

# Ergonomic Exposure Case Studies in Massachusetts Fishing Vessels

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**Background** *Musculoskeletal disorders may not have been studied as much as greater risks in the dangerous environment of commercial fishing. Primary prevention of risk for these kinds of injuries and illnesses begins by a detailed understanding of what risks are likely to be common in the different fisheries, and how those risks might be reduced.*

**Methods** *Ergonomic job analyses were conducted on three different types of fishing vessels in Massachusetts: gillnetting, otter trawling, and lobstering. Direct observation was used to link posture to task. Noise measurements, tool analysis, and cycle time measurements were also included.*

**Results** *Production speed, materials handling, and vessel movement contributed to musculoskeletal stress by affecting observable postural deviation, repetition, and forceful exertions.*

**Conclusions** *Interventions to reduce ergonomic risk factors might be possible through utilization of below deck space in certain boats, through better technology, or through simple tool adjustments.* Am. J. Ind. Med. Suppl. 2:10–18, 2002. © 2002 Wiley-Liss, Inc.

**KEY WORDS:** *fishing vessel; ergonomics; musculoskeletal; cumulative trauma*

## INTRODUCTION

Fishing has long been recognized as a dangerous occupation, consistently ranking at or near the top of all occupations in fatalities in states where the industry employs a significant population. In Alaska, for instance, between 1991 and 1996, the fatality rate for fishing was 140/100,000, 28 times the national average [Lincoln, 1997]. During the same time period, the non-fatal injury rate for fishing in Alaska was 459/100,000. Comparable data on other industries in Alaska show that non-fatal injury rates in fishing are less than construction and mining, but more than land transportation, seafood processing, and petroleum.

Although selected use of existing data from large, local surveillance efforts has increased, such as the Alaska Trauma Register [Husberg, 1998], and the Scandinavian system, Nordic Medico Statistical Committee [Jensen, 2000], systematic data on non-fatal injuries, particularly musculoskeletal disorders (MSD) brought on by cumulative trauma rather than acute events, are not considered complete in the commercial fishing industry [National Research Council Committee on Fishing Vessel Safety, 1991]. Nevertheless, the International Labor Organization [1999] cited gutting (highly repetitive, awkward postures) and heavy lifting (overexertion) in fishing as risks for MSDs in a 1999 report, "Safety and Health in the Fishing Industry."

Literature in occupational epidemiology continues to grow, which links certain occupational risk factors to the incidence of musculoskeletal injury and illness [Bernard, 1997], namely awkward and static postures, repetition, forceful exertions, cold, and vibration. Törner et al. [1988a] showed a correlation between musculoskeletal symptoms in Swedish fishermen and tasks with recognizable ergonomic risk factors. Some of the work observed in this study is comparable to land-based fish processing, which has been shown to be a risk factor for increased disorders of the neck

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and upper extremity [Ohlsson et al., 1994] due to exposure to repetition, and forceful exertion [Chiang et al., 1993]. Identifying and reducing exposure to the most severe elements of work processes through ergonomic improvements in the fishing industry should result in a corresponding reduction in injuries. Another study by Törner et al. [1988b] showed that hull redesign could reduce knee bending and contact stress to the knee in certain fisheries in Sweden.

The present study characterized the work processes involved in different types of fishing in Massachusetts. Specifically, observations were made to qualify and quantify risk factors that may be reducible by applying ergonomic principles to the design of the work environment in fishing vessels. The purpose of this article is to describe ergonomic risk associated with various types of fishing operations, and to suggest intervention strategies. The data from this study, though mainly descriptive, can be compared to similar data from studies such as the one on Danish fishermen [Stage et al., 1999]. This type of study is in accordance with recommendations put forth by the Fishing Vessel Casualty Task Force Report [Spitzer, 1999], calling for research into occupational hazards that consider deck arrangements, exposure to the elements, machinery, control stations, and fishing gear.

Many different methods of harvesting fish are used throughout the various fisheries of Massachusetts. Fishing boats are classified by gear type. The boats investigated in this study were two lobster boats, a gillnetter and an otter trawler. The three gear types observed in this study make up about 70% of all fishing boats licensed in Massachusetts. This is a case study of these vessels and crews, and may not be representative of all boats of these types.

