Improving postharvest swordfish quality

Steve Slattery and Andrew Forrest

Queensland Government
Department of Primary Industries and Fisheries

Australian Government
Fisheries Research and Development Corporation

Project No. 2002/235

Improving postharvest swordfish quality

Steve Slattery and Andrew Forrest

October 2004

Innovative Food Technology

Queensland Department of Primary Industries and Fisheries

19 Hercules Street

HAMILTON

Brisbane Qld 4007

Ph: 07 3406 8623

Email: Steve.Slattery@dpi.qld.gov.au

The research work within this report was generously supported by the Fisheries Research and Development Corporation.

QO04011
ISSN 0727–6281
KEYWORDS: swordfish; quality measures; chilling; handling

Our business is about:

- innovative science and commercial uptake of new technology by food and fibre industries
- sustainable use of natural resources
- food safety and protection against imported pests and diseases
- market-driven and ethical food and fibre production.

OBJECTIVES:

1. Identify key factors responsible for loss of quality of broadbill by assessing current handling and storage procedures.
2. Design and trial modifications to current methods to eliminate problem areas.
3. To determine if rapid sensing NIR equipment and other technologies can be developed to screen for parasite infestation.
4. To provide information that will contribute to a bar coding system for tracking swordfish.
5. Produce best practice manual for industry.

Inquiries should be addressed to:
Steve Slattery, Senior Seafood Technologist,
Innovative Food Technology19 Hercules Street
Hamilton Q 4007
+61 7 3406 8623
Steve.Slattery@dpi.qld.gov.au

2002/235 Improving postharvest swordfish quality

PRINCIPAL INVESTIGATOR: Steve Slattery
ADDRESS: Innovative Food Technology
Emerging Technologies
19 Hercules Street
Hamilton Brisbane Qld 4007
Telephone: 07 3406 8623 Fax: 07 3406 8698

OBJECTIVES:

1. Identify key factors responsible for loss of quality of broadbill by assessing current handling and storage procedures.
2. Design and trial modifications to current methods to eliminate problem areas.
3. To determine if rapid sensing NIR equipment and other technologies can be developed to screen for parasite infestation.
4. To provide information that will contribute to a bar coding system for tracking swordfish.
5. Produce best practice manual for industry.

OUTCOMES ACHIEVED TO DATE

A variety of biological and handling conditions of swordfish capture, processing and storage conditions have been evaluated both on board vessels and in the factory prior to shipment. The information is now available for fishers that will assist them to improve the quality of the swordfish catch marketed.

The attachment of a tag to swordfish and recording whether it was alive when landed will assist grading and processing at the factory. The improvements to the initial chilling tanks recommended in this report will assist industry to improve swordfish quality for consumers.

NIR technology is not suitable for identifying parasitised swordfish. Other technology such as PCR and Elisa technology could detect infested swordfish in the time required when packing and may not be too expensive for industry use. The incidence of parasitised swordfish during this project was very low.

A number of industry workshops were conducted on both the east and west coasts with interested industry members. A manual in book form and a DVD have been developed so that training can be conducted on land and at sea.

KEYWORDS: swordfish; quality measures; chilling; handling

NON-TECHNICAL SUMMARY

While swordfish are considered a minor component of the longline catch they contribute up to 40% of the total revenue. There is a perception amongst fishers that swordfish is a robust product which can tolerate certain conditions that tuna cannot (Ward and Elscot, 2000). More recent research has found that the two are a lot more similar than originally thought. Some handling and storage practices for swordfish used by industry are similar to those applied to tuna even though the fish are quite different in size and shape. Improved handling practices will lead to higher quality which then should result in better returns. This project sought to identify what improvements could be achieved for swordfish quality.

During the project a total of 110 days were spent at sea on 7 sampling voyages. More than 8,000nautical miles were covered to collect 226 swordfish from more than 90,000 hooks set. Approximately 40% of the swordfish catch examined was landed alive. A number of improvements to handling practices were identified during this project that would have an impact on the quality of swordfish.

1. All swordfish should have the nerve tissue running along the spinal column cored in a similar way to that applied to tuna.

2. Small swordfish should not be stored under large swordfish when packing under ice, limit the number of layers stacked and do not stand on fish when stacking.

3. Do not leave swordfish on the wharf for more than 10 minutes without a covering of ice.

4. There is a major difference in quality between swordfish landed alive and dead which carries though to unloading at the factory. This situation will be similar for tuna. While it may be physically impossible for all swordfish to be landed alive, some thought should be given to the soak times, hook types and setting times prior to fishing so the proportion of fish landed alive can be increased.

5. To expedite the grading of fish at the factory swordfish landed alive should be marked in some way. This aspect alone is justification for tagging individual fish at the time of landing but it may also help crew with better returns if they can show they are consistently producing better quality fish.

6. There is no major difference in quality between swordfish landed pre and in rigor which has any impact on the grade or export prospects. This condition should not play a role in sorting and handling the catch.

7. There is not difference between the sexes that impact on quality.

8. Swordfish caught during the warmer seasons may be of lower quality and will have shorter shelf life. There may be a need to limit the load placed in cooling tanks during warmer conditions to increase the rate of cooling.

9. Holding swordfish at higher than sea temperature for more than a few minutes after landing will directly lead to a loss in quality. The elevation of temperature in the initial chilling media (above 5° for several hours) will also lead to lower quality.

10. Do not keep the initial chilling water for more than two days as bacteria can build up in the bloody water.

11. Refrigerated brine followed by seawater storage systems, when not operating ineffectively, can preserve quality aspects better than a static ice slurry. Problems will occur when cooling coils in the wet holding tanks ice over preventing further cooling of the surrounding water, when compressors are turned off for long periods, when the tanks are overloaded for the capacity of the system, when an ineffective circulation system is present or due to mechanical problems.

12. All vessels should use circulation pumps in their chilling tanks when fish are present. A problem with any holding tank is that a heat sink can develop. This happens because waters with different density do not mix well. In RSW tanks freshwater is removed from the brine as it freezes to the cooling coils resulting in brine of a higher salinity which then sinks as it becomes denser. The body temperature of freshly landed fish that are introduced will cause some initial melting of the ice around the coils that will then float on top of the denser brine. Melting ice in an ice slurry tank behaves in a similar way. Most holding tanks on vessels are deeper than they are wide which restricts mixing even further even during rough weather. The fish suspended vertically in the tank will also restrict water movement around the holding tank.

13. Large swordfish (>100kg) should be in the chilling tank for 48 hours to attain a core temperature near 0°C.

14. The quality of swordfish drops as storage time progresses. There will come a time when revenue will be lost if extended trips result in excessively long storage times.

15. The flesh at the edge of any damage or cuts has a significantly high bacterial load. The bacterial count is lower further away from the edge of the exposed flesh. To minimise the deterioration of swordfish flesh that consumers would encounter, a trim of the exposed flesh no less than 20mm is recommended.

16. The NIR measurements show that the penetration ability of the set-up is insufficient for assessment of whole fish trunks and that the light intensity cannot be increased without causing heat damage (parboiling) of the sample. This technology is not suitable for detecting parasitised swordfish.

17. Parasitised swordfish exhibiting textural loss have only been identified after they have left the processing factory. It is likely that the cold storage systems used by the vessels and the factories are effective in keeping the muscle tissue cold enough to limit any significant protease activity and thus prevent any textural changes that could be detected at the time of grading.

18. The type of technologies that could be used to identify parasitised swordfish may have to rely on testing samples of flesh containing the parasite, preferably taken from the site of maximum concentration (usually close to the vertebrae). PCR equipment can give the type of rapid results needed when packing an export shipment of swordfish but the price per test may be prohibitive for some fishers.

19. The tuna bayonet developed by this laboratory is suitable for obtaining such samples as no complaints have been recorded for fish sampled during this project.

20. The loss of quality of swordfish stored during long fishing trips is such that less than 50% can be exported after 12 days.

21. An industry training DVD has been developed presenting handling and processing methods for swordfish and tuna.

ACKNOWLEDGEMENTS

This project was actively supported by both the east coast and west coast longline fisheries, for which we are grateful. We would especially like to thank Michael Boschetti and Erica Starling and Darren Kolnn, skipper of the Discovery III, of Indian Ocean Fresh Australia, Geoff Diver of Tuna West, Stuart Parkes of Tohzai King P/L, the skipper of the 34 South Graham Wilkinson, the skipper of the Ocean Odyssey Bernie Manston, skipper of the Ocean Wanderer Michael Kenny, skipper of the Ocean Dawn Peter Grennel, Mike Madden of Tasmanian Blue Fin P/L and all the staff of De Brett Seafood, Mooloolaba.

1. BACKGROUND

Swordfish are a high value catch that represent an increasingly important source of revenue to many coastal nations in the Pacific and Indian oceans, e.g. Australia and La Reunion. By 1999 landings of swordfish from the AFZ had grown to 2513 t. It is thought that the good fresh-chilled storage qualities of swordfish can allow long fishing trips. US boats regularly return swordfish that have been stored chilled for 14 days. While the price of swordfish appears to be less sensitive to product quality, it has fluctuated globally due to adoption and easing of restrictions due to mercury content, boycotts initiated by environmental groups and oversupply of the US market. It is thought that a significant decline in the value of the US dollar could make several swordfish fisheries unprofitable (Ward and Elscot, 2000, BRS report).

"As swordfish is an incidental catch of longliners targeting tuna it is usually sold for lower prices. This relegates the handling of swordfish to a lower priority to that of tuna with consequently poorer quality sometimes being produced. There is a perception amongst fishers that swordfish is a robust product which can tolerate certain conditions that tuna cannot " (Ward and Elscot, 2000, BRS report). Some companies such as Southern Moves do target swordfish during periods when tuna catches are low. These fishers are more reliant on getting good prices for swordfish. Improved handling practices will lead to a consistently higher quality that should then result in better returns. On the Brisbane Grounds longliners target swordfish from small hotspots 20-30nm off the continental shelf along the East Australian Current. Catch rates for July-September are usually two or three times higher than in January-March, however there is no clear seasonal pattern for these grounds. The management area that encompasses these grounds has produced consistent catches between 1996 and 2000 (Malcolm, AFMA Logbook Program).

Swordfish catches are unlikely to improve in inshore waters. Australia's longliners will be forced to undertake longer trips to obtain the catch levels necessary to maintain economically feasible operations (Ward and Elscot, 2000, BRS report). This will result in longer storage times for product. The expansion of swordfish fisheries in the southwest Pacific will increase competition amongst longliners and increase pressure on these stocks.

While the majority is exported, the domestic sale of swordfish is increasing. The domestic production is mainly composed of second grade fish that were rejected for export. Just seven years ago swordfish was rarely seen in the Sydney Fish Market but now it ranks as the eighth most important species to Sydney's retail fishmongers (Ruello, 1998). Nearly 7,000kg was sold in Sydney alone in 1999, with the main forms sold as steaks and a new development, loins. All of this was sourced from Australian production. If seafood consumption trends are maintained this will grow further. Much of the growth has been attributed to the FRDC/CSIRO book "Seafood The Good Food" where swordfish was identified as one of the oiliest fish available in Australia.

There is very little information available in the literature about appropriate handling of swordfish. Most papers and articles that relate directly to swordfish describe the different types of onboard processing that occurs within and between different fleets but none make any direct comparisons, evaluations or recommendations of specific practices.

