capacity remains decreased and continues to decrease as the body remains in the water.
- Cooling of the external tissues reduces coordination and functioning of the extremities.
- Breath rate to swimming stroke rate is no longer equal.

  - Swimming angle increases, stroke rate increases, and stroke length decreases.
  - Swimming motion begins to fail as coordination is significantly reduced; signals from the brain do not reach the limbs.
  - Cardiovascular and/or respiratory events can lead to drowning.

One's swimming ability in warm water has little relationship to swimming ability in cold water. In warm water, a swimmer will take one breath per stroke. In cold water, respiratory rate and stroke rate both increase, but not together and quickly diverge. This can enhance the sense of panic. Cooling of the extremities and subsequent decrease in functioning with the increase in stroke rate leads to an increase in the angle of the swimmer in the water. Increasing the angle of the swimmer in the water increases drag and substantially increases the energy required to move through the water. This is happening in a body using all available energy to maintain core body temperature and can lead to a further increase in the feeling of panic, as well as an increase the risk of cardiovascular or respiratory failure. These continuing physiological responses and increasing panic dramatically increase the risk of drowning.

Stage 3 – Hypothermia

Hypothermia is a well-documented physiological event that will be understood at some level by most people in the fishing industry. In cold water, a thermally unprotected individual can die from the effects of hypothermia in approximately 30 minutes. The physiological responses to hypothermia are as follows:

  - Continued shunting of blood away from the periphery to the core.
  - Shivering begins in an attempt to generate heat.
  - Loss or semi-loss of consciousness, leading to drowning.
  - Heart failure.

Hypothermia is generally diagnosed when core body temperature drops at least 2 °Celsius (4 °Fahrenheit). It is usually fatal when core temperature drops by 12 °Celsius (22 °Fahrenheit). The body loses heat four times faster in water than in air. While continued immersion in any water below 35 °Celsius (95 °Fahrenheit) will eventually lead to hypothermia, it is water temperatures below 15 °Celsius (59 °Fahrenheit) that pose the most immediate risks. After surviving the first two stages of cold water immersion, the early onset of hypothermia can lead to a decrease in the will to survive.

There will be a progressive loss of function until the individual loses consciousness and ultimately drowns. Heart failure becomes an issue early in the cooling process as blood vessels constrict, making the heart work harder.

Stage 4 – Post-rescue collapse

Post-rescue collapse is thought to account for as much as 20% of all immersion-related deaths. Issues at this stage occur at the time of or following an individual's removal from the water. The physiological responses to removal from water and rewarming are as follows:

- Significant decrease in blood pressure in the core.
- Aspirated water can degrade lung tissue, affecting the oxygen transfer process.
- Internal injuries sustained during the accident can impact survival.

There are three conditions when this stage most often occurs. The first is when the core blood pressure will decrease suddenly and significantly in response to the vasodilatation of the peripheral blood vessels with removal from the water's hydrostatic pressure and rewarming. This decrease in blood pressure can lead to sudden failure of the heart or brain due to oxygen deprivation. Rewarming should be directed at the core, ensuring that the person is treated much as they would be for shock. This would include maintaining a horizontal position to avoid blood pooling in the lower extremities.

The second condition of concern is when water has been aspirated into the lung tissue, initiating several physiological events. The alveoli are degraded, and oxygen exchange can be seriously compromised. This can lead to death many hours after rescue as inflammation and continued tissue damage result in a pneumonia-type response. This must be treated medically.

Lastly, internal injuries and head and neck injuries can easily occur as someone fell overboard. Internal injuries can lead to fatal bleeding as rewarming stimulates the flow of blood throughout the body.

Summary

Knowing and understanding the four stages of cold water immersion and their effects can lead to the development of protocols to protect individuals in the fishing industry. It is very likely that the casualties from the *Nopsa*

and the *Golden Dragon* succumbed to drowning as a result of cold shock (stage 1). It also appears that the master from the *Ocean Jade* and the fishery technician on the Skeena River were classic examples of swimming failure drowning in stage 2 of cold water immersion.

Although hypothermia is commonly recognized as a potentially fatal event and does account for many deaths, in actual fact it may not be responsible for as many deaths as cold shock and swimming failure. Surviving the first two stages will lead to hypothermia becoming a serious risk where drowning may result even with the use of floatation devices. The exception is the use of a survival or immersion suit, which will add many hours to survival time in cold water.