## MATERIALS AND METHODS

Two of the four boats observed were lobstering operations, one was a gillnetter and the other was a trawler. Each had a crew of two—one captain and one sternman—except the trawler, which had a second sternman. The boats were out of Gloucester, Rockport, and Fairhaven, Massachusetts, and observed in 1997 and 1998. Though these types of boats make up the majority of fishing vessels in Massachusetts, no method other than convenience was used to select the study participants.

Direct observations of the four boats were made during their regular operations in order to identify risk factors for MSDs, acute injury, and noise-induced hearing loss. Video recordings were made of the operations, which helped in analyzing the elements of the required tasks. Still photography was used to document tasks and non-neutral postures.

An ergonomic job analysis [Keyserling et al., 1991] in which the observed risk factors for MSDs were described

was completed for each boat. The risks were identified after reducing the work description to an elemental level, then associating those elements with postural risk factors. Review of the videotape allowed selected analysis of the observed work elements defined through task, activity, and posture codes. Each element was associated with posture codes derived from the Ovako Work Posture Analyzing System [Karhu et al., 1977].

The fish harvesting process is a set of tasks completed in a fixed area defined by the dimensions of the boat. The duration of the various cycles of work could be measured and used to assess the overall percent of time an individual would be exposed to a particular risk factor. For instance, if shoulder extension occurred for a measured fraction of a cycle, and the cycle is repeated a known number of times, then the expected amount of time the shoulder is extended in this fashion can be estimated.

Noise was measured using an audio dosimeter (DuPont MK3 Wilmington, DE) clipped to the observer on the boats where the observer was able to locate himself close to the working fishers.

The condition of tools (sharpness of knives, integrity of handles, rust, etc.) and estimated weights were noted when possible.

The observer had informal conversation with the subjects and qualitative data were extracted from these conversations.

## RESULTS

In general, economic success in commercial fishing increases when the volume of catch increases. Harvest limits on certain species are regulated by state and federally mandated governing bodies. Crews try to haul in as much fish or shellfish as possible, stow it into some kind of holding area after it is cleaned and prepared as needed. Each boat has its own methods, even within fisheries and gear types, particularly regarding how the catch is stored.

The three kinds of fish harvesting observed in this study used gear designed for the particular fishery. The majority of fishing vessels in Massachusetts are of these three types. Other notable types not studied are long-lining, seining, and dredging. Each of the gear types was designed to trap and remove fish or shellfish from their natural environment. Lobstering and gillnetting were examples of stationary gear, while otter trawling used mobile gear.

The major risk factors for MSDs are related to manual materials handling. The frequent hauling of traps requires some awkward postures and frequent and sometimes forceful lifts. Handling of bait and catch usually does not require great force, but when the catch is grouped or loaded into buckets and baskets, the handling may often require high forces. In addition, handling bait and catch is repetitive, requiring both speed and precision.

The movement of the observed fishing boats at sea was substantial and only partially predictable. Vessel motion was observed to complicate materials handling and even make maintaining neutral posture a challenge. The potential for sudden movements increased the risk for acute muscle strain, and added to the cumulative strain of the lower extremities and upper extremities during materials handling. Though these were less than ideal working conditions, experienced individuals reported having some skills in using the movement to their mechanical advantage, i.e., lifting as the boat's upward movement accelerated. Presumably, better skills at utilizing mechanical advantages develop as a result of increased awareness and experience.

## Lobstering

Lobstering had the most repetitive haul and set cycle of the three types of operations observed. On the day they were observed, one crew handled 240 traps, the other 290. Both captains commented that they commonly handle 300 traps per day.