Two problems occur in maintaining quality:

1. Parasites infect most pelagic species of fish. Swordfish exhibit a condition described by industry as having a jelly like consistency. The jellied condition is a textural softening of the muscle tissue due to action by proteolytic enzymes released by both the parasites and the fish's own immune system. The incidence of this condition is about 5% of the catch from both east and west coasts. Previous research by the University of Queensland into these parasites (Kudoa musculoliquefaciens) has identified that the majority are present in the dorsal region close to the backbone yet when fish are packed for export processors they are usually sampled for grading purposes in the tail region (Undergraduate projects supervised by RJGL (PA305) Sullivan, P. 1998. "The location of Kudoa sp. in swordfish trunks" and Jones, C. 1999. "Identification of Kudoa from dolphin fish and swordfish using morphological and molecular techniques"). Most swordfish are shipped as trunks, consequently infested individuals are usually only detected by customers, after costly airfreight, when the fish is finally dressed into cutlets. A minimal or non-invasive method of parasite detection would reduce loses to the Australian industry. NIR equipment has proved effective in identifying changes that have occurred in food products. A NIR method has been developed by the QDPI for industry to identify the level of ripeness in rock melons in a non-destructive manner. NIR can differentiate between frozen and unfrozen beef (Thyholt and Isaksson, 1997). The changes that occur in muscle tissue due to proteolytic action of enzymes can be more extreme than those that occur due to freezing.

2. Many fishers and processors are concerned about the effect on quality when swordfish are retrieved dead from the longline. They require some form of indicator that may assist with the identification of these fish because they may deteriorate further during export shipment. It is known that the grading of some fish identified at the processing factory will change after processing. The tuna industry has markedly improved its returns by changing standards for grading. There is little tracking of individual fish from capture through to customer delivery so this aspect is currently impossible to predict. In consultation with the QDPI&F unit Innovative Food Technology a project has been initiated between Sastek and De Bretts Seafood Ltd which will improve tractability of fish leaving the factory but this needs to be extended to the fish directly after capture for all of industry.

2. NEED

Increased competition from other swordfish fisheries and a reduction in local catches will require Australia to produce the best quality possible. There are a number of factors which affect quality including life status, handling, storage conditions and parasites. A reduction in the amount of second grade fish currently being produced and shipped will help improve industry returns. Specific experiments need to be conducted at sea to identify the best handling and processing conditions that can be carried out onboard the capture vessels.

About 60-70% of swordfish caught by Japanese and Australian longliners in the AFZ are landed dead (Ward and Elscot, 2000, BRS report). The effect on flesh quality of landing dead swordfish needs to be known by processors. Using a wholesale price for swordfish of $15/kg and the cost of packing and shipment as an extra $4.50/kg, the loss to the industry of rejection of exported fish infested with Kudoa could be more than $2,000,000. Even at lower levels of infestation this is a significant amount of cost to processors and the savings should more than cover the cost of a piece of equipment that can identify the presence of parasites. We need to identify minimally or non-invasive methods of detecting parasites to improve

profitability by removing infested fish from shipments. The Principal Investigator has access to several types of equipment that show promise but their suitability needs to tested rigorously under a range of operating conditions such as on board a vessel or in factory, different levels of infestation and storage time of fish. This will result in an improvement in the reputation of Australian fish as a more reliable product, reduce wastage at either end of the chain and increase returns for the whole catch.

As traceability becomes a part of the seafood industry operations the use of identifications systems such as bar coded tags will be required. We need to evaluate traceability techniques for the longline industry. We need to research these issues as the information required to compile this manual is not available from the literature. We need to supply industry with an easy to access manual detailing best practice

3. OBJECTIVES

1 Identify key factors responsible for loss of quality of broadbill by assessing current handling and storage procedures.

2 Design and trial modifications to current methods to eliminate problem areas.

3 To determine if rapid sensing NIR equipment and other technologies can be developed to screen for parasite infestation.

4 To provide information that will contribute to a bar coding system for tracking swordfish.

5 Produce best practice manual for industry.

4. METHODS

The researchers intended to sample swordfish catches while on board vessels operating from ports in Queensland and Western Australia over a two-year period. The fieldwork recorded detailed information about individual swordfish and utilized a number of measuring techniques. The experiments were planned around four milestone deadlines.

4.1 Milestones

30/12/2002

A meeting with the WA Pelagic Longline Association (direct beneficiaries of the research) on the 6th May 2002 was held to establish the logistics of the first field trips on the west coast and the extension strategy. A similar meeting was convened on the east coast. As the fishery exists on both coasts it would be impossible to convene a proper steering committee composed of representatives from both geographic areas without a large increase in project costs. As the west coast associate meets regularly it will be used as a proxy steering committee while taking into account feedback from the east coast beneficiaries of the research. The draft milestone report was to be submitted at these venues. After feedback the milestone report was to be prepared and forwarded to FRDC and SSA.

The following methods were identified at the industry workshops on each coast as the basis for this evaluation. Landed fish will be tagged and have their biological information recorded (size, sex, whether alive upon landing, presence of damage, etc). The core temperature at landing was to be recorded. A muscle necropsy sample will be taken using the minimally invasive tuna bayonet sampler developed by the AFFS branch Food Technology. This will be analyzed for initial pH and colour (using a Minolta Chromometer and colour reference panels) and stored in liquid nitrogen for nucleotide and lactate analysis back at the laboratory. It is hoped that the current FRDC Project 99/358 will assist in reducing the

turnaround time for chemical indicators of freshness. The dressed carcass will be monitored for temperature using waterproof loggers during cooling and on board storage. The progression of rigor will be recorded during storage.

A tag system similar to that already being trialed in the factory will be trialed at sea. The factory tag consists of bar coded plastic tag with numbers while the vessel system used numbered sheep ear tags. They are composed of one piece of plastic with a 6mm pin that is inserted in the gill plate of tuna or the tail flesh of swordfish. As the swordfish are graded from tail cuts this may have an impact on the apparent grade of the fish and will be investigated. The hand held bar code reader is capable of recording parameters such as weight, temperature, visual damage, where and when caught, whether alive or dead when landed etc. The reports from these records can be downloaded to Excel or Access databases. Data will also be recorded in the factory such as weight after trimming and comments for grading.

A number of different storage methods that are currently being used by industry were to be evaluated (e.g. freshwater ice, seawater ice or refrigerated seawater). At the time of unloading swabs will be taken for total microbiological and psychrotroph count. Another sample will be removed for pH, colour, nucleotide, lactate analysis and the presence of parasites back at the laboratory. Fish of poor condition will also be tested for histamine.

Portions of fish identified with parasite infestations will be sent along with undamaged fish to the DPI&F laboratory in Rockhampton for testing by Near Infra Red Spectroscopy (NIR). This equipment is currently in use by the fruit industry for evaluating ripeness in a non-invasive manner. Instrumental measurements from the outer surface of a portion with the skin intact will be made of parasitised and non-parasitised issue. The data will be analyzed for significant differences. Other researchers in NIR technology (Dr Robert van Barneveld, Dr Richard Musgrove and Brenda Woods) have already been contacted during the preparation of this application. This link will continue with the SBT Aquaculture Subprogram and SARDI on the application of NIR technology to seafood during and after this project.

Through Sastek another non-invasive chemical lean detection unit can be accessed for testing. This equipment is currently in use by the beef industry for evaluating fat content. A third piece of equipment held by the DPI&F which would have been trialed if damaged fish were identified in sufficient numbers was a Pig Fat/Back Fat/Pregnancy Detector.

30/06/2003

Field collection in two states will again be conducted. Fish will be appraised for biological and physiological parameters. Samples will be taken for chemical testing. Parasitised individuals will be tested using the different technologies. The data collected from the two seasons will be analyzed. The draft milestone report will be submitted and after feedback the milestone report will be prepared and forwarded to FRDC and SSA.

30/12/2003

A further field collection will occur. The data obtained from testing will be statistically analyzed for significance differences between landed condition and treatment. The information and samples obtained from all previous collections will be used to develop strategies for best practice. The best method of processing and storage will be identified and then trialed at sea by an industry participant. The most effective equipment for detecting parasitisation will be identified. Possible improvements for equipment may be identified and initiated. The draft milestone report will be submitted and after feedback the milestone report will be prepared and forwarded to FRDC and SSA.

Table of Contents

2002/235 Improving postharvest swordfish quality

PRINCIPAL INVESTIGATOR: Steve Slattery
ADDRESS: Innovative Food Technology
Emerging Technologies
19 Hercules Street
Hamilton Brisbane Qld 4007
Telephone: 07 3406 8623 Fax: 07 3406 8698

OBJECTIVES:

1. Identify key factors responsible for loss of quality of broadbill by assessing current handling and storage procedures.
2. Design and trial modifications to current methods to eliminate problem areas.
3. To determine if rapid sensing NIR equipment and other technologies can be developed to screen for parasite infestation.
4. To provide information that will contribute to a bar coding system for tracking swordfish.
5. Produce best practice manual for industry.

OUTCOMES ACHIEVED TO DATE

A variety of biological and handling conditions of swordfish capture, processing and storage conditions have been evaluated both on board vessels and in the factory prior to shipment. The information is now available for fishers that will assist them to improve the quality of the swordfish catch marketed.

The attachment of a tag to swordfish and recording whether it was alive when landed will assist grading and processing at the factory. The improvements to the initial chilling tanks recommended in this report will assist industry to improve swordfish quality for consumers.

NIR technology is not suitable for identifying parasitised swordfish. Other technology such as PCR and Elisa technology could detect infested swordfish in the time required when packing and may not be too expensive for industry use. The incidence of parasitised swordfish during this project was very low.

A number of industry workshops were conducted on both the east and west coasts with interested industry members. A manual in book form and a DVD have been developed

KEYWORDS: swordfish; quality measures; chilling; handling

NON-TECHNICAL SUMMARY

While swordfish are considered a minor component of the longline catch they contribute up to 40% of the total revenue. There is a perception amongst fishers that swordfish is a robust product which can tolerate certain conditions that tuna cannot (Ward and Elscot, 2000). More recent research has found that the two are a lot more similar than originally thought. Some handling and storage practices for swordfish used by industry are similar to those applied to tuna even though the fish are quite different in size and shape. Improved handling practices will lead to higher quality which then should result in better returns. This project sought to identify what improvements could be achieved for swordfish quality.

During the project a total of 110 days were spent at sea on 7 sampling voyages. More than 8,000nautical miles were covered to collect 226 swordfish from more than 90,000 hooks set. Approximately 40% of the swordfish catch examined was landed alive. A number of improvements to handling practices were identified during this project that would have an impact on the quality of swordfish.

1. All swordfish should have the nerve tissue running along the spinal column cored in a similar way to that applied to tuna.

2. Small swordfish should not be stored under large swordfish when packing under ice, limit the number of layers stacked and do not stand on fish when stacking.

3. Do not leave swordfish on the wharf for more than 10 minutes without a covering of ice.

4. There is a major difference in quality between swordfish landed alive and dead which carries though to unloading at the factory. This situation will be similar for tuna. While it may be physically impossible for all swordfish to be landed alive, some thought should be given to the soak times, hook types and setting times prior to fishing so the proportion of fish landed alive can be increased.

5. To expedite the grading of fish at the factory swordfish landed alive should be marked in some way. This aspect alone is justification for tagging individual fish at the time of landing but it may also help crew with better returns if they can show they are consistently producing better quality fish.

6. There is no major difference in quality between swordfish landed pre and in rigor which has any impact on the grade or export prospects. This condition should not play a role in sorting and handling the catch.

7. There is not difference between the sexes that impact on quality.

8. Swordfish caught during the warmer seasons may be of lower quality and will have shorter shelf life. There may be a need to limit the load placed in cooling tanks during warmer conditions to increase the rate of cooling.

9. Holding swordfish at higher than sea temperature for more than a few minutes after landing will directly lead to a loss in quality. The elevation of temperature in the initial chilling media (above 5° for several hours) will also lead to lower quality.

10. Do not keep the initial chilling water for more than two days as bacteria can build up in the bloody water.

11. Refrigerated brine followed by seawater storage systems, when not operating ineffectively, can preserve quality aspects better than a static ice slurry. Problems will occur when cooling coils in the wet holding tanks ice over preventing further cooling of the surrounding water, when compressors are turned off for long periods, when the tanks are overloaded for the capacity of the system, when an ineffective circulation system is present or due to mechanical problems.