In recent decades, many fishermen have become well-informed on the physiology of hypothermia, and they will contend that immersion in cold water for a short period of time is not terribly risky. There are countless anecdotal accounts of people falling overboard and being pulled safely back onto the vessel within a seconds or short minutes. What is not understood is that a seemingly insignificant variation in an identical situation could have fatal results. For example, an occasional occurrence among the herring and salmon seine fisheries is having a crewman go overboard clinging to the net twine. If the individual's head never submerges or he never lets go of the net, he may be retrieved with little trouble. However, all it takes is for the person's mouth to be below the water when cold shock causes the initial inspiratory gasp reflex and the outcome can be substantially more catastrophic.

Even the abbreviated literature review conducted for this report substantiates the events leading to drowning during cold water immersion when related to actual fatal incidents in British Columbia's commercial fisheries. Understanding the very high risk potential that cold water immersion poses and giving it the concern it deserves will motivate masters and crew to arrange work spaces and wear appropriate personal floatation protection to minimize the risk of these types of injuries. Masters and crew will also develop and practice procedures to quickly recover a crew member overboard on the first attempt!

Conclusions

Fishermen on Canada's west coast have long known the effects of hypo-

thermia. This is a result of tremendous educational initiatives from a large number of agencies. Fishermen are not very aware that there are other stages of cold water immersion that may pose a greater threat to their lives than hypothermia (stage 3). Cold shock (stage 1) and swimming failure (stage 2) appear to be responsible for more drowning fatalities in BC's commercial fisheries than either hypothermia or post-rescue collapse (stage 4). What is also little known is that being prepared to prevent or react to a cold water immersion event can greatly reduce the sometimes fatal effects of entering the water.

It is important for fishermen to become aware of the human body's physiological responses to the first two stages of cold water immersion. Vessel crew must understand how important keeping afloat in the water, which gives a rescue crew time to react, can be in improving their chances of survival. They must also understand and believe that how well they swim in warm water has no bearing on what they will be able to do in cold water. Only when fishermen understand what happens to the human body during the first two stages of cold water immersion will they willingly take the steps and precautions necessary to save lives.

The physiological effects of cold shock and swimming failure in themselves are not necessarily fatal. Hypothermia generally does not become a significant threat to survival for upwards of 30 minutes. It is therefore clear that keeping an individual's head above water and keeping the person afloat at the surface without requiring an expenditure of energy will substantially increase the chance of survival. Federal legislation in Canada requires that all vessels of a certain class, including many fishing vessels, carry one inherently buoyant keyhole style lifejacket for every person on board. However, the health and safety of crew on fishing vessels in Canada are the jurisdiction of the provinces and territories. In British Columbia, provincial regulations require that a personal floatation device or life jacket be worn whenever a work activity exposes a worker to the risk of drowning. The Workers Compensation Act allows various devices to be worn, including inherently buoyant lifejackets and manual and auto-inflating personal floatation devices. It should be noted that some fishermen contend that inherently buoyant life jackets are impractical for work.

Recently, a review of all occupational drownings reported to the Board from 1976 to 2002 was undertaken. This report ("A Retrospective Analysis of Drownings Reported to the British Columbia Worker's Compensation

Board 1976-2002," C.J. Brooks and K.A. Howard, unpublished) found no evidence that victims died from cold shock or swimming failure while wearing floatation devices. This determination, though, cannot be confirmed as many of the incident reports lacked sufficient detail to make this conclusion absolute.

Understanding, even at a basic level, the four stages of cold water immersion and their physiological effects should lead vessel masters and crew to being better prepared for immersion events before they happen. A three-point solution to address these issues is provided as follows:

1. Arrange the vessel's decks and work procedures to ensure crew exposure to entering the water is reduced.
2. Stay out of the water! If there is a risk of entering the water, be prepared to stay afloat to survive the effects of cold shock, to reduce the need to swim, and to give rescuers time to react.
3. Wear a personal floatation device or lifejacket if you are exposed to the risk of entering the water. A person who is unprotected by a floatation device can drown very quickly, often in as little as 3 minutes from initial immersion.
4. Develop and practice procedures to recover a crew member who is overboard quickly and be prepared to abandon a distressed vessel in a manner that eliminates or minimizes the need for crew to become wet!

There are many different types of lifejackets and personal flotation devices available on today's market. It is unlikely that any device will work well in all fisheries or even across all seasons and weather conditions. Auto-inflate flotation devices offer excellent floatation in a small, lightweight, unrestrictive package and are used successfully throughout the year in British Columbia. Immersion suits (survival suits) are required by provincial regulation for each crew member on every fishing vessel, but are far too bulky to work in. They do, however, save countless lives when there is enough warning to allow crew to get them on before they find themselves in the water. Between these ends of the equipment spectrum, there are many variations that can be explored.