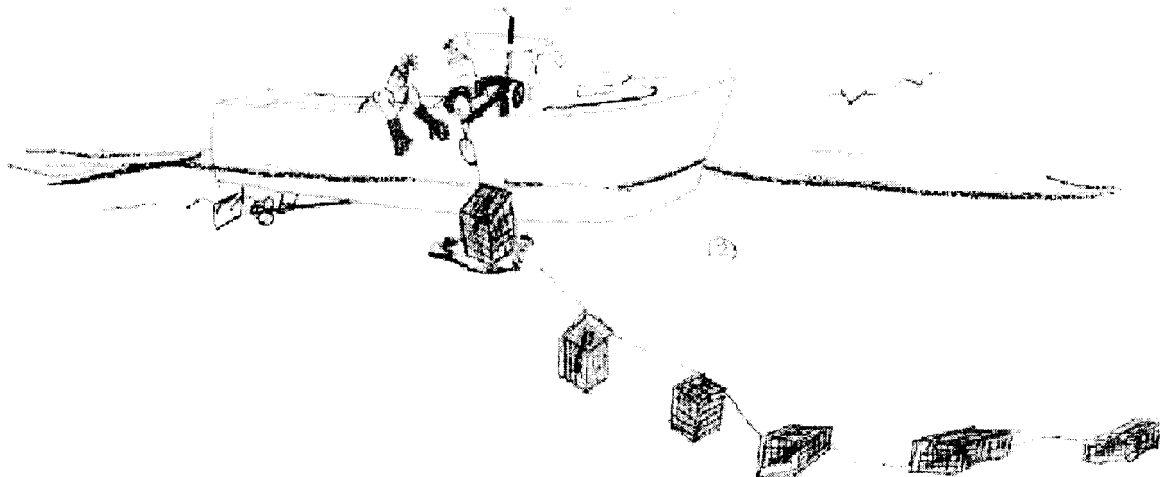
The two operations observed are interesting to compare because their techniques differed in three major ways that affect health and safety. One boat set traps individually attached to buoys, known as "singles." The other boat set groups of 10 or 20 traps attached to buoys, known as "trawls" (Fig. 1). The crew of the boat setting and hauling trawls did so for 45% of the day, whereas hauling and setting strings of singles required about 70% of the day. Lifting and pulling the trap onto the boat for the trawling set was observed only 10% of the time that it was on the singles set. Awkward postures of the back and upper extremities and high force were associated with this lifting and pulling (Table I).

On both boats, the captain did the lifting and pulling of the trap. The captain of the boat setting and hauling singles was exposed to ten times the number of these awkward lifts than the captain of the trawl set. The rate of repetition in either boat is strictly under the control of the captain, who operates the boat. Apparently, the method used by each boat is as much to do with local convention as anything else. Rougher water, more common in the area where singles were set, is tougher on the trawls.

The second effect of the trawl set regarded the lines. The lines used to connect the traps to each other in the trawl set were piled on the deck at the feet of the crew, and were a risk for entanglement and loss of life from drowning. In contrast, the lines connected to the single strings were immediately placed on top of the trap at waist height once the trap was hauled in, which decreased the risk of entangling the lower extremities.

The third difference in technique was not related to the traps, but to the bait loading. One boat ran a spike through the baitfish's eye sockets and then down a string attached to the trap. The other loaded baitfish into onion bags and tied the bag into the trap with a drawstring. Neither sternman reported pain associated with this task, but significant differences in wrist posture were noted. The associated repetition and postures would make this task an area of concern for reducing risk for MSD.

The technique of hauling and setting the traps was otherwise similar between the two lobster boats. Captains were exposed to the awkward trunk and upper extremity postures, high force, and repetition of pulling in the trap. Sternmen were exposed to repetition, high force, and awkward posture in their back and shoulders when handling traps, as well as to repetition and awkward postures associated with gauging and banding the lobster. One sternman reported pain associated with the use of the lobster gauge.



**FIGURE 1.** Drawing of lobstering.

**TABLE I.** Tasks, Associated Ergonomic Risk Factors, Tools, and Affected Body Areas Observed in Two Lobstering Operations in Massachusetts

Task	Percent of day or defined cycle (avg.)	Body areas	Risk factors	Tools
Gaff—secure trawl line	5 sec/trap	Back	Severe forward flexion, repetition	Gaff, line, buoy
Pull in trap	3 sec/trap	Shoulder	Above shoulder, repetition	Winch, trap
		Shoulder	Awkward posture	
Remove trap contents	7 sec/trap	Back	High force, lateral bending	None
		Hand/wrist	Repetition	
Rebait—reset trap	8 sec/trap	Shoulder	Awkward posture	Spike, bait bag, trap
		Hand/wrist	Repetition, awkward posture	
Gauge lobster	3 sec/lobster	Hand/wrist	Pinch grip, repetition	Gauge
Stack traps	8 sec/trap	Back	High force, repetition	None
Band lobster	5 sec/lobster	Wrist	Awkward posture, repetition	Banding tool
Rinse down	5% day	Knees	Kneeling	Hose, brush
Repair gear	Irregular	Hand/wrist	High force, awkward posture	Needle

Noise was close to OSHA's standard of 90 dBA for 8 hr on one boat, but much less on the other (Table II). Particular manufacturers have reputations for producing either "loud" or "quiet" engines, according to both captains, which may account for the measured difference.

