Project Title

New Methods to Chill Giant Bluefin Tuna

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Abstract

The Atlantic bluefin tuna is the most sought after fish in the worlds oceans. Ex-vessel prices during the early and mid 1990's were typically $15.00 to $20.00 per pound. Unstable overseas markets combined with increased processing cost and reductions in fish quality have reduced prices to $4.00 to $8.00 per pound. High internal temperatures of bluefin tuna delay shipping time and often increase the incidence and effect of tuna burn further reducing the commercial value of these fish. We designed and implemented a novel new chilling method for reducing the internal temperatures of bluefin tuna. This simple and cost effective design is suitable for vessels of all sizes, thus it can be widely distributed throughout the fishery. Initial results suggest that internal temperatures of bluefin tuna cooled four times faster when perfused with this system compared with control fish. Chilling bluefin tuna quicker will reduce the effects of tuna burn and decrease the time between capture and shipment to market potentially leading to higher ex-vessel prices.

Introduction

The Gulf of Maine commercial Atlantic bluefin tuna (*Thunnus thynnus*) fishery has been operating since the late 1950's. During that time, the fishery has experienced many changes including those associated with fishery regulations, market demand and acceptable types of fishing gear. These changes have had substantial effects on the financial returns to this industry. However, none of these have been more influential than the emergence of the Japanese sushi and sashimi market which developed during the mid 1970's. Unlike previous markets which focused on quantity, the Japanese raw fish market preferred individual, high quality fish. As a result, the value of the bluefin tuna industry and the number of its participants increased rapidly over the next 20 years (Figure 1). Recently, however, economic problems in Japan, unprecedented low levels of catch combined with low quality fish have caused prices to drop considerably. Currently, boats receive about a third to half the price per fish than they did 15 years ago.

The value of any individual bluefin tuna will depend on its quality and current market conditions at the time of harvest. While market conditions are largely out of the fishermen's control, improving the quality of the catch is not. Electrified harpoons, specialized packaging materials to wrap the fish and immediate processing at sea have all

helped to improve flesh quality and subsequently selling price. In the bluefin tuna industry, freshness, color of the muscle, fat content, and shape are the main concerns for many buyers. Due to the heat retaining properties of the bluefin circulatory system combined with their large body mass internal body temperatures may reach 32 degrees C. These high internal temperatures create two problems with regards to bluefin quality.

First, the Hazard Analysis and Critical Control Points (HACCP) branch of the FDA requires that internal temperatures of bluefin tuna be chilled below 5 degrees C before shipping. Current chilling methods (submersion in an ice bath) can take one or two days to reach the compliant shipping temperature depending on the size of the fish. In a best case scenario, with current chilling methods and direct shipping fish are three to four days old by the time they arrive at market. This can substantially reduce the price of the fish by affecting the freshness grade.

Second, the build up of internal heat can also affect the color and consistency of bluefin tuna muscle tissue due to a condition known as tuna burn. Although not entirely understood, tuna burn is thought to be an intracellular proteolysis reaction that destroys the filaments which bind the actin and myosin fibers together. It is most often observed in fish that have been captured by rod and reel. The enzyme responsible for this reaction is calpain. Calpain's functionality has a wide thermal range, but is most effective between 25-30 degrees C (the typical internal temperature of bluefin tuna). Chilling a bluefin tuna quickly will reduce the amount of damage from this enzyme, but current methods chill bluefin from the outside in. Temperatures of the tissues at the inner most margins of the fish can remain elevated for several hours extending the proteolysis reaction.

The bluefin tuna fishery is comprised of thousands of different vessels of various sizes. Only a small fraction of these boats have the capacity to begin chilling the fish at sea. Typical methods involve burying the fish in ice at the back of the boat or for a limited number of boats, lowering the fish into a specialized hold that contains chilled seawater. These additions are often quite costly and most vessels are not equipped with them. Likewise, many boats are not capable of carrying the required 500-1000 pounds of ice to adequately start chilling the fish at sea. The lack of efficient chilling between time of capture and transfer at the dock often results in a reduction in flesh quality and increased time to reach HACCP standards. Improved chilling methods implemented at sea and the dock will shorten the time between capture and shipment improving fish quality and price while ensuring compliance with HACCP standards for many vessels in this commercial fishery.