12. All vessels should use circulation pumps in their chilling tanks when fish are present. A problem with any holding tank is that a heat sink can develop. This happens because waters with different density do not mix well. In RSW tanks freshwater is removed from the brine as it freezes to the cooling coils resulting in brine of a higher salinity which then sinks as it becomes denser. The body temperature of freshly landed fish that are introduced will cause some initial melting of the ice around the coils that will then float on top of the denser brine. Melting ice in an ice slurry tank behaves in a similar way. Most holding tanks on vessels are deeper than they are wide which restricts mixing even further even during rough weather. The fish suspended vertically in the tank will also restrict water movement around the holding tank.

13. Large swordfish (>100kg) should be in the chilling tank for 48 hours to attain a core temperature near 0°C.

14. The quality of swordfish drops as storage time progresses. There will come a time when revenue will be lost if extended trips result in excessively long storage times.

15. The flesh at the edge of any damage or cuts has a significantly high bacterial load. The bacterial count is lower further away from the edge of the exposed flesh. To minimise the deterioration of swordfish flesh that consumers would encounter, a trim of the exposed flesh no less than 20mm is recommended.

16. The NIR measurements show that the penetration ability of the set-up is insufficient for assessment of whole fish trunks and that the light intensity cannot be increased without causing heat damage (parboiling) of the sample. This technology is not suitable for detecting parasitised swordfish.

17. Parasitised swordfish exhibiting textural loss have only been identified after they have left the processing factory. It is likely that the cold storage systems used by the vessels and the factories are effective in keeping the muscle tissue cold enough to limit any significant protease activity and thus prevent any textural changes that could be detected at the time of grading.

18. The type of technologies that could be used to identify parasitised swordfish may have to rely on testing samples of flesh containing the parasite, preferably taken from the site of maximum concentration (usually close to the vertebrae). PCR equipment can give the type of rapid results needed when packing an export shipment of swordfish but the price per test may be prohibitive for some fishers.

19. The tuna bayonet developed by this laboratory is suitable for obtaining such samples as no complaints have been recorded for fish sampled during this project.

ACKNOWLEDGEMENTS

This project was actively supported by both the east coast and west coast longline fisheries, for which we are grateful. We would especially like to thank Michael Boschetti and Erica Starling and Darren Kolnn, skipper of the Discovery III, of Indian Ocean Fresh Australia, Geoff Diver of Tuna West, Stuart Parkes of Tohzai King P/L, the skipper of the 34 South Graham Wilkinson, the skipper of the Ocean Odyssey Bernie Manston, skipper of the Ocean Wanderer Michael Kenny, skipper of the Ocean Dawn Peter Grennel, Mike Madden of Tasmanian Blue Fin P/L and all the staff of De Brett Seafood, Mooloolaba.

1. BACKGROUND

Swordfish are a high value catch that represent an increasingly important source of revenue to many coastal nations in the Pacific and Indian oceans, e.g. Australia and La Reunion. By 1999 landings of swordfish from the AFZ had grown to 2513 t. It is thought that the good fresh-chilled storage qualities of swordfish can allow long fishing trips. US boats regularly return swordfish that have been stored chilled for 14 days. While the price of swordfish appears to be less sensitive to product quality, it has fluctuated globally due to adoption and easing of restrictions due to mercury content, boycotts initiated by environmental groups and oversupply of the US market. It is thought that a significant decline in the value of the US dollar could make several swordfish fisheries unprofitable (Ward and Elscot, 2000, BRS report).

"As swordfish is an incidental catch of longliners targeting tuna it is usually sold for lower prices. This relegates the handling of swordfish to a lower priority to that of tuna with consequently poorer quality sometimes being produced. There is a perception amongst fishers that swordfish is a robust product which can tolerate certain conditions that tuna cannot " (Ward and Elscot, 2000, BRS report). Some companies such as Southern Moves do target swordfish during periods when tuna catches are low. These fishers are more reliant on getting good prices for swordfish. Improved handling practices will lead to a consistently higher quality that should then result in better returns. On the Brisbane Grounds longliners target swordfish from small hotspots 20-30nm off the continental shelf along the East Australian Current. Catch rates for July-September are usually two or three times higher than in January-March, however there is no clear seasonal pattern for these grounds. The management area that encompasses these grounds has produced consistent catches between 1996 and 2000 (Malcolm, AFMA Logbook Program).

Swordfish catches are unlikely to improve in inshore waters. Australia's longliners will be forced to undertake longer trips to obtain the catch levels necessary to maintain economically feasible operations (Ward and Elscot, 2000, BRS report). This will result in longer storage times for product. The expansion of swordfish fisheries in the southwest Pacific will increase competition amongst longliners and increase pressure on these stocks.

While the majority is exported, the domestic sale of swordfish is increasing. The domestic production is mainly composed of second grade fish that were rejected for export. Just seven years ago swordfish was rarely seen in the Sydney Fish Market but now it ranks as the eighth most important species to Sydney's retail fishmongers (Ruello, 1998). Nearly 7,000kg was sold in Sydney alone in 1999, with the main forms sold as steaks and a new development, loins. All of this was sourced from Australian production. If seafood consumption trends are maintained this will grow further. Much of the growth has been attributed to the FRDC/CSIRO book "Seafood The Good Food" where swordfish was identified as one of the oiliest fish available in Australia.

There is very little information available in the literature about appropriate handling of swordfish. Most papers and articles that relate directly to swordfish describe the different types of onboard processing that occurs within and between different fleets but none make any direct comparisons, evaluations or recommendations of specific practices.

Two problems occur in maintaining quality:

1. Parasites infect most pelagic species of fish. Swordfish exhibit a condition described by industry as having a jelly like consistency. The jellied condition is a textural softening of the muscle tissue due to action by proteolytic enzymes released by both the parasites and the fish's own immune system. The incidence of this condition is about 5% of the catch from both east and west coasts. Previous research by the University of Queensland into these parasites (Kudoa musculoliquefaciens) has identified that the majority are present in the dorsal region close to the backbone yet when fish are packed for export processors they are usually sampled for grading purposes in the tail region (Undergraduate projects supervised by RJGL (PA305) Sullivan, P. 1998. "The location of Kudoa sp. in swordfish trunks" and Jones, C. 1999. "Identification of Kudoa from dolphin fish and swordfish using morphological and molecular techniques"). Most swordfish are shipped as trunks, consequently infested individuals are usually only detected by customers, after costly airfreight, when the fish is finally dressed into cutlets. A minimal or non-invasive method of parasite detection would reduce loses to the Australian industry. NIR equipment has proved effective in identifying changes that have occurred in food products. A NIR method has been developed by the QDPI for industry to identify the level of ripeness in rock melons in a non-destructive manner. NIR can differentiate between frozen and unfrozen beef (Thyholt and Isaksson, 1997). The changes that occur in muscle tissue due to proteolytic action of enzymes can be more extreme than those that occur due to freezing.

2. Many fishers and processors are concerned about the effect on quality when swordfish are retrieved dead from the longline. They require some form of indicator that may assist with the identification of these fish because they may deteriorate further during export shipment. It is known that the grading of some fish identified at the processing factory will change after processing. The tuna industry has markedly improved its returns by changing standards for grading. There is little tracking of individual fish from capture through to customer delivery so this aspect is currently impossible to predict. In consultation with the QDPI&F unit Innovative Food Technology a project has been initiated between Sastek and De Bretts Seafood Ltd which will improve tractability of fish leaving the factory but this needs to be extended to the fish directly after capture for all of industry.

2. NEED

Increased competition from other swordfish fisheries and a reduction in local catches will require Australia to produce the best quality possible. There are a number of factors which affect quality including life status, handling, storage conditions and parasites. A reduction in the amount of second grade fish currently being produced and shipped will help improve industry returns. Specific experiments need to be conducted at sea to identify the best handling and processing conditions that can be carried out onboard the capture vessels.

About 60-70% of swordfish caught by Japanese and Australian longliners in the AFZ are landed dead (Ward and Elscot, 2000, BRS report). The effect on flesh quality of landing dead swordfish needs to be known by processors. Using a wholesale price for swordfish of $15/kg and the cost of packing and shipment as an extra $4.50/kg, the loss to the industry of rejection of exported fish infested with Kudoa could be more than $2,000,000. Even at lower levels of infestation this is a significant amount of cost to processors and the savings should more than cover the cost of a piece of equipment that can identify the presence of parasites. We need to identify minimally or non-invasive methods of detecting parasites to improve

profitability by removing infested fish from shipments. The Principal Investigator has access to several types of equipment that show promise but their suitability needs to tested rigorously under a range of operating conditions such as on board a vessel or in factory, different levels of infestation and storage time of fish. This will result in an improvement in the reputation of Australian fish as a more reliable product, reduce wastage at either end of the chain and increase returns for the whole catch.

As traceability becomes a part of the seafood industry operations the use of identifications systems such as bar coded tags will be required. We need to evaluate traceability techniques for the longline industry. We need to research these issues as the information required to compile this manual is not available from the literature. We need to supply industry with an easy to access manual detailing best practice

3. OBJECTIVES

1 Identify key factors responsible for loss of quality of broadbill by assessing current handling and storage procedures.

2 Design and trial modifications to current methods to eliminate problem areas.

3 To determine if rapid sensing NIR equipment and other technologies can be developed to screen for parasite infestation.

4 To provide information that will contribute to a bar coding system for tracking swordfish.

5 Produce best practice manual for industry.

4. METHODS

The researchers intended to sample swordfish catches while on board vessels operating from ports in Queensland and Western Australia over a two-year period. The fieldwork recorded detailed information about individual swordfish and utilized a number of measuring techniques. The experiments were planned around four milestone deadlines.

4.1 Milestones

30/12/2002

A meeting with the WA Pelagic Longline Association (direct beneficiaries of the research) on the 6th May 2002 was held to establish the logistics of the first field trips on the west coast and the extension strategy. A similar meeting was convened on the east coast. As the fishery exists on both coasts it would be impossible to convene a proper steering committee composed of representatives from both geographic areas without a large increase in project costs. As the west coast associate meets regularly it will be used as a proxy steering committee while taking into account feedback from the east coast beneficiaries of the research. The draft milestone report was to be submitted at these venues. After feedback the milestone report was to be prepared and forwarded to FRDC and SSA.

The following methods were identified at the industry workshops on each coast as the basis for this evaluation. Landed fish will be tagged and have their biological information recorded (size, sex, whether alive upon landing, presence of damage, etc). The core temperature at landing was to be recorded. A muscle necropsy sample will be taken using the minimally invasive tuna bayonet sampler developed by the AFFS branch Food Technology. This will be analyzed for initial pH and colour (using a Minolta Chromometer and colour reference panels) and stored in liquid nitrogen for nucleotide and lactate analysis back at the laboratory. It is hoped that the current FRDC Project 99/358 will assist in reducing the

turnaround time for chemical indicators of freshness. The dressed carcass will be monitored for temperature using waterproof loggers during cooling and on board storage. The progression of rigor will be recorded during storage.

A tag system similar to that already being trialed in the factory will be trialed at sea. The factory tag consists of bar coded plastic tag with numbers while the vessel system used numbered sheep ear tags. They are composed of one piece of plastic with a 6mm pin that is inserted in the gill plate of tuna or the tail flesh of swordfish. As the swordfish are graded from tail cuts this may have an impact on the apparent grade of the fish and will be investigated. The hand held bar code reader is capable of recording parameters such as weight, temperature, visual damage, where and when caught, whether alive or dead when landed etc. The reports from these records can be downloaded to Excel or Access databases. Data will also be recorded in the factory such as weight after trimming and comments for grading.