Stacking traps on board increased the vertical distance of the Sternman's lift by the height of a trap. One boat was large enough that stacking was only necessary when 20 traps were on deck at once (which only happened when traps were being relocated). The open stern of the other boat required lifting and carrying, and extreme forward flexion of that sternman to place the trap on the deck floor before setting out. The closed hull allowed the sternman of the other boat to maintain a neutral trunk, and to only slide the traps before setting out.

## Otter Trawling

Otter trawling is a method of dragging named for the large doors that hold open the mobile gear (the net) being dragged either through mid-water or across the bottom (Fig. 2). When the doors shimmy through the water, they look like otters swimming. The opening of the net is very large, and narrows to a "cod end" where the catch gets trapped.

**TABLE II.** Noise on Fishing Boats Observed in Massachusetts

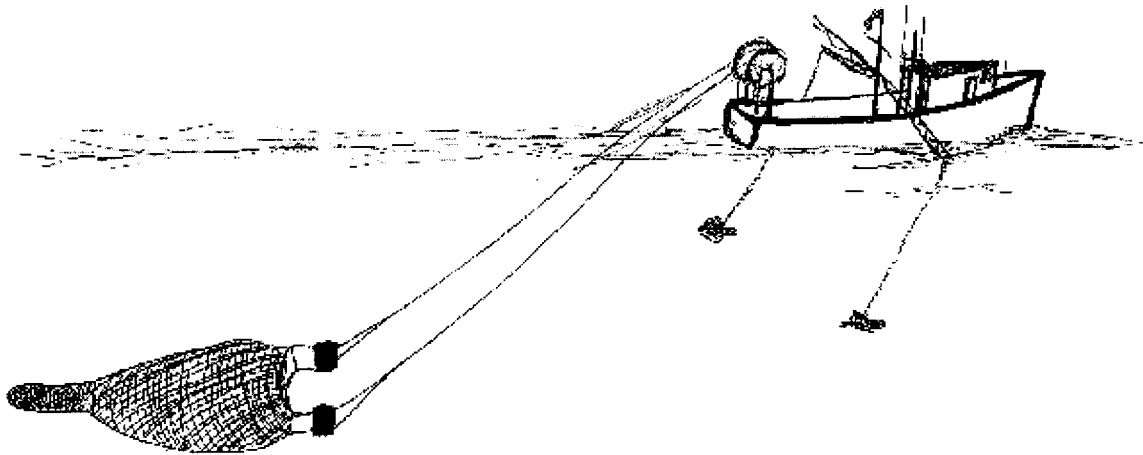
Vessel	8 hr TWA dBA	Max dB
Lobster 1	89.5	116.2
Lobster 2	75.2	101.5
Otter trawl	Not measured	Not measured
Gillnet	87.0	124.1

Repetition in the otter trawling process is less frequent than in lobstering. On the observed day, the crew set and hauled back the net three times. They could remain idle, while if there were no fish to process while the net was dragging, or tend to miscellaneous maintenance tasks.

The large otter doors required forceful exertions (Table III) to guide them as they were hoisted from their secure slot into the water to begin the haul, and in the reverse process, to secure the door into its slot after hauling back the net. Static force was required to hold a bar against the cable in order to guide and prevent tangling when the cable was wrapped around a large spool during haul back. The catch emptied onto the deck of the boat after dragging for about 2 hr. The crew sorted the fish into baskets. The work surface was below the feet, and required severe forward trunk flexion and/or kneeling for extended periods. Once in baskets, the catch was loaded into the hold without mechanical aids. The captain estimated that full baskets weighed up to 80 lb, and were passed from above deck by one man to below deck to another. The second man's arms had to be fully extended above his head to grab the basket from above deck. An extremely forceful pull was required to haul in the "bird," a 200-lb iron winged paravane on each side of the boat set out into the water on either side of the boat during dragging to dampen the movement of the hull of the vessel. High force may be required for irregular lifts of any large objects dragged off the ocean floor, such as oil cans, boulders, or broken and discarded fishing equipment.

## Gillnetting

In gillnetting, an extremely long, practically invisible, monofilament fiber net is set vertically like a fence in mid-water or near the floor and hauled back after about 12 hr (Fig. 3). Fish swim unaware into the net and are entangled.