A final recommendation is for the collection of much more data on the issues surrounding cold water immersion. As stated previously, a recent review of WCB files on drowning fatalities concluded that most investigations were incomplete when it came to determining the events that led to the drowning. It is important to understand that the preventative measures for reducing the

risk of hypothermia are different from the preventative measures that need to be put in place to reduce the risks posed by cold shock and swimming failure. The WCB, in conjunction with Dr. Chris Brooks and his assistant, Kimberley Howard, has developed an investigation checklist for immersion-related fatalities. This checklist is found in the appendix to this report.

References

Brooks CJ (2003). *Survival in Cold Waters.* Marine Safety Directorate, Transport Canada.

Golden F and Tipton M (2002). *Essentials of Sea Survival.* Human Kinetics Europe, Ltd.

Appendix: Investigation Checklist–Water-Related Incidents

INVESTIGATION CHECKLIST - WATER RELATED INCIDENTS
(Fill in a separate form for each worker)

PART 1 – Physical Information

Category of Incident (Fishing, Logging, Diving, MVA, etc) _____

If Vessel involved   Name Of Vessel _____
                             Length of Vessel_____
                             Vessel Registration Number _____
                             Vessel License Number _____

If Vehicle involved, type of vehicle (type, make and model) _____

Speed of vehicle or vessel at time of accident _____

Activity of vehicle or vessel at time of accident_____

Turnaround time of the vehicle/vessel_____

Estimated distance from shore or edge of river _____ (metres, kilometres)

Did incident occur in: ☐ ice   ☐ water

Depth of water _____(metres)

Time of day _____(24 hour clock)

Daylight: ☐   Twilight: ☐   Darkness: ☐   Other: ☐ _____

Weather conditions:	Observed	Estimated
Air Temp (°C)	_____	_____
Water Temp (°C)	_____	_____
Sea State (metres)	_____	_____
Wind Speed (knots)	_____	_____
Direction	_____	_____

Brief description of the incident:

_____
_____
_____
_____
_____
_____
_____
_____
_____

PART 2 – Human Factors Information

Number of people involved _____

Number of persons injured _____

Number of persons fatally injured _____

Injured Workers Information

Name _____   Date of Birth _____

Height _____   Weight_____

☐ Fatal   ☐ Injury

Body Core Temperature at Site   ___°C   Body Core Temperature at Hospital ___°C

Could worker swim? ☐ well   ☐ average   ☐ poor   ☐ no   ☐ not known

Did the worker sustain injuries other than immersion injuries? ☐ yes   ☐ no   ☐ not known
      If yes, describe
      _____
      _____

Had worker taken any survival training?   ☐ yes   ☐ no
      If yes, explain
      _____
      _____

- Was worker alive when entered the water?   ☐ yes   ☐ no   ☐ unknown

Does autopsy clarify whether worker was alive or dead upon entry   ☐ yes   ☐ no

If the worker was dead before entering the water then this is not a water related incident and there is no need to proceed further. If it remains unclear as to the condition of the worker prior to entering the water then continue as if the worker were alive as s/he entered the water.

- If a motorized vehicle or piece of equipment was involved, was a seat belt available?
      ☐ yes   ☐ no

Was a seat belt used?   ☐ yes   ☐ no

- Was the worker physically trapped within the vessel, vehicle, etc.? ☐ yes   ☐ no
      Describe:
      _____
      _____

How easy or difficult is it to operate the doors/windows underwater? Describe.
      _____
      _____

Do post mortem reports aid in answering above questions?   ☐ yes   ☐ no ☐ undetermined

- If the reports do help, then was worker _physically_ drowned (i.e. entrapped) or did they drown by other means?
      ☐ yes, physically drowned   ☐ no, drowned by other means

Was worker observed to: (tick appropriate box)
      ☐ make ineffective swimming strokes/struggle violently and appeared to be alive/conscious and even reaching for life rings etc?
            If so, for how many minutes? _____

- ☐ commence to swim either to other vessel or shore?
  - If yes, how many minutes or hours? _____.
    What distance was covered before worker seen to succumb?_____(metres/kilometres)

- Can you conclude how soon after water entry did worker succumb?
  - ☐ within first 5 minutes
  - ☐ between 5 and 30 minutes
  - ☐ after 30 minutes
  - ☐ at or shortly after rescue
  - ☐ unknown