A number of different storage methods that are currently being used by industry were to be evaluated (e.g. freshwater ice, seawater ice or refrigerated seawater). At the time of unloading swabs will be taken for total microbiological and psychrotroph count. Another sample will be removed for pH, colour, nucleotide, lactate analysis and the presence of parasites back at the laboratory. Fish of poor condition will also be tested for histamine.

Portions of fish identified with parasite infestations will be sent along with undamaged fish to the DPI&F laboratory in Rockhampton for testing by Near Infra Red Spectroscopy (NIR). This equipment is currently in use by the fruit industry for evaluating ripeness in a non-invasive manner. Instrumental measurements from the outer surface of a portion with the skin intact will be made of parasitised and non-parasitised issue. The data will be analyzed for significant differences. Other researchers in NIR technology (Dr Robert van Barneveld, Dr Richard Musgrove and Brenda Woods) have already been contacted during the preparation of this application. This link will continue with the SBT Aquaculture Subprogram and SARDI on the application of NIR technology to seafood during and after this project.

Through Sastek another non-invasive chemical lean detection unit can be accessed for testing. This equipment is currently in use by the beef industry for evaluating fat content. A third piece of equipment held by the DPI&F which would have been trialed if damaged fish were identified in sufficient numbers was a Pig Fat/Back Fat/Pregnancy Detector.

30/06/2003

Field collection in two states will again be conducted. Fish will be appraised for biological and physiological parameters. Samples will be taken for chemical testing. Parasitised individuals will be tested using the different technologies. The data collected from the two seasons will be analyzed. The draft milestone report will be submitted and after feedback the milestone report will be prepared and forwarded to FRDC and SSA.

30/12/2003

A further field collection will occur. The data obtained from testing will be statistically analyzed for significance differences between landed condition and treatment. The information and samples obtained from all previous collections will be used to develop strategies for best practice. The best method of processing and storage will be identified and then trialed at sea by an industry participant. The most effective equipment for detecting parasitisation will be identified. Possible improvements for equipment may be identified and initiated. The draft milestone report will be submitted and after feedback the milestone report will be prepared and forwarded to FRDC and SSA.

30/06/2004

The impacts of the improvements on the product will then be evaluated during a fourth season. Ways of predicting downstream quality due to landing characteristics e.g. live/dead may be identified when the data has been fully analyzed. The specific recommendations for swordfish handling were to be extended to industry via a best practice manual that can be delivered at workshops in three states. If a technology is successful in identifying parasitised individuals then the manufacturer of the effective equipment will be encouraged to produce models suitable for the seafood industry.

4.2 Physical methods

At the start of each fishing day the date, geographic location and surface sea temperature were recorded. When each swordfish was landed and killed a number of biological and physical aspects were documented. These included:

- the time of capture
- whether the swordfish was alive or dead
- if dead what the rigor condition was
- the orbital fork length (distance from the rear of the eye socket to the fork of the tail)
- the girth (circumference at the widest part of the trunk)
- presence of damage such as cookie cutter shark bites and whether fresh or old
- number of bites
- number of fresh wounds that were not bites
- whether they were deep or shallow
- possible sex

A deckhand using the vessels normal technique processed the swordfish into trunks. A number of tests were then undertaken prior to the insertion of the trunk in the chilling media. When unloaded at the factory these measurements of the swordfish trunk were then repeated.

4.2.1 Internal Temperature

A select few swordfish from each trip had their internal temperatures monitored during chilling and storage. Temperature probes approximately 10cm long were inserted into the trunk core adjacent to the backbone above the anus up into the muscle tissue. The probe was pushed up all the way so that only the electrical lead protruded. The probes were connected to small data loggers that recorded the temperature of the probe every 10-15 minutes. These temperatures were then plotted against time. A similar probe attached to a hand held TPS pH unit (Model No. WP 80) was used to measure the anterior and tail temperature of the swordfish trunk. Figures 32 to 45 in the Appendices show these records.

4.2.2 pH measurement

The pH was measured using a stab electrode connected to a hand held TPS pH unit (Model No. WP 80). This was standardised several times daily before use.

4.2.3 Bayonet sampler

The meat from the shoulder was then removed from the swordfish as soon as possible after landing on the vessel. It was also taken after unloading at the factory using a bayonet sampler designed at this laboratory for tuna. The sampler is a flat blade 25mm wide that was inserted at the site where the dorsal fin emerged from the swordfish trunk, going inwards along the bone that protrudes vertically from the vertebrae (neural spines). The blade was pushed almost the whole of the 300mm length with only some of the blade showing below the handle. A covering cutting sheath was then slipped over the blade at the base of the handle down to the bottom of the blade, while being levered into the flesh by the handle. The process is displayed in four pictures in Figure 1.

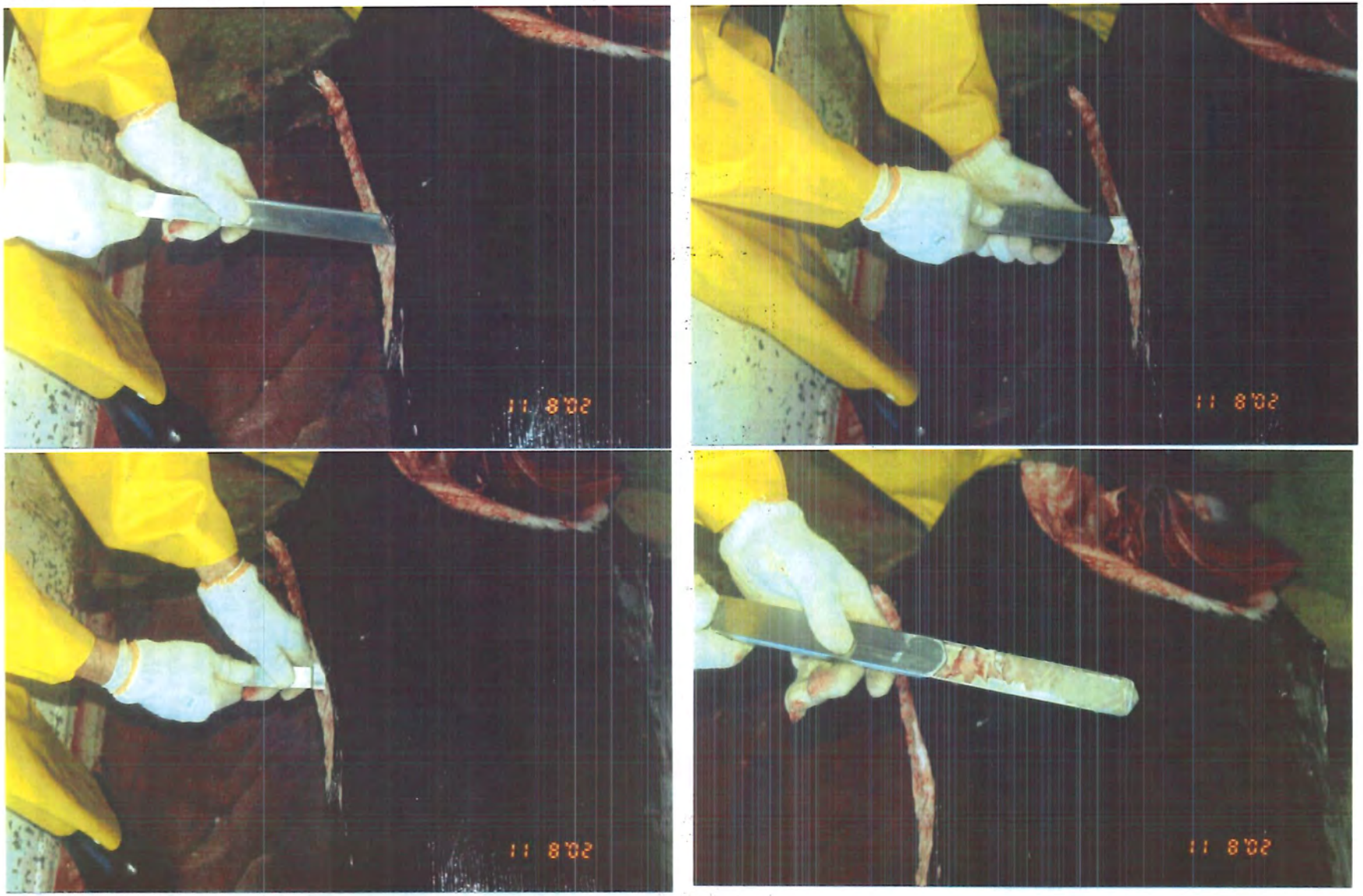


Figure 1. Photographs of taking swordfish flesh samples using the tuna bayonet tool.

Throughout the project there were no comments received from either factory staff or customers about swordfish that had been sampled by this device. The meat sample was then used for the following measurements.

4.2.4 Colour Measurement

A Minolta Chroma Meter (Model CR-300) was used to measure the colour of swordfish flesh. Our goal was to use colour science to assess and communicate information about the appearance of swordfish flesh. To do so, we needed to gain a clear understanding of the three dimensions that contribute to colour. Figures 2 and 3 below show these.

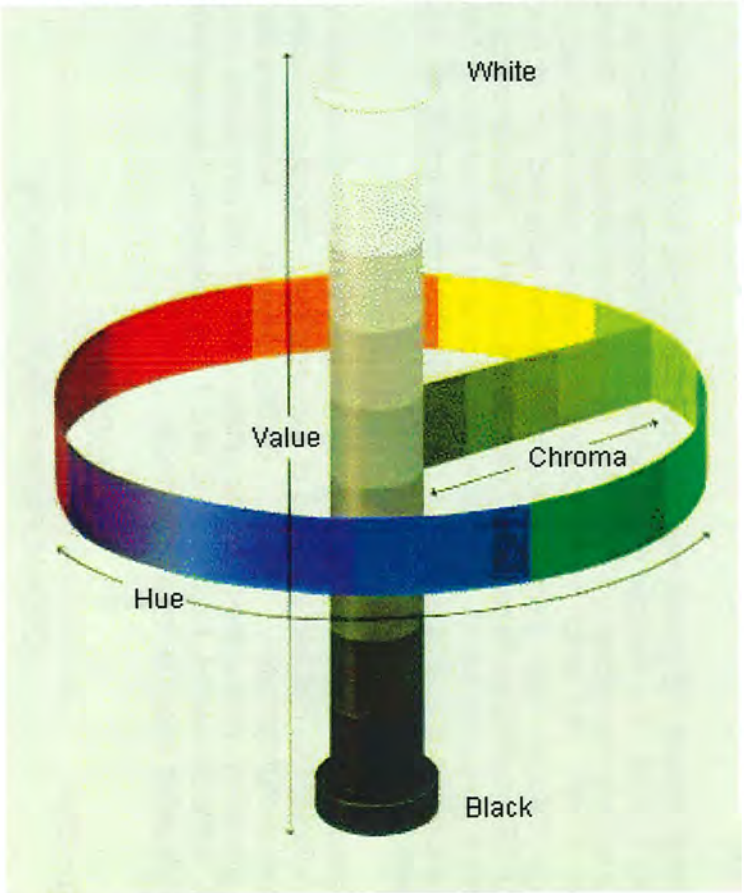
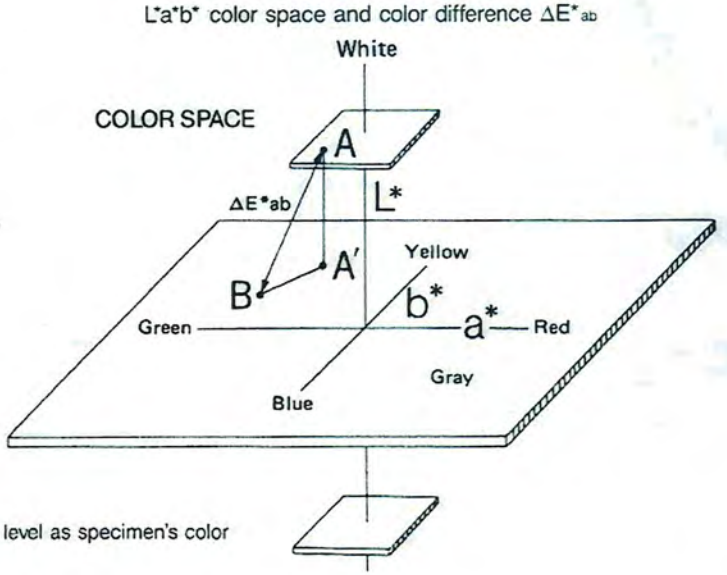


Figure 2. Model of colour characteristics.