**FIGURE 2.** Drawing of otter trawling.

A circular lifter mechanically hauled back the net slowly and steadily for about an hour per net. The crew untangled and removed each fish, shellfish, or other article, one by one, from the net.

Though gillnetting was similar to otter trawling in that only a few reiterations of setting out and hauling back are completed in a day. The work required to remove all of the fish from the gillnet involved highly repetitive motions of the arms, often forceful and jerking motions, with the elbows above shoulder height (Table IV). This high degree of repetition did not have predictable cycles, in contrast to the cycles of handling lobster traps. The lobstermen's cycles were shorter, allowing for 1–3 min of idle time between about 12 min of intense materials handling. Gillnetters responded to each fish as the net was slowly hauled back by the lifter. When fish were spaced closely in the net, a flurry of work had to be sustained until an empty space in the net came up. Conceivably, the repetition could last for the entire haul back, which lasted about an hour for each net.

Two brief lifts were particularly forceful: when the “stone”—a large piece of iron used to weight one end of the net to the bottom—was thrown overboard, and when the anchor was hauled in to the bow. On longer trips, the catch would need to be iced below deck. Removing the iced catch required forceful shoveling in very awkward positions.

## Tools

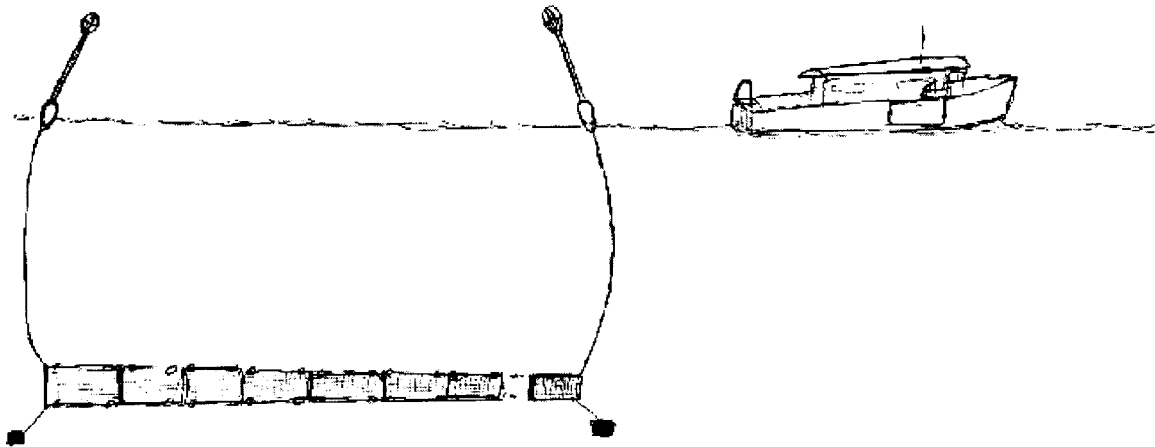
Tools observed (Table V) were non-powered hand tools with a single purpose. The gaff, in lobstering, and the hook, in gillnetting, each had user made handles. Other deck equipment were powered by hydraulics.

## DISCUSSION

Being careful not to view these case studies as representative of the Massachusetts fleet, certain risk factors could be expected on other boats because of the nature of harvesting.

**TABLE III.** Tasks, Associated Ergonomic Risk Factors, Tools, and Affected Body Areas Observed in an Otter Trawling Operation in Massachusetts

Task	Percent of day or defined cycle	Body areas	Risk factors	Tools
Set/haul “bird”	1/day	Back	High force, awkward posture	None
Sort fish	2 hr/day	Back Knee	Severe forward trunk flexion Kneeling	Spike, basket
Stow full bucket	30 min/day	Back	Severe forward trunk flexion, high force	Basket
Hook otter door	1/trawl	Back	High force	None
Open/shake net	1/trawl	Shoulders Back	Arms above shoulder High force	None
Pull guide bar	20 min/trawl	Shoulder	Static force	Bar
Shoveling ice	30 min/day	Back	Severe forward trunk flexion, force	Shovel



**FIGURE 3.** Drawing of gillnetting.

## Generalizable Risk Factors

Repetition was an important risk factor for injury in each of the observed fisheries. The volume of catch was a major determinant in how much repetition, except in handling lobster traps (where each trap had to be hauled, new bait set, and then reset in the water regardless of the trap's contents). The captains determined the rate of the repetition.