- Length of time in water before retrieval?
  - ☐ under 5 minutes
  - ☐ between 5 and 30 minutes
  - ☐ over 30 minutes
  - ☐ over 1 hour
  - ☐ unknown

Were the above estimations determined from:
- ☐ witness testimony
- ☐ investigator's estimation (an estimate is encouraged if it is possible and there is no witness testimony)
- ☐ other (i.e. video) Describe_____

- How well clothed was the victim?
  - ☐ light ☐ medium ☐ heavy ☐ unknown

  Briefly describe how worker was clothed:
  _____
  _____

Did worker wear a lifejacket, floater coat, pfd, etc.?
☐ yes   ☐ no ☐ unknown.

Describe type, make, age and model:
_____
_____

- Did floatation device perform to specifications? ☐ yes   ☐ no   ☐ unknown

If 'no', describe what went wrong:
- ☐ unable to put on while in the water
- ☐ came off in the water
- ☐ not secured correctly
- ☐ poor maintenance
- ☐ inappropriate selection of gear
- ☐ did not inflate
- ☐ punctured
- ☐ damaged
- ☐ did not provide enough buoyancy
- ☐ other, describe:

  _____
  _____

- Were PFD's/Lifejackets carried on vessel or in vehicle? ☐ yes   ☐ no   ☐ unknown

- Were there enough PFD's/Lifejackets for all on board? ☐ yes   ☐ no   ☐ unknown

Did worker wear an immersion suit?   ☐ yes   ☐ no   ☐ unknown
    Briefly describe the type (make and model number):
    _____
    _____

- Were immersion suits carried on the vessel? ☐ yes   ☐ no   ☐ unknown

- Were there enough immersion suits for all on board? ☐ yes   ☐ no   ☐ unknown

Did immersion suit perform to specifications? ☐ yes   ☐ no   ☐ unknown

- If 'no', describe what went wrong:
    - ☐ sinking occurred too quickly to locate and don.
    - ☐ stowed in a place already underwater
    - ☐ physically stowed in an inaccessible place
    - ☐ no knowledge that suits were on board
    - ☐ suits leaked badly
    - ☐ no training in how to don/doff the suits
    - ☐ poor maintenance
  - ☐ other, describe:
    _____
    _____

- Were lifeboats, life rafts or skiffs carried?   ☐ yes   ☐ no   ☐ unknown
    - What type? _____

Were lifeboats, life rafts or skiffs deployed? ☐ yes   ☐ no   ☐ unknown

- If deployed, did they perform to specifications? ☐ yes   ☐ no   ☐ unknown

 If 'no', describe what went wrong:
With Launch
    - ☐ in ability to launch
    - ☐ vessel sank too quickly to launch
    - ☐ didn't know how to launch
    - ☐ too much list to launch
    - ☐ already underwater
    - ☐ weather made it too difficult to launch
    - ☐ got entangled
    - ☐ blew up against side of sinking vessel
    - ☐ failed to inflate
    - ☐ punctured
    - ☐ crew too cold and fatigued to launch
    - ☐ other, describe:
      _____
      _____

When in Water
- ☐ capsized
- ☐ blew over
- ☐ deflated
- ☐ washed overboard
- ☐ inability to get back in after being washed overboard
- ☐ flooded
- ☐ other, describe:

_____
_____

- How many hours/days did the worker work in the last:
  - 24 hours _____ hrs
  - last one week _____ days
  - last one month _____ days

Was there any medical condition that contributed to the incident (i.e. Epilepsy, Diabetes, Heart Disease, etc.)
☐ yes   ☐ no   ☐ unknown
If 'yes', describe: _____

- Were any other medication, drugs or alcohol involved? ☐ yes   ☐ no   ☐ unknown
  (Ask specifically about antihistamines and anti-fungals and whether medication was prescribed or over-the-counter)
  Describe: _____

Include a brief description of the autopsy results:

_____
_____
_____
_____
_____

- State the Coroners Cause of Death:

_____
_____
_____

Final determination
- ☐ Drowning from entrapment
- ☐ Drowning from Cold Shock
- ☐ Drowning from Swimming Failure
- ☐ Drowning or Death from Hypothermia
- ☐ Drowning or Death from Post Rescue Collapse
- ☐ Drowning or Water Related Death from Undetermined Cause
- ☐ Drowning – Other _____

Checklist for water related fatalities: C.J. Brooks, K.A. Howard, and S.K. Neifer