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$



A: Target color
B: Specimen's color
A': Target color at the same lightness level as specimen's color

Figure 3. Chromaticity coordinates diagram.

Every colour has three basic characteristics; hue, saturation (chroma), and value (lightness). A black and white photograph contains value, but no hue or chroma. The parameter is also known as the **lightness** measurement (**L* value** in Figure 3). A 3 dimensional model (Figure 2) can illustrate these characteristics. Circular movement around each disk varies the hue. Upwards movement from one disk to another increases the lightness. Other important attributes of an object also affect what the eye sees. They are sometimes termed modes of appearance, and include translucency, transparency, and surface gloss. The ability to define colours accurately is essential to successful colour reproduction and assessment. A committee known as the CIE ("Commission Internationale de l'Eclairage") in 1931 established numerical values that quantify the responses of the average human eye to different wavelengths of light.

Most colour science uses the CIE L*a*b* system. Under this system, colours are judged as to relative redness or greenness (opposites) and yellowness or blueness. The vertical dimension is termed "lightness" (the "L" in L*a*b*). a* and b* are represented in + and - values, with a* representing relative redness (+) or greenness (-) and b* representing relative yellowness (+) or blueness (-).

4.3 Chemical Methods

After testing the muscle sample on the vessel and at the factory it was covered in aluminium foil and frozen in liquid nitrogen. The samples remained frozen at this low temperature until returned to the laboratory. Back at the laboratory the frozen samples were processed and tested for K value and lactate content.

4.3.1 K value

The K-value is used as an index of freshness (Izquierdo-Pulido & others, 1992) and is derived from the nucleotide degradation profile. A low K value is indicative of very fresh, prime quality product, e.g., "sashimi quality" used in Japan has a K value<20% (Haard, 1992). Swordfish is fortunate in that the rate of nucleotide breakdown and hypoxanthine accumulation operates at a very slow rate (Dyer and Hiltz, 1969) and this may explain why it has such a long shelf life.

Swordfish muscle (10 g) was homogenised with 50 mL 0.6 N perchloric acid for 1 minute in a Waring blender. The blended material was filtered through Whatman No. 1 paper and the acid filtrate quickly neutralised to pH 6.8 with 2 N potassium hydroxide. This extract was stored on ice for 30 min, after which the precipitated potassium perchlorate was removed by filtration through 0.45 µm filter discs. Separations were achieved on a Nova-PAK C_{18} column (150 x 3.9 mm, Waters Associates, Millipore Corporation, Massachusetts, USA) in series with a reverse phase µ-Bondapak C_{18} stainless steel column (300 x 3.9 mm, Waters Associates) with a mobile phase of 0.06 M K_2HPO_4 + 0.04 M KH_2PO_4 containing 50 mL methanol per litre. The flow rate was 2 ml/min.

The absorbance detector was set at 254 nm and the response for each of the six nucleotides was calibrated by injecting a cocktail of each reference compound containing 1.068 µmoles/mL Adenosine-triphosphate (ATP), 0.894 µmoles/mL Adenosine-diphosphate (ADP), 0.99 µmoles/mL Adenosine-monophosphate (AMP), 1.045 µmoles/mL Inosine-monophosphate (IMP), 0.939 µmoles/mL Inosine (HxR) and 1.102 µmoles/mL Hypoxanthine (Hx). The K-value was calculated using the following formula:

$$\text{K-value (\%)} = \frac{[HxR] + [Hx]}{[ATP]+[ADP]+[AMP]+[IMP]+[HxR]+[Hx]} \times 100$$

4.3.2 Lactate

Lactate is the principal end product of carbohydrate metabolism in fish and mammalian muscle via the classic glycolytic pathway (Hiltz and Dyer, 1971). As the supply of oxygen to the muscle becomes depleted after harvest, glucose is supplied to the muscle by phosphorolysis and/or hydrolysis of glycogen and is converted to lactate by this pathway (Haard, 1992). The pH decline in muscle is associated with lactate accumulation from glycolysis and caused by ATP hydrolysis. Lactate is routinely used as an indicator of freshness and quality. In this instance it can also help identify individual swordfish that have put up lengthy struggles while being landed.

For lactate analysis an aliquot of the extract prepared for nucleotide analysis was applied to an Aminex HPX-87H stainless steel column (300 x 7.8 mm, Bio-Rad Laboratories, North Ryde, NSW) that was heated to 40°C. A 0.01 N H_2SO_4 mobile phase was applied with a flow rate of 0.6 mL/min. The absorbance detector was set at 210 nm and the response for a lactate standard was calibrated by injecting a sample containing 81.8 µmoles/mL.

4.3.3 Histamine evaluation

The histamine content was determined for a representative batch of swordfish using the Alert Histamine Screening Test kit available from Neogen. Only fish landed dead were tested, as there was little chance of live landed fish developing histamine under the normal operating conditions. 100g of fish flesh was homogenised in a Waring blender. 10g of this homogenate was blended with 190g of distilled water, shaken several times over 5 minutes, left to settle and then filtered. 0.1mL of this extract was then used for the kit procedure.

4.3.4 Microbiological methods

First the skin was removed revealing the flesh adjacent to the damaged site. Fish cut for the domestic market may have the skin be trimmed off or left on depending on the purchaser. The samples were taken directly from the edge of the damage at a width of 10mm and to a depth of approximately 20mm to provide a minimum 10g of sample. The next cut was a 10mm wide piece directly next to this cut of the same width and depth and then a third piece of similar proportions starting 20mm further away from the original edge of the damaged site.

A 10g swordfish sample was diluted in 90mL of Peptone water and homogenised in a stomacher bag. Aliquots were then plated out using a variety of methods. **Standard Plate Count** (**SPC**) was carried out by the surface spread method (Australian Standard, 1991) using nutrient agar. The plates were incubated at 30°C to enumerate **Mesophiles** and at 4°C to enumerate **Psychrotrophs.**

The counts are expressed in colony forming units per gram of sample (cfu/g). Log counts are used because of the rapid growth rates of bacteria. Counts around 10^6 or 10^7 are considered to high for safe human consumption.

4.4 Industry grading and export scoring

At the factory swordfish grades rated by experienced staff were recorded. The trimmed weights were then recorded from the boxed export packs. While industry on both the east and west coasts use tail cuts to give a quality score, the actual units and range for the different extremes in quality are not identical. This divergence in rating systems reflects the different markets each supply. The majority of the catch exported from the East coast goes to the United States while that exported from the West coast goes to Japan and Singapore, and these markets have different indicators for quality. The different target markets are

largely due to the geographic location of the packing factories and shipping agents. There are significant delays a shipment would encounter if sent from the West coast across to the East coast and then on to the US.

As the majority of trips were conducted from the East coast, the grade data in this report only applies to swordfish unloaded at the factory at Mooloolaba. There was considerable effort expended to keep the sampling trips evenly representative but of the three excursions conducted to the west coast unfortunately only one produced a catch that could be used in this analysis.

The rigor of the grading also changes depending on the market climate at the time. Initially graders informed the researchers that a swordfish gaining a score of 7- or higher would be exported. Later it was discovered that when there was a flood of swordfish at a particular market, even fish with this score were retained for the domestic market because the lower price being received did not cover much more than the shipment costs. Because of this, the different treatments analysed by this project may have little direct affect on the grade that a swordfish receives. As exports are compiled from the best of the catch the score for this parameter should be viewed as a better expression of quality for the treatments analysed.

Examples of tail cuts can be seen following in Figure 4. The high scoring tail cuts in the upper photographs have clearly defined transition from the red muscle tissue to the white muscle while the lower photographs show low scoring tail cuts with leakage of red pigment. The East coast factories rate both the red muscle bundles (called the bloodline by industry) and the degree of leaking of myoglobin into the surrounding white muscle tissue (called tightness by industry). The West coast factories tend to rate not only the red muscle tissue but also try to provide an estimation of the level of fat present.

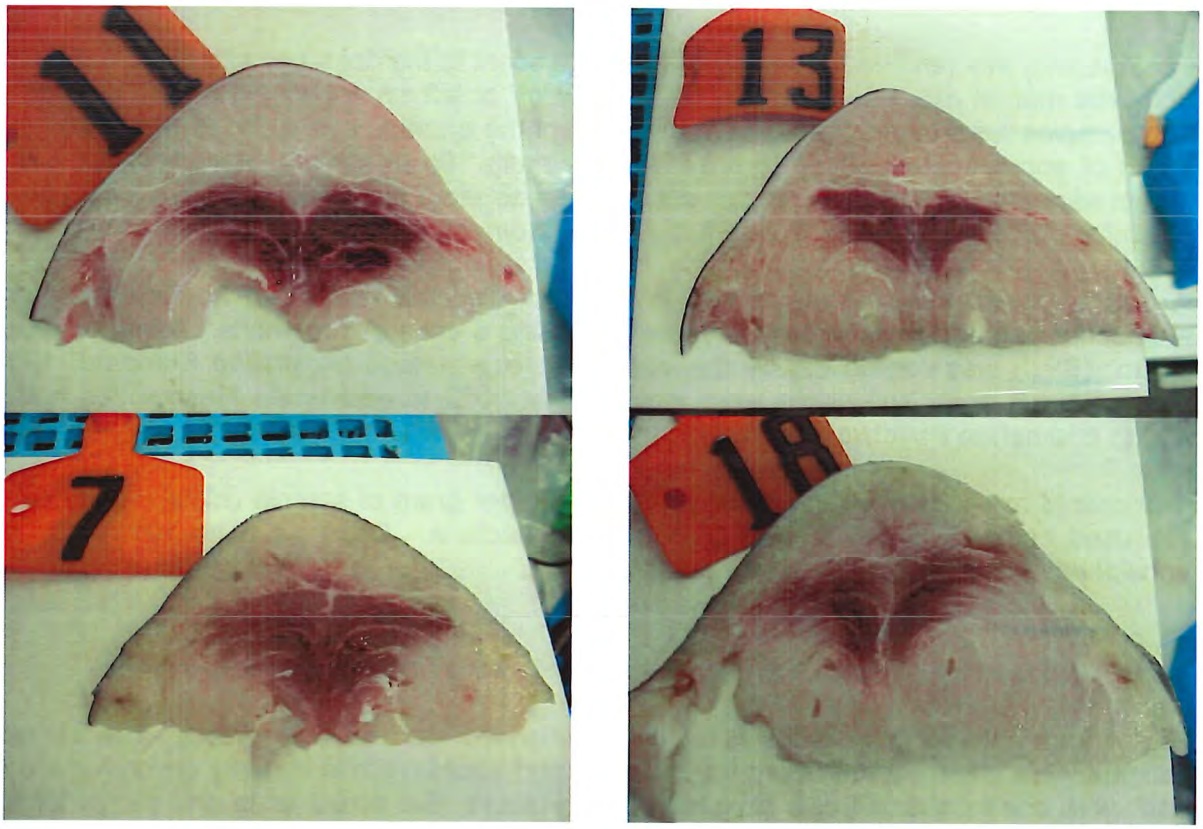


Figure 4. Swordfish tail cuts showing good grades (upper photographs) and poor grades (lower).