Forceful lifts in awkward postures were seen on each boat. In lobstering, and less consistently in gillnetting, these were accompanied by the risk factor of repetition when handling the gear. Forceful exertions of the hand and wrist were also seen in the handling of the catch in lobstering and gillnetting. Given existing technologies, these tasks would likely be required on any boat of the respective gear type.

The smaller boats reacted more noticeably to the waves. None of the boats observed was big enough to dampen the effects of the waves moving the boat, even on calm days.

Muscle force was not measured in this study, but the observer and the subjects reported that they felt additional strain due to force of muscles recruited to maintain balance. Decks, gear, and catch were wet, a factor that also tends to increase the strain on the musculoskeletal system: grip forces need to be higher and footing needs to be securer than with similar circumstances under dry conditions.

Irregular tasks also put the worker at higher risk. In lobstering, the high force and awkward wrist angle during line repair was only observed once in 20 hr of work. In otter trawling, high force and awkward posture was required to move an old and full lobster trap that got hauled in by the net. The subjects report that these observed irregular events are not uncommon.

These operations were observed for one fishing trip each. Crews commented that the long workdays and sleep deprivation accompanied by overnight trips does contribute to stress. Sleep deprivation and fatigue have been well studied [Calhoun, 1999], though no data on fatigue were

**TABLE IV.** Tasks, Associated Ergonomic Risk Factors, Tools, and Affected Body Areas Observed in a Gillnetting Operation in Massachusetts

Task	% of day or defined cycle	Body areas	Risk factors	Tools
Remove fish from net	40 min/haul	Hand/wrist Shoulder	Repetition Arms above shoulders	Picker
Set out net—spread	10 min/set	Armpit	Impact	Spreader
Gut fish	1.5 hr/day	Hand/wrist	High force, awkward posture, repetition, cold	Knife, hose, picker
Set out stone	1/set	Shoulder	High force	None
Haul in anchor	1/day	Back	High force	None
Shovel ice	1 hr/catch	Back, shoulder, knees	High force, awkward posture	Shovel

**TABLE V.** List of Hand Tools, and Materials and Equipment Handled by Hand Observed in Three Types of Fishing Operations in Massachusetts

Name	Operation	Used to	Estimated weight or force required
			(L = 0–10 lbs, M = 11–50 lbs, H > 50 lbs)
Spike	Lobstering, otter trawling	Spike bait, sort fish	Light
Gaff	Lobstering, gillnetting	Hook buoy	Light to medium
Trap	Lobstering	Trap lobster	40 lbs empty
Bait bucket	Lobstering	Hold bait	Up to 100 lbs when full
Mallet	Each observed	Irregular	Light
Banding tool	Lobstering	Band lobster claws	Light
Line	All observed	Attached to traps, boat, nets, buoys, etc.	Light to medium, heavy, when attached
Bucket	Lobstering	Cleaning supplies	40 lbs full
Basket	Otter trawling	Sort and transport fish	Up to 80 lbs full
Knife	Each observed	Gutting, various	Light to medium
Shovel	Gillnetting, otter trawling	Shoveling ice	Medium
Warp head	Otter trawling	Mechanical aid in hoisting line	Occasional high force
Bar	Otter trawling	Guide cable onto spool	Medium
Anchor stone	Gillnetting	Weigh net down in water	High
Anchor	Gillnetting	Anchor boat at night	High, 100 lbs
Picker	Gillnetting	Stabbing or hooking	Light to medium
Net	Otter trawling, gillnetting	Trap fish	Light to medium
Flyer/buoy	Lobstering, gillnetting	Attached to net or trawl	Light to medium

directly collected in this study. During conversation, individuals mentioned heat and sun in the summer and cold temperatures in the winter as some of their health concerns, though neither of these factors was observed to be extreme.

## Interventions Generalizable to Industry

Available workspace determined posture for some of the repetitive tasks, such as stacking traps in lobstering, icing fish in gillnetting, and sorting fish in otter trawling. In ergonomic intervention of any kind, attention should be given to ensuring that maximum utility of the limited space is achieved and that the work processes require as little unnecessary lifting as possible. Bigger boats ease some of this pressure on efficiency.