Project Objectives

The main goal of this project is to rapidly decrease the internal temperature of bluefin tuna through the design and implementation of a cost effective and novel chilling procedure. Successful application of this method would provide an inexpensive and effective alternative for chilling commercial sized Atlantic bluefin tuna which would improve the flesh quality and remain in compliance with HACCP guidelines for shipping consumable goods. This has the potential to give U.S. commercial bluefin tuna fishermen an advantage over competing worldwide markets resulting in higher ex-vessel prices.

Approach and Work Plan

Currently, bluefin tuna are submerged in ice baths and chilled from the outside in. This is a very inefficient method of chilling since temperatures are warmest at the inner most portion of the bluefin tuna body. As such, heat must be conducted out to the surrounding water through more than a foot of very dense muscle. Our approach is to chill simultaneously from both the outside and inside of the fish to substantially decrease overall chilling time. This is accomplished by utilizing the fish's own cardiovascular system as a heat exchanger.

Prior to 2004 arrangements were made with two commercial bluefin tuna boats. Both captains agreed to full participation in the project, which included offering any captured fish as experimental subjects. Fish were brought on board and Omegasoft thermocoupler probes were inserted into the fish to record internal temperatures. During the first year two probes were inserted into each fish. One approximately four inches above the lateral line above the pectoral fin in the dorsal musculature the other just posterior to the second dorsal fin. During the second year three probes were inserted in a straight line extending from the dorsal side of the fish towards the lateral line. These probes were inserted at different depths to check internal temperatures at different distances from the main vessels. This type of configuration allowed us to track the cooling effects at different depths within the muscle. The chilling system consisted of two coolers. The first was a ten gallon water cooler filled with chilled saline solution containing the equivalent osmolarity of bluefin blood (300mosm/L). The second cooler contained a coiled piece of stainless tubing submerged in an ice bath (Figure 2). A Rule bilge pump located inside the 10 gallon cooler pumped chilled saline from the first cooler into the stainless tubing within the second. Chilled saline flowed through the stainless

coil and out to the dorsal aorta and lateral cutaneous arteries of the tuna through a small section of tygon tubing (Figure 3). Saline flowed throughout the circulatory system exiting the tail end of the fish where a small incision is made to allow a flow through system. This approach requires minimal set-up, cost and time to implement. The entire set-up has a footprint of about three square feet thus it takes up very little room on board. In addition, no specialized equipment is involved making setting up or replacing systems cost effective, easy to assemble and readily available to all members of the fleet.

Opportunities for Partnership Between Commercial Fishermen and Researchers

Participation between scientists and fishermen has been quite extensive over the last threeyears. Scientists from the University of New Hampshires Large Pelagics Lab, members of the Yankee Fishermens Co-op, commercial fishermen and bluefin tuna buyers have all participated in this project. Catch rates during the last four seasons have been at historically low levels subsequently decreasing each year. This past season the commercial fleet landed just 10% of its allocated quota. Thus, the number of fish available for experimentation has been very limited and decreased each year. Although only two vessels have actively participated in the onboard experiments the last two years, our results have now sparked the interests of many more fishermen who want to use this system on their boats. The results to date show great promise for improving flesh quality and easily transferring this technology to several hundred commercial bluefin tuna fishermen throughout the region.

Work Completed to Date

Since this projects inception we have designed, built and tested three different chilling systems. The first prototype was heavy with a large footprint and found to be impractical for use on different size vessels. The second system was much smaller and lighter than the previous model making it more practical for widespread use, but impractical to use if the fish was not cleaned and the arteries and veins for chilling carefully isolated. The third system allowed fishermen to entirely clean the fish at sea, insert the chilling probes into three different vessels, turn the machine on and continue fishing or steaming back to port. Over the past three years we have been able to perfuse 9 fish and track the temperatures of 5 control fish. In 2007, due to extremely low catch levels we have not had access to any bluefin. Fish used in this study ranged in size from 183 to 260 cm and weighed between 80 kg-205 kg.