The scores given at this factory ranged from 4 to 8 accompanied by + and – annotations. To obtain pure numbers that could be analysed statistically a + score was given the value of 0.3 and a – score was given a value of –0.3. There were no half scores given by the grader so this interpretation provides the closest numerical rating possible based on one significant figure for the scores.

So that the likelihood of a swordfish being exported could be analysed statistically, it was decided to identify any swordfish with a score of 7- or greater as having been exported. For this parameter a fish with a grade of 6.7 or higher were given an export rating of 1 while fish with a domestic market grade of 6.3 or lower was given an export rating of 2.

4.5 Comparison of shoulder samples to tail cut samples

As the number of fish that could be sampled at one time was limited to what was caught during the field trips the tail cut (Figure 4 in Appendix 1) that industry use to grade the fish at the factory (both on the east and west coast) was evaluated as a possible replacement. This might allow the testing of many more fish during factory visits as the tail cuts are thrown away after grading.

As there was no history of handling practice or temperature conditions during storage this material was only to be used to increase the amount of replication available for correlating the grades with the flesh chemistry. The data obtained by Colour Meter, pH and K value analyses were statistically analysed using ANOVA.

4.6 Storage conditions

There were three types of chilling systems evaluated by this project. The first storage system involved storage of freshly landed swordfish in seawater, which was cooled via refrigerated coils attached to a heat exchange unit, for one to two days and then being removed from the tank and buried under ice (usually freshwater).

Another storage media utilised a refrigeration system similar to the first except that more salt was added to the seawater to make a brine. This particular media remained with the fish for the duration of the voyage. These two methods can be effective because they can cool fish to just above the freezing point (-1 to –2°C) rapidly, cause less physical damage due to crushing and require less labour. There is however the need to train personnel to operate the system effectively, capital and operating costs can be too high, the psychrotrophic bacteria may build up in the closed systems, and the flesh may pick up salt from the seawater (Haard, 1992).

The other method (number two for this report) involved the use of an ice slurry without the support of refrigerated coils. As the ice melted more was placed on the top. After a period of time the water was drained and the spaces between individual fish packed with ice.

4.7 Bar code reader

Sastek made a digital bar code reader available for the researchers to show to industry. An insurance agreement had to be signed before the unit could be taken from the factory. The risk of losing or damaging the unit precluded taking it out to sea. The unit could record up to 10 different different parameters.

5 RESULTS AND DISCUSSION

The operation of this project was fraught with difficulty because of a number of situations that occurred outside the control of the Principal Investigator. Only those familiar with conducting research at sea know how the vagaries of weather and fishing can delay the best of plans for field studies and research outcomes. The Research Officer initially identified to conduct the fieldwork withdrew in the first month of the project. This position was funded as a scholarship for a Masters or PhD candidate. It took until October 2002 to find a replacement, Andrew Forrest. This delayed the operation of the first field trip by three months. It was hoped this time could be made up but by November 2003 it was clear that an extension of the milestones had to be requested. This was approved in February 2004 with the draft report due in May 2004 and the final report due in October 2004.

During 2003 the Australian dollar rose to very high levels. This limited profits made from exports of swordfish and tuna. Many companies continued to operate, some at a loss, while others ceased fishing until there was an improvement in the exchange rate. Because of the poor returns it became hard to find sufficient crew to man the fishing vessels. One trip to the west coast in September 2003 failed because an engineer and a deckhand could not be found. The vessel was eventually tied up at the wharf for nearly 6 months. Andrew waited in Geraldton but as this was consuming project travel funds for little return, he returned to Brisbane after taking numerous samples from returning vessels at the factory. He departed almost immediately on a vessel out of Mooloolaba even though he had been away from home for almost two weeks.

This port was also suffering from the same situation. If not for the dedication of Andrew Forrest the completion of this project would have gotten even further delayed. On the trip in October 2003 Andrew had to agree to operate as a deck hand in order for the vessel to go out fishing. This limited the collection of samples to only half of the swordfish landed, but still resulted in good numbers. By this time we were also attempting to repeat some of the storage system studies so that only a select few vessels were options for us.

The turnaround time from each field trip was also lengthy. Processing and testing of the samples returned took two people up to two months to complete. Andrew returned in May 2004 with samples from the last field trip that resulted in the even replication of all three storage systems being studied. This timing was obviously a bit late for submitting a completed draft report.

Even before the departure of this trip, or the sample extraction had been completed and the data analysed for the whole of the collection, workshops with the steering committees had been called. These were held in Fremantle on 14th July and in Mooloolaba on 16th August to discuss and plan a possible field trial that could investigate any other best practice procedures that had not already been repeated. Most meetings were planned around the new moon as this is the time that most skippers are in port. Most individuals were contacted by phone the week before the meetings. No industry participants attended the meeting in Fremantle and only two in management and two deckhands attended the meeting in Mooloolaba. One reason for the poor attendance came from a major longline industry identity. It was suggested by industry that financial losses had stifled any thought that there was much of a future in this type of fishing activity and so a meeting about quality aspects was redundant. This is not a view held by these researchers. Further extension is planned.

The large numbers of swordfish and systems already evaluated and the limited turnout, even though industry had been given up to two months notice of the meetings, convinced these researchers that no further trips were needed if the final report was to be completed by the new deadline. The final analysis and report was completed by the end of September 2004.

5.1 Industry steering committees

As part of the conditions stated in the approval notice, participation of industry has been a key component of the planning and execution of this project. Appendix 1 contains lists of meeting attendees and findings from meeting held on the east and west coasts. Without this level of participation the field trips would have been very difficult to complete. It must be said here, regardless of the difficulty of getting numbers of industry together at the same time in the latter stages of the project, that industry support for this research was good. Regardless of the economic climate, no request for access to fishing vessels was denied and owners went out of their way to accommodate project requirements for the type of facilities needed.

Prior to the official start of the project, meetings had been held with industry to establish steering committees on both coasts to plan the research topics and field trips identified in the original application. Each milestone report was sent to steering committee members so they could get up to date details of the field trips. They were also solicited for their comments and recommendations for the continuing work. It was unfortunate but not dissimilar to many other research projects that most findings were only available at the end of the project, due to the way the data had to be collected and analysed.

OBJECTIVE 1. IDENTIFY KEY FACTORS RESPONSIBLE FOR LOSS OF QUALITY OF BROADBILL BY ASSESSING CURRENT HANDLING AND STORAGE PROCEDURES.

To meet this objective numerous field trips were planned to sample swordfish at landing and unloading. The goal was to replicate trips on vessels for each of the storage systems utilised and to cover both fisheries equally. Unfortunately due to the many things that impact on fishing, bad weather, lack of crew due to poor income and low catches, this ambition was not fully achieved.

5.2 Trip summary

This project saw the initiation of 3 and completion of 2 fishing trips (only one could be considered successful) on board longline vessels operating in the Southern and Western Tuna and Billfish Fishery (SWBTF), and the planning and completion of 5 fishing trips on board longline vessels operating in the Eastern Tuna and Billfish Fishery (EBTF). A total of 110 days were spent at sea covering greater than 8000 nautical miles, shooting more than 90,000 hooks and sampling of 226 swordfish. Small swordfish landed alive are returned to the water while those smaller than 20kg remain on the domestic market and were not tested.

In total 10 vessel unloads were sampled as part of this research. Formal interviews were carried out with skippers, processors and buyers to obtain operating details. The broad findings are present in the non-technical summary of this report. The data obtained for each trip are briefly reported individually in Appendices 2 to 8 as Tables 26 to 32. The graphs of temperature during storage and unloading can be seen in Appendices 2 to 8 as Figures 5 to 22. All the samples taken on the vessel and at the factory were frozen in liquid nitrogen. It was not until the samples from the very last trip had been processed that any major analysis of key factors could be undertaken.

5.2.1 Observations on handling practices

There were only a couple of handling practices identified that would have had a direct negative impact on quality. Most swordfish were processed very quickly when landed, usually taking no more than 10 minutes. Because of this, the fact that deck hoses were operating almost constantly and the difficulty of measuring deck temperature, only the temperatures of the sea surface and swordfish body were recorded. What was noticed was that not all vessels used the coring wire on swordfish that was always used on tuna. As it is well recognised by industry that this treatment does lead to better quality in tuna there is no reason it should not also be applied to swordfish.

The water used to chill the catch becomes bloody providing a good growth environment for psychrotrophic bacteria. It should be changed after two days with clean seawater. Water should never be pumped for fish storage while in port. Chemical additives such as chlorine dioxide can help suppress bacterial growth in the chill water.

When swordfish were taken from the first stage cooling media and packed in ice, many of the fish were layered in stacks. This means that the swordfish on the bottom may have more than several hundred kilograms weighing down on it for up to two weeks. It would be preferable that only smaller sized swordfish be placed on top of layers. Also during the icing of the fish it was noted that crew actually stood on swordfish while placing later catch. This and the stacking described above will lead to damage to the texture of the fish. A system of boards should be used for the crew to stand above iced swordfish to prevent trampling. It was noted on numerous occasions that swordfish at unloading were stacked after weighing without any ice for up to 30 minutes. Internal temperatures measured within the factories went up to 8°C which were much higher than when the fish were removed from the ice

packing. This warming will accelerate some enzyme systems leading to poorer quality at the shipment end than expected from the grading score given at the factory.

5.2.2 Conclusions and recommendations

- All swordfish should have the nerve tissue running along the spinal column cored in a similar way to that used on tuna.
- Chilling water should not be kept for more than two days as bacteria can proliferate
- Water required for the chill tanks should not be pumped from port waters
- Small swordfish should not be stored under large swordfish, limit the number of layers stacked.
- Do not stand on fish when stacking.
- Do not leave swordfish on the wharf for more than 10 minutes without a covering of ice.

5.3 Factory evaluations

Those swordfish sampled at landing were also sampled in the same way as those taken while at sea when delivered to the cold rooms of the factories. Due to trip difficulties a number of samplings were undertaken only at the factory of swordfish caught by other vessels not sailed on. This aspect of the project was an attempt to correlate grades given by factory staff for tail cuts with the non-invasive sample measurements normally taken. This work was extra to the collection of grades of fish tracked directly from capture. The factory graders used the tail cut to determine quality, rating both the white and red muscle tissue, as described in the methods section 4.2.

This material was used for pH, temperature and colour measurements instead of a shoulder sample taken by bayonet, to obtain large numbers of fish for measurement. As there are two different muscle types, colour measurements were taken of each. No chemical analysis was performed due to this unplanned cost.

Factory visits in Queensland on 27th May and 24th June 2003 were conducted where the pH, temperature and colour meter readings were measured and grades recorded. While originally we were led to believe that fat content also played a role in their scores, it appears that the white muscle tissue contributes in only a minor way to the final score at this factory. Mainly, the proportion of red muscle tissue present determines the score. This plays a larger role than the colour. We noted a situation where one fish had a much darker coloured red muscle block yet was scored the same as a less oxidised fish. There may have been a misunderstanding of what the original trainer of the grader currently doing the evaluations meant by the size of the red muscle bundles. While the red muscle is normally consistent in proportion with respect to the rest of the tail cut tissue, it would appear to be larger when the blood leaks out into the surrounding white muscle. This behaviour is related to storage temperatures and duration.

A visit to the WA factory on 6th September 2003 was also completed. It found that the grader not only applied a score to the red muscle tissue that industry regard as the "blood line" but also gives a separate score for fat in the white muscle tissue. As the east coast factory used a numerical system for recording grades and the west coast factory used a letter of the alphabet it was impossible to compare the two systems directly. Photographs were taken of representatives of a graded swordfish tail cuts and examples can be seen in as Figure 4 on page 14. While the top grade fish in the upper photographs display dark coloured red muscle tissue, there was no leaching into the surrounding white muscle that can be seen in the lower photographs of the tail cuts of domestic grade swordfish.