However, the biggest boat observed, the otter trawler, could improve the biomechanical aspects of the job by putting a workstation in the hold of the boat. The described process of sorting fish while kneeling could be eliminated if the catch were lowered onto a sorting table under the deck. The catch could be sorted and iced by sliding the fish, and the work height would be near waist level. The forceful and repetitive lifting of the baskets would be eliminated also. In the wintertime, it would be warmer below deck. A possible negative effect would be increased noise.

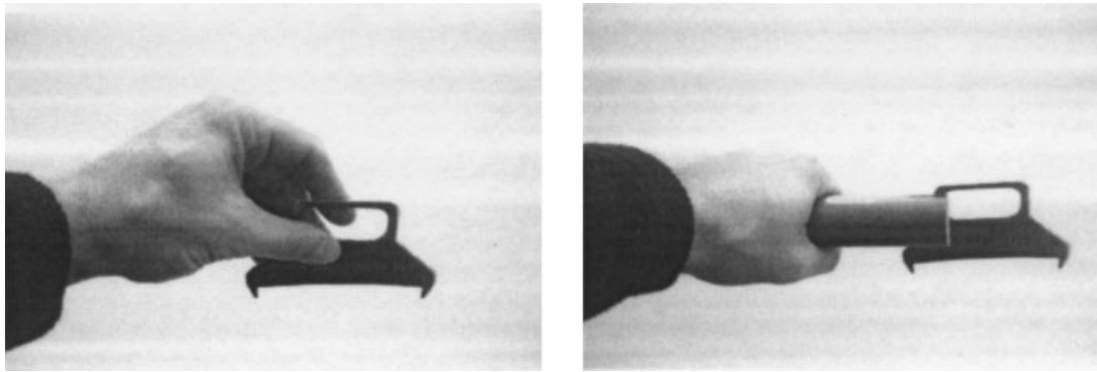
When gutting fish, bent handle knives similar to those introduced into meat packing would reduce wrist deviations.

A gutter-like slot would act like a vise to hold fish and lessen the demand on upper extremity forces.

In lobstering, a hoist that engages the trap buoy overboard and hauls the trap or trawl of traps up to and then onto the boat would eliminate a very large proportion of highly forceful and highly repetitive lifts done in awkward postures. Changing the banding tool and gauging tool handles could reduce the need for non-neutral postures and thus some of the stress to the hand and wrists (Fig. 4). The captains of both lobster boats mentioned that after many years of experience, they deliberately avoid working too fast and find it's easier on their body without significantly reducing their production rate.

## Stability

Regarding ergonomic interventions that alter a boat's structure, vessel stability deserves consideration. The United States Coast Guard has a case report on a fishing vessel that tipped over and sunk as a result of a cable stuck to the sea bottom while suspended from a high, stern mounted derrick [USCG MSO Portland, 1996]. The report demonstrates the seriousness that stability plays in the use or modification of deck structures, and suggests that the easiest way to prevent similar incidents is to lower the towing point. Transport Canada [1997] has published a small booklet with the physics of vessel stability outlined particularly for fishermen



**FIGURE 4.** Official Massachusetts lobstering gauge with and without handle that would reduce pinch gripping and awkward posture in the wrist.

and useful as an introduction during consideration of vessel alteration.

## Big Picture

Anecdotal evidence suggests a great deal of stress resulted from the condition and management of the fisheries. One captain pointed to concern he had for the “big picture.” He was most concerned about over-fishing. In particular, he felt that the government was not taking adequate measures to manage the lobster stock. He anticipated that regulators would be forced to react too forcefully to what he envisioned would be an unavoidable need for emergency protection. If this were to happen, competitive forces would make economic survival more of a challenge than it was at the time of the study. These forces, or the mere perception of these forces, would present an increased risk for poor health outcomes in multiple ways. Primarily, they would put pressure on the observed vessels to put more time at sea to compensate for the decrease in the fishery resource. More time at sea would increase the exposure to the observed risk factors. Secondly, but no less significantly, systemic stress would affect fish harvesters who, rightly or wrongly, perceived that the work that they were doing was not truly a path to economic well-being. Effectively, the work was not worth the risk, yet they were bound and committed to it by virtue of being boat owners or experienced hands without immediately viable alternatives. Karasek and Theorell [1990] has shown increased risk for poor health outcomes where a high job demand is exacerbated by low decision latitude. Viewing the “big picture,” described by several subjects in informal conversation as vitally important, underscores the importance of recognizing occupational health from a community perspective.

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