Results to Date

At the projects inception it was not clear how accessible and suitable the cardiovascular vessels would be for transporting chilled saline. Repeated dissections revealed these vessels to be easily accessed during routine cleaning, and perfectly placed to cool the interior of these fish. Blood vessels were quite robust withstanding pressures well in excess of optimal flow for chilling. Perfusion worked best when all three vessels, the dorsal aorta, and both lateral cutaneous arteries were intact. On two fish one or more of these vessels were severed by the harpoon dart. Initial perfusions were carried out for a maximum of 30 minutes. At the time caution was applied because of concern the white muscle would lose color as a result of being perfused with saline. Experiments later showed this was not the case and perfusion times were increased up to one hour and thirty minutes.

There were dramatic increases in cooling between perfused and non-perfused fish. Internal temperatures of bluefin tuna perfused with chilled saline decreased at an average rate of 3.3 degrees C per hour (Figure 4). Temperatures of fish that were not perfused decreased at an average rate of 0.76 degrees per hour (Figure 5).

At this time the data have not been submitted to the Northeast Consortiums database. Our plans regarding this matter are to wait until the 2008 season has been completed in an effort to add more fish to the database, after which time we will submit our complete results for five seasons. The dramatic decline in the numbers of giant bluefin tuna in the Gulf of Maine during the last three years has made it difficult to perfuse enough fish for statistical analysis. Our goal is to continue this experiment through 2008 in hopes of obtaining additional numbers of fish to carry out further analysis.

Impacts and applications

Temperature profiles from perfused bluefin have been shown to tuna buyers and initial responses to the quick drop in temperature and improvement in quality have been very positive. Buyers also confirm perfusion does not change the color of the fish. There are no current estimates for the dollar value which perfusion may add to the price per pound, but even a modest increase of twenty-five cents per pound (times the average size fish) could result in 100 dollars more per fish. Multiplied out across many vessels over the entire season this simple system has the potential to add tens of thousands of dollars to the industry. Due to its low cost and small footprint this system is ideally suited for large scale application on a variety of different sized vessels.

Related projects

There are no other related projects going on at this time.

Published reports and papers

At this point we have not published or presented this material. It is our intention to publish this research once we have perfused a sufficient number of animals.

Student participation

To date two commercial fishermen, two industry representatives, a tuna buyer, two research scientists and four graduate students have participated in this work.

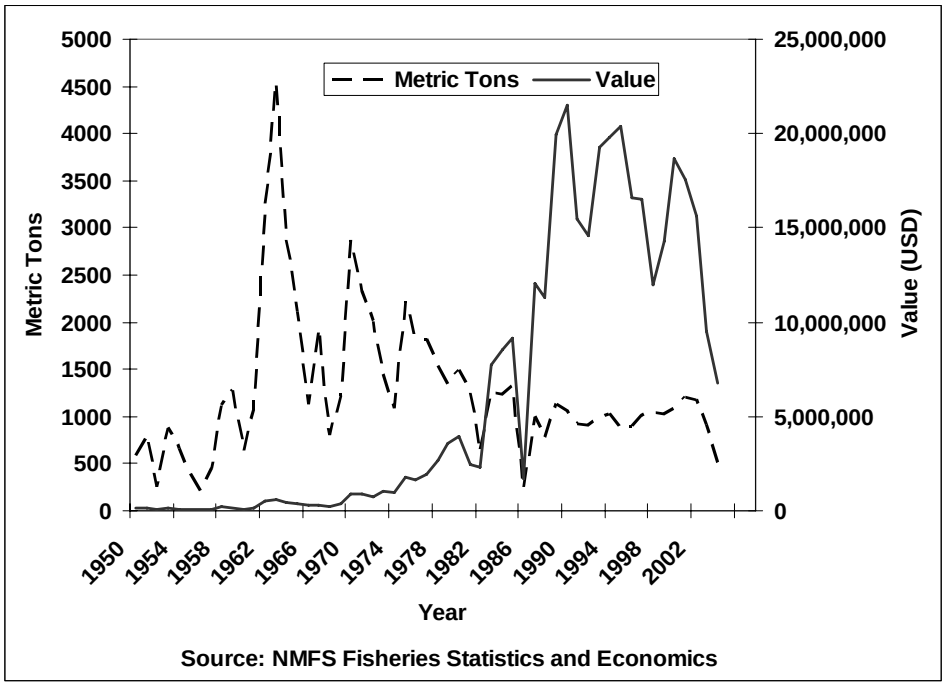

Figure 1 Landings and value of commercially harvested bluefin tuna in the Gulf of Maine.