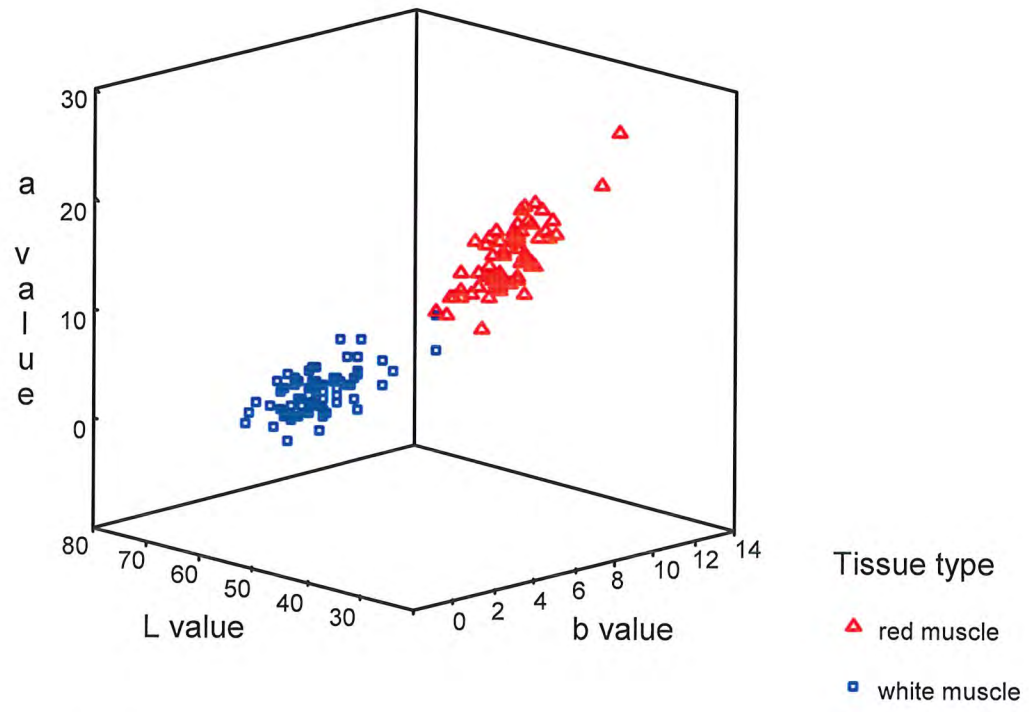


Figure 5. Minolta readings taken at the factory for white and red muscle within the tail cut.

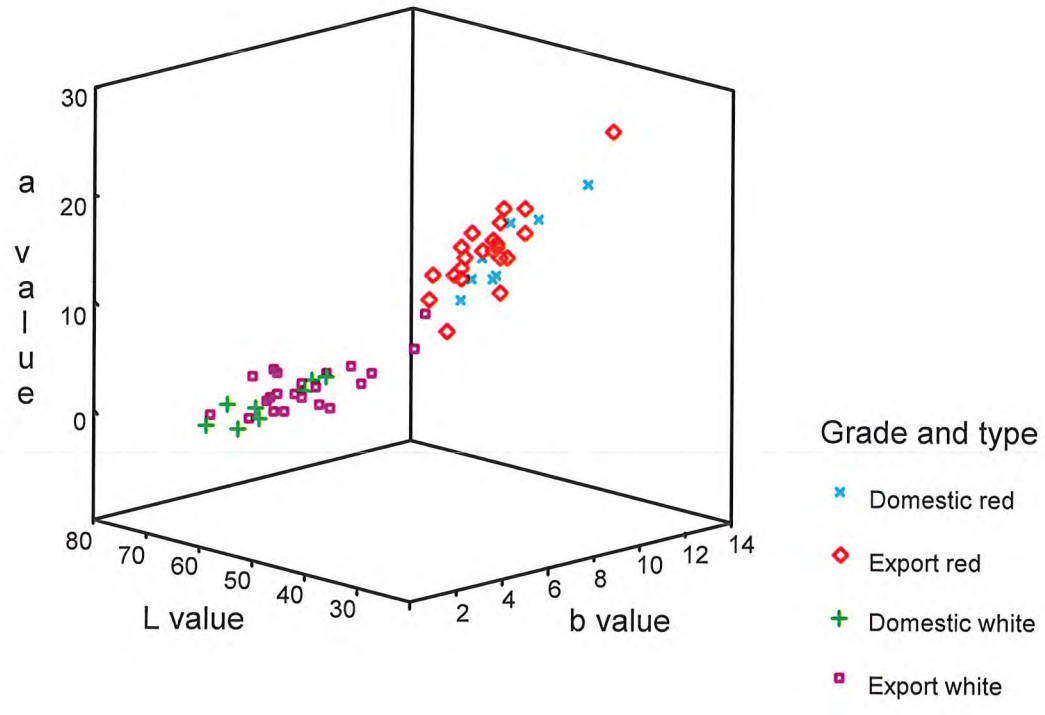


Figure 6. Minolta readings taken at the factory for tissue type and grade.

As would be expected, when the L*, a* and b* colour values for fish from both coasts were plotted in 3 dimensions (Figures 5 and 6 above) there was a clear separation of the two muscle types. When statistically analysed there were significant differences for all three colour measurements ($P<0.01$) between white and red muscle tissue. The second measurement of Queensland production had significantly lower ($P<0.05$) L* values for the white muscle tissue. As the two visits were only one month apart it was probably not due to seasonal effects but may be due to handling and storage differences of the two fishers. Numerically the difference was not large. The red muscle exhibited significant differences between the different measurements for the a* and b* values but with no real trends identifiable. While there appeared to be a trend in the data there was no obvious separation of the colour measurements for the different grades for each of the muscle types for the east coast fish. There were also no differences for colour measurements between export and domestic grade fish ($P>0.05$), except for the L* value of red muscle tissue where the export fish exhibited less lightness ($P<0.05$). There were no significant differences between the different grades for the red muscle measurements.

Statistical analysis of the pH measurements of these groups found no significant differences for individual shipments. When the two collections evaluated at the Queensland processing premises had been combined, a significant difference ($P<0.05$) was present between export and domestic marketed fish for anterior pH. This also was present for the four different grades scored. Even when the analysis included data from a shipment that was biased by directing higher grades toward the domestic market there were significant differences for grade. These differences were not present for the tail pH until the data from the biased export were excluded from the analysis, identifying two groups that were not significantly different from each other ($P<0.01$).

Because of the limited information about the conditions these fish experienced before unloading, the measurement of tail cuts at the factory alone cannot give insight into the reasons for high and low quality swordfish. The information on the condition of the fish at harvest and the changes that occurred over storage and transport to the factory provide a better tool for identifying best practice.

5.4 Comparison of shoulder samples to tail cut samples

The two types of muscle tissue do have different chemistry. While red muscle has a higher capacity for the resynthesis of energy rich compounds (Love 1970) there is also the potential to utilise these more because of the higher metabolism and thus exhibit lower quality parameters than the white muscle. In the tail section there is a larger proportion of red muscle than white muscle and this may lead to chemical and colour differences to muscle in the shoulder region. Comparisons of the proportions of tail cut and trunk muscle types can be made from the photographs presented below.

As discussed in the previous section it was hoped that the differences might not have been too large and so allow the tail sections to replace the shoulder samples as the main sampling region. This would have provided many more fish for testing and allowed the evaluation of many more fishers' handling and storage practices than could have been achieved by going out on capture voyages to obtain samples. Table 1 shows the colour and chemical measurements.

Table 1. Comparison of colour measurement of shoulder with tail cut white muscle.

Parameter	Shoulder value	Tail cut value	Probability
L* value (lightness)	53.12[b]	55.13[a]	<0.01
a* value (redness)	1.74[b]	3.00[a]	<0.01
b* value (yellowness)	1.17[b]	2.51[a]	<0.01
K value	40.92[b]	71.02[a]	<0.01
ATP	0.11[b]	0.15[a]	<0.05
ADP	0.17[a]	0.13[b]	<0.05
AMP	0.20[a]	0.13[b]	<0.05
IMP	4.27[a]	1.50[b]	<0.01
Inosine	0.92[b]	2.15[a]	<0.01
Hyperxanthine	2.24	2.27	NS
Total nucleotides	7.91	8.29	NS
Lactate	1063[b]	1212[a]	<0.05
pH	6.28[a]	6.10[b]	<0.05

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

Table 1 shows there is a large difference between the white muscle samples taken from the shoulder region and the tail cut. It might have been somewhat intuitive that the tail end of the fish would experience more exercise than the head end but due to several trip failures, the need to increase the sampling rate encouraged us to look at this option. When the grade was available it was used to separate domestic fish (grade<6.5) from export fish (grade>6.5).

What this outcome does tell us is that the use of a tail cut to represent the overall quality of individual fish is fraught with difficulty. It needs to be reiterated here that it is the shoulder region that provides the bulk of the edible material. The researchers have had numerous discussions with different processors about this situation. While most accept that they are not seeing the majority of the edible portion when rating tail cuts, they insist that have attained enough experience to be able to appraise fish consistently so that few exported fish (with the exception of parasitised individuals) fail to achieve prices that justify the cost of their export. The need to sterilise the bayonet sampler between each fish and the small numerical differences one would have to use to distinguish between export and domestic fish is also an aspect that they feel would limit adoption of this technique.

The outcome to this scenario was that the quality should always be better than what is perceived from the tail cut. Anecdotal information from the companies interviewed is that the system currently used does correlate well with the rating of the fish by the overseas buyers. As this is the goal of any quality appraisal system there is little that this project could do to help improve the system, as long as there is consistent training of new graders.

5.4.1 Grading Systems

It unlikely that there is an alternate method of grading that the swordfish industry could or would adopt wholeheartedly. While several individuals have been interested in obtaining the bayonet sampler they have stated that they would tend to use it for the higher value tuna they export rather than swordfish.

5.5 Review of all data collected from all 7 trips

Only when the data from all trips is available in one set can one draw conclusions about the different handling and storage practices carried out by fishers. Table 2 below contains the biological and environmental conditions that were present for each trip.

Table 2. Mean biological and environmental measures for each trip and their significance when analysed by ANOVA.

Parameter	Trip number							Significance
	1	2	3	4	5	6	7	
Coast	West	East	West	East	East	East	East	
Numbers of swordfish landed	23	38	3	30	38	46	48	
Numbers landed alive	7	18	0	11	20	10	23	
Mean orbital fork length (cm)	163	164	157	163	164	149	170	
Mean weight (kg)	70	-	68	69	-	69	74	
Storage media	RSW then ice	Ice slurry then ice	RSW then ice	RSW then ice	Brine then ice slurry	Brine then ice slurry	Ice slurry then ice	
Maximum storage time (days)	10	15	2	15	15	14	14	
Accumulated storage time for catch (hrs)	2965	9632	140	6686	8784	8480	9889	
Season	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	
Mean sea temperature for trip	21.8^{d}	23.1^{c}	23.9^{bc}	20.0^{e}	-	26.6^{a}	24.5^{b}	<0.001
Anterior temperature on landing	21.5^{cd}	22.4^{c}	22.9^{c}	21.2^{d}	21.6^{cd}	26.1^{a}	24.8^{b}	<0.001
Tail temperature on landing	21.3^{bc}	22.1^{bc}	22.6^{abc}	20.6^{c}	22.5^{bc}	25.6^{a}	24.3^{ab}	<0.001
Difference of anterior from sea temperature	0.3^{ab}	0.6^{a}	1^{a}	-1.2^{c}	-	0.4^{a}	-0.3^{b}	<0.001
Difference of tail from sea temperature	0.5^{ab}	1.0^{a}	1.3^{a}	-0.6^{c}	-	0.9^{a}	0.2^{b}	<0.001

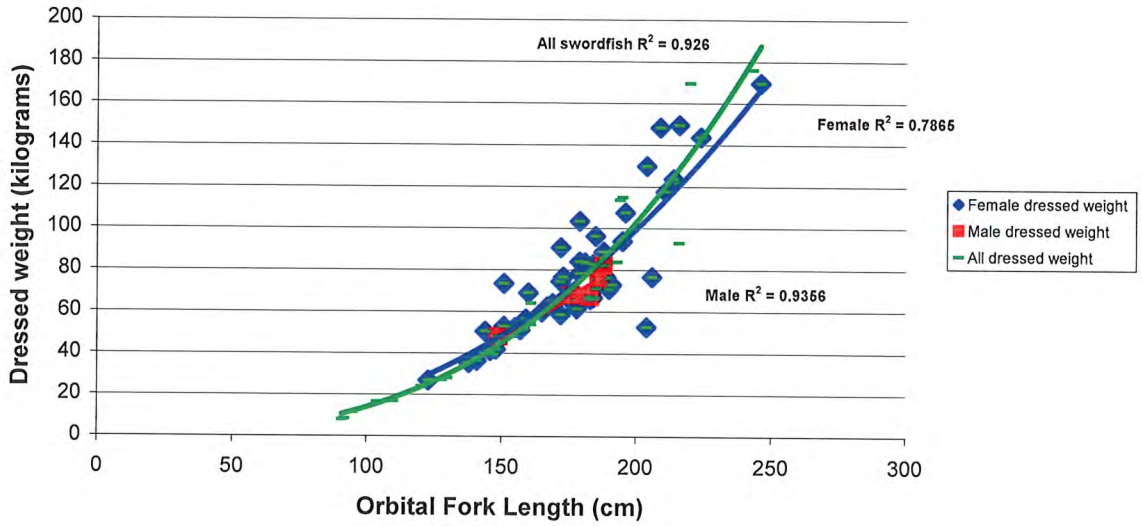
Means followed by a different letter are significantly different at the stated level.