Figure 2 Chilled saline solution was housed in a ten gallon water cooler. Water was pumped through a short section of Tygon tubing into an additional chilling system. The temperature of the saline solution was chilled further by passing it through a stainless steel coil submerged in a freshwater ice solution. This lowered the temperature of the saline solution to 1°C.

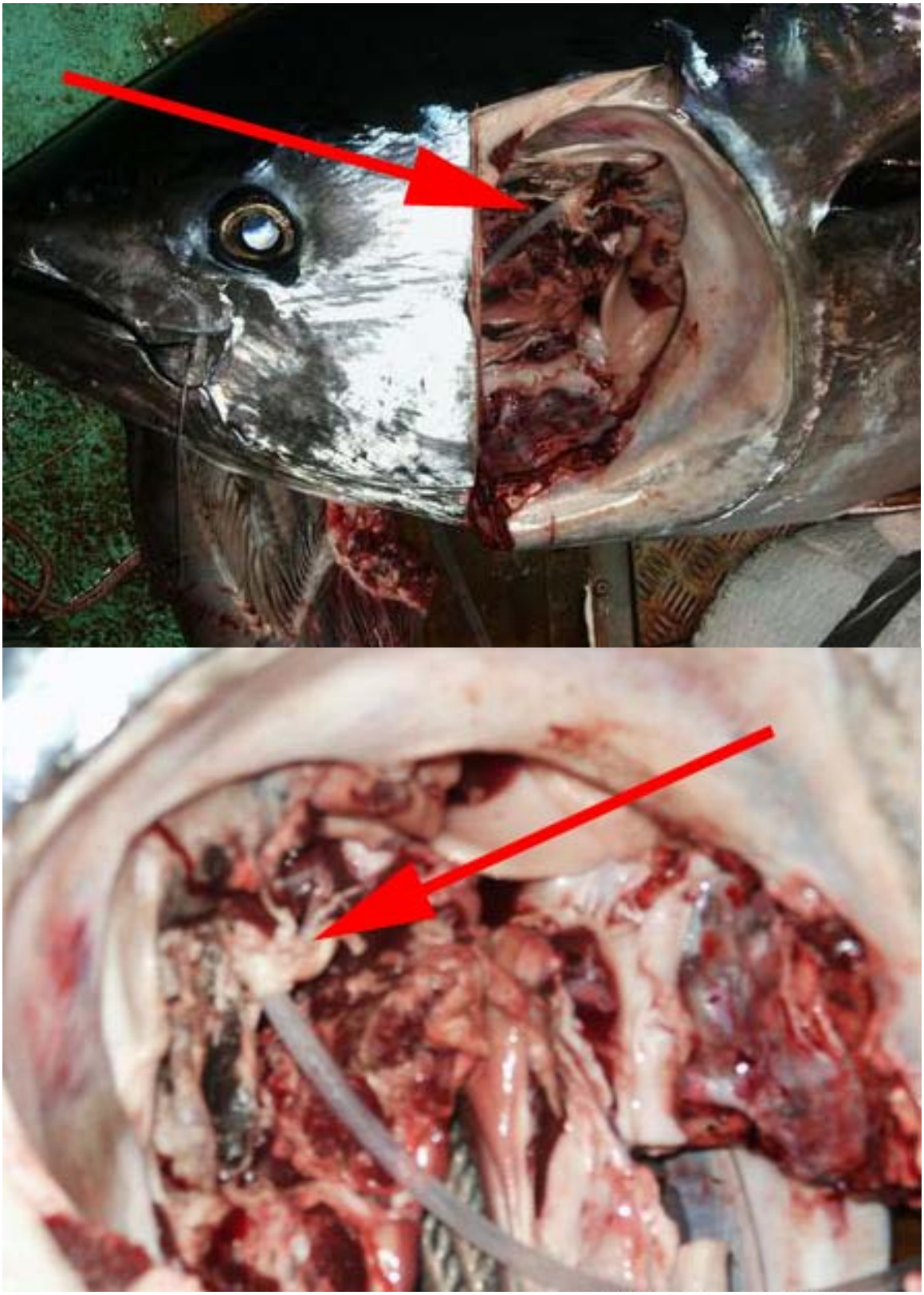

Figure 3 Bluefin tuna that have been cleaned and are being perfused with chilled saline. The tygon tubing is inserted into the dorsal aorta and lateral cutaneous arteries and held in place with a cable tie.

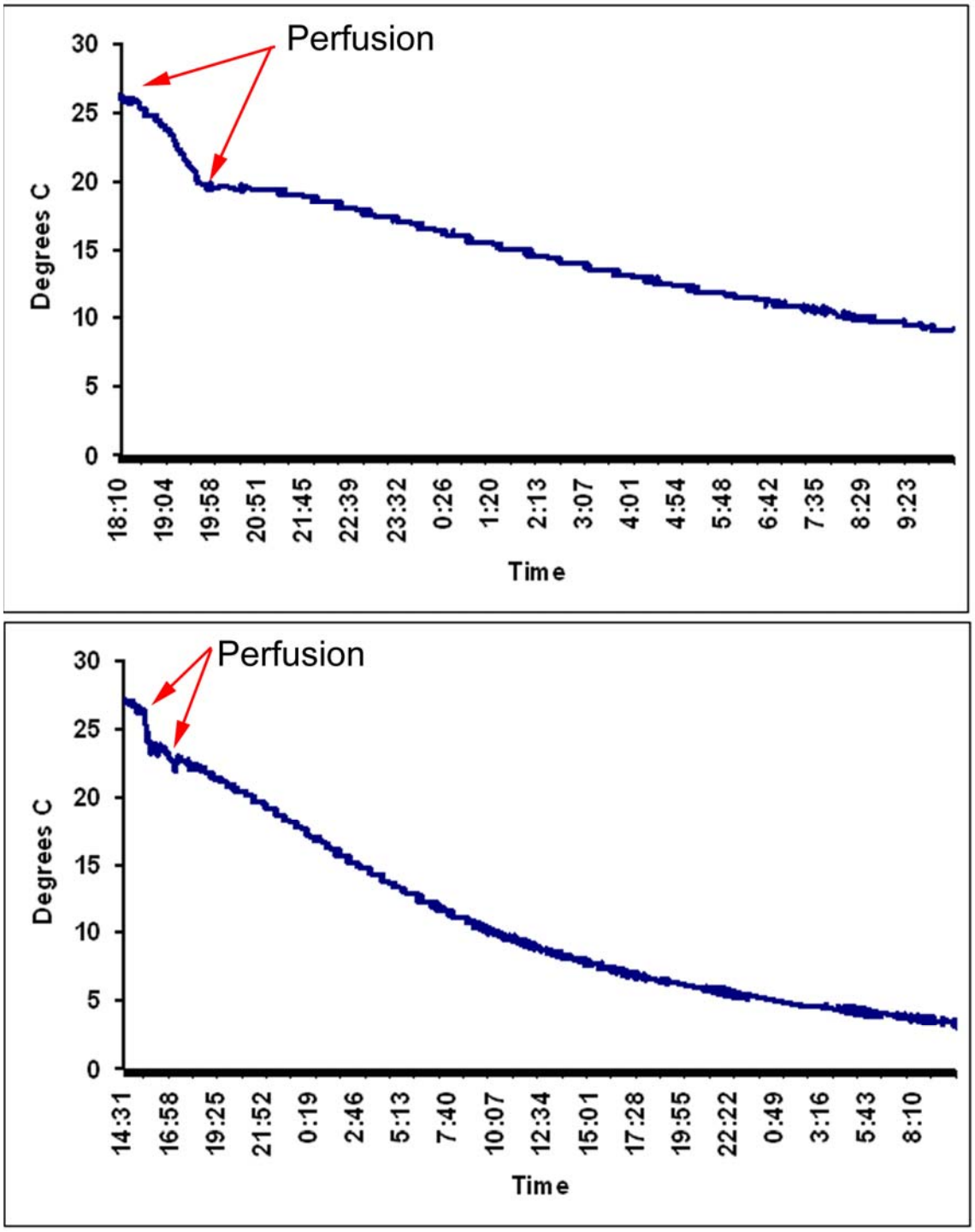

Figure 4. Two temperature profiles of bluefin tuna (top 117kg bottom 119kg) perfused with chilled saline solution for one hour. Marked differences in the rate of cooling are evident during perfusion.