The sea temperatures were not obtained for trip 5 as the skipper left the company not long after returning to shore. Trip 3 was cut short by bad weather resulting in only 3 swordfish being sampled. The data from this trip has been left out of all following trip analyses. Due their struggling swordfish landed alive had significantly higher ($P<0.01$) anterior temperatures compared with the seawater surface temperature than the dead swordfish. This was also the case for the tail temperatures ($P<0.01$). As rigor progressed the body temperature dropped below that of the seawater at the surface probably due to the fish sinking deeper into the water column.

Size related aspects of swordfish can be important and as the factory deals with only the weight of the trunk the relationship between the orbital fork length of freshly landed swordfish

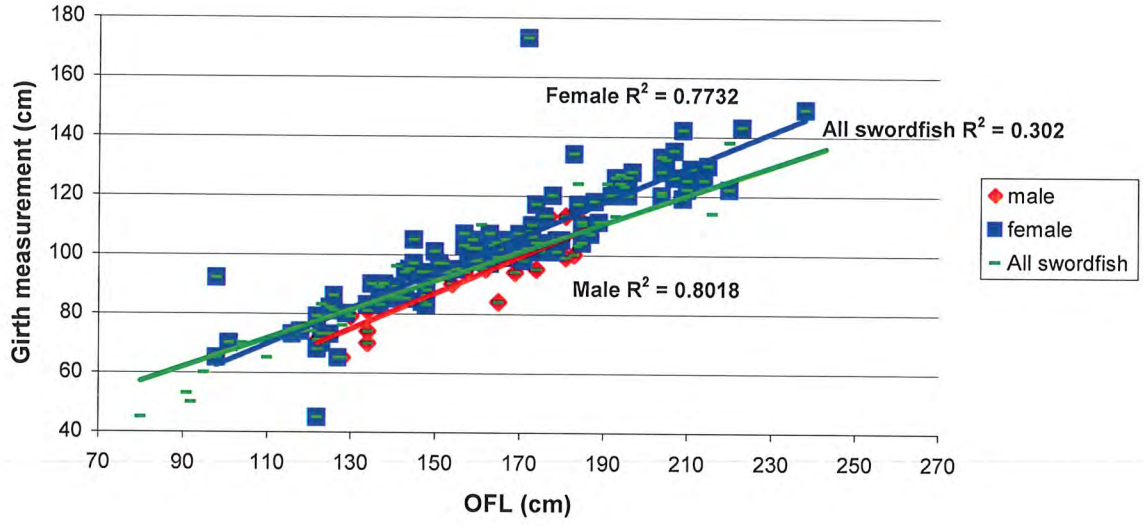
and final dressed weight at the factory before shipping was identified. This is presented below in Figure 7.

Figure 7. Relationship of dressed weight to orbital fork length for the swordfish catch.



Although the original data is for whole swordfish it shows a remarkably similar profile to that presented by Punt *et al* (2001). This indicates the sample of swordfish collected during this investigation is truly representative of the normal population available to fishers off the east coast. Figure 8 shows the relationship between orbital fork length and girth.

Figure 8. Swordfish orbital fork length compared with girth circumferance



The low R^2 value for the best fit line for both swordfish sexes in the graph shows that there are major differences between the sexes for girth, unlike fork length.

5.5.1 Differences between the landing and unloading

Table 3 contains a summary of quality measurements of swordfish when freshly landed and then after unloading at the factory for all trips.

Table 3. Means of all parameters measured for all trips.

Sampling time	Parameter	Mean measurement	Number of measurements
Landed On Deck	K value	11.94[a]	190
	Lactate	809.1[a]	190
	Anterior pH	6.2[a]	226
	Tail pH	5.93	225
	L* value	53.52[a]	217
	a* value	1.60[a]	217
	b* value	1.23[a]	217
At The Factory	K value	49.71[b]	195
	Lactate	902.9[b]	195
	Anterior pH	5.96[b]	202
	Tail pH	5.99	217
	CIE L*	57.07[b]	195
	CIE a*	1.32	195
	CIE b*	0.57[b]	195
	Grade	6.27	141

Mean measurements of the factory samples followed by a [b] are significantly different to the landed measurement at 1%.

Table 3 shows there are a number of measurable changes that occur in the quality of swordfish from landing till they are unloaded at the factory. This validates their selection as quality indicators.

How much difference there is between the colour samples at the different times is important if this tool is to be developed for industry use. The following Figure has been prepared to help determine differences between various treatments.

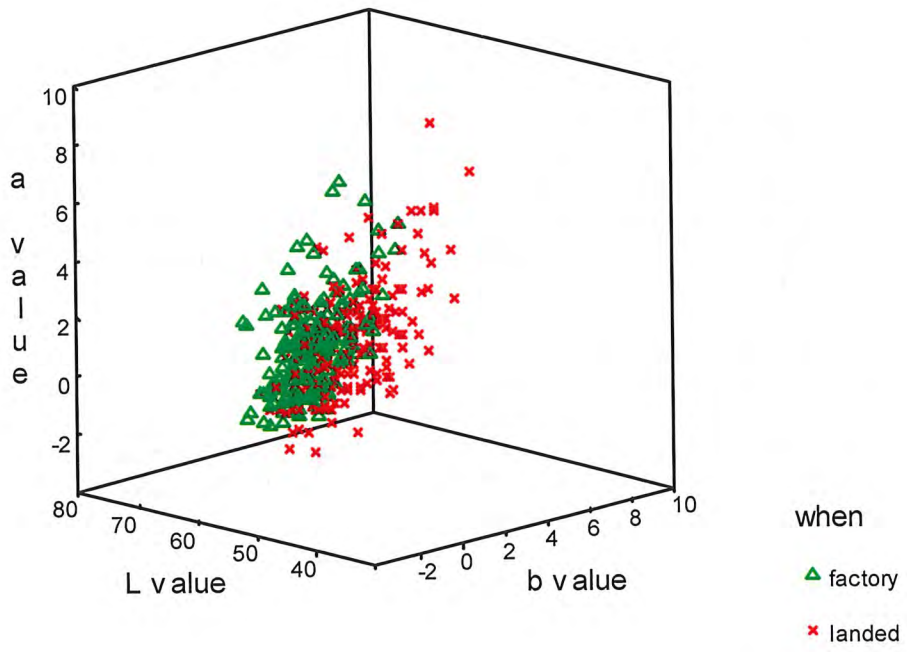


Figure 9. Minolta readings taken at capture when landed and unloaded at the factory from all trips.

5.5.2 Differences between the trips

Where possible the data for each trip were analysed for significant differences. While there were significant differences between trips for the raw data there were no discernable trends. This was probably because of the different mixtures of live landed swordfish and storage times for the each trip. Table 4 following contains the mean landed and factory quality measurements for each trip.

Table 4. Mean quality measures for each trip minus trip 3 and their significance.

Parameter	Trip number						Significance
	1	2	4	5	6	7	
Landed K Value (%)	7.5^{b}	6.6^{b}	7.4^{b}	5.8^{b}	18.8^{a}	12.2^{ab}	<0.001
Landed Lactate (µg/100g)	777^{ab}	768^{ab}	934^{a}	818^{ab}	860^{ab}	707^{b}	<0.001
Anterior Landed pH	6.25^{ab}	6.27^{ab}	6.08^{b}	6.03^{b}	6.01^{b}	6.53^{a}	<0.001
Tail Landed pH	5.96^{ab}	6.18^{a}	5.87^{ab}	5.63^{b}	5.71^{b}	6.23^{a}	<0.001
Landed L* value (lightness)	54.2^{ab}	55.7^{a}	52.3^{ab}	52.9^{ab}	56.5^{a}	50.1^{b}	<0.001
Landed a* value (redness)	1.73^{ab}	0.90^{b}	2.87^{a}	2.00^{ab}	1.20^{b}	1.33^{b}	<0.001
Landed b* value (yellowness)	1.83^{a}	1.34^{a}	1.66^{a}	1.74^{a}	1.09^{ab}	0.39^{b}	<0.01
Factory K Value (%)	30.8^{c}	47.7^{bc}	43.0^{bc}	30.8^{c}	68.7^{a}	53.1^{b}	<0.001
Factory Lactate (µg/100g)	944^{abc}	807^{c}	1125^{a}	1045^{ab}	893^{bc}	790^{c}	<0.001
Anterior Factory pH	4.82^{c}	6.13^{a}	6.21^{a}	5.49^{b}	6.27^{a}	6.28^{a}	<0.001
Tail Factory pH	4.88^{c}	6.22^{a}	6.21^{a}	5.47^{b}	6.17^{a}	6.40^{a}	<0.001
Factory L* value (lightness)	60.2^{a}	57.1^{ab}	54.9^{b}	59.6^{ab}	57.6^{ab}	55.8^{b}	<0.001
Factory a* value (redness)	1.12^{b}	0.29^{c}	2.32^{a}	1.30^{b}	1.59^{b}	1.25^{b}	<0.01
Factory b* value (yellowness)	1.09^{a}	0.55^{ab}	1.25^{a}	1.26^{a}	0.10^{b}	0.10^{b}	<0.01
Factory grade (east coast only)	-	6.8^{a}	6.2^{b}	6.2^{b}	6.8^{a}	6.0^{b}	<0.001
Export rating (east coast only)	-	1.71^{a}	1.52^{ab}	1.32^{b}	1.52^{ab}	1.53^{a}	<0.05

Means followed by a different letter are significantly different at the stated level.

The K value at landing was highest for trip 6 probably because sea temperature was high and most of the fish were landed dead. Sea temperature had the greater influence though as fish from trip 7 were also landed with elevated K values even though a higher proportion of fish were landed alive. This trend carried through to the factory but the amount of change in K value was also high for the other ice slurry storage trip B. The rate of change was higher only for the warmer trips (6 & 7).

Lactate did not follow the trend of K value as it was higher when the sea temperature was lowest and appeared to not be influenced by landed condition. Storage time did not appear to have a big impact on the differences present between trips. The pH of the anterior and tail regions of the swordfish trunks at landing varied between trips but there were no significant relationships for sea temperatures or proportion of swordfish