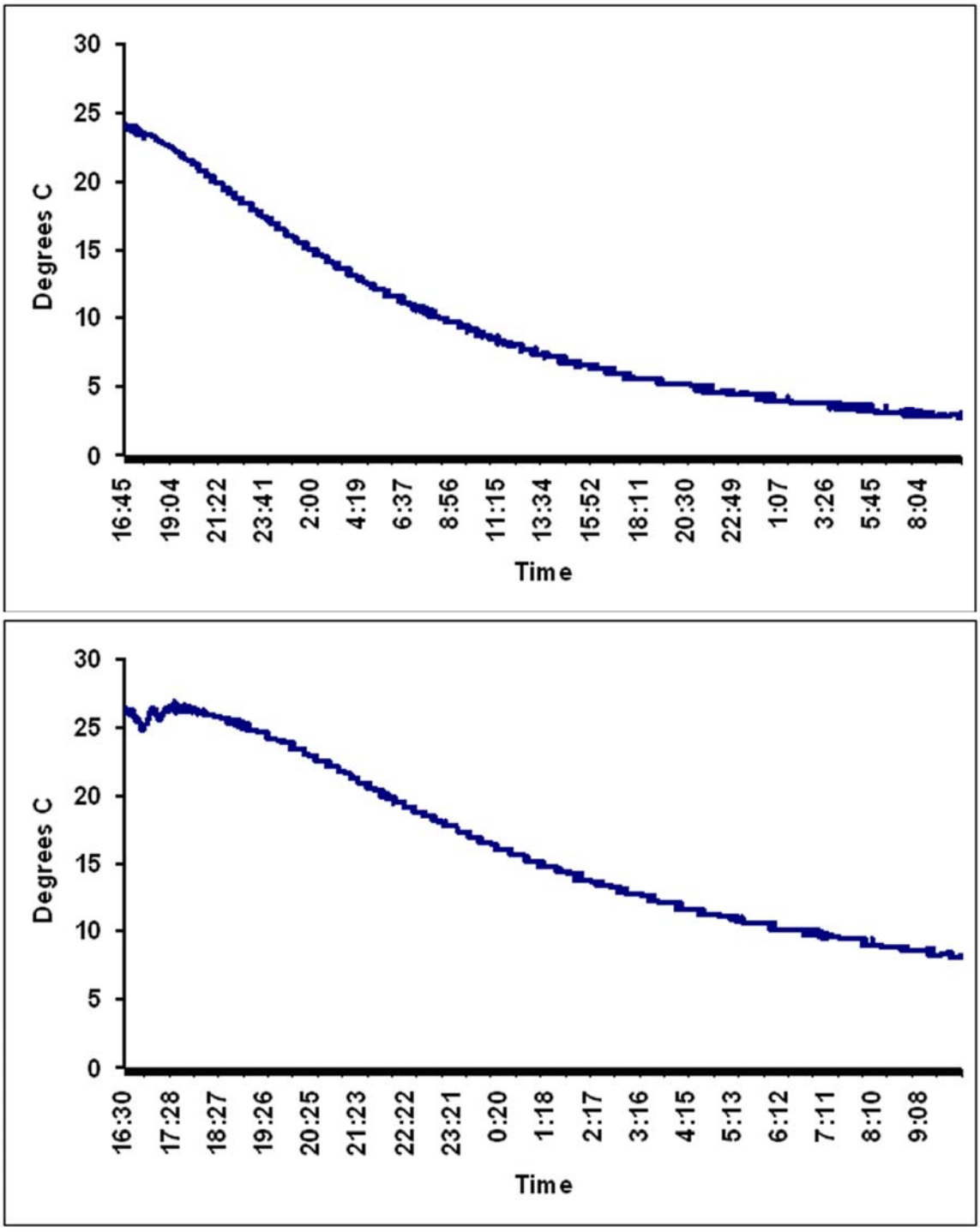

Figure 5. Temperature profiles from two bluefin tuna (top 82kg bottom 170kg) that were not perfused with chilled saline. At sea processing for these fish included gutting and immediately placing on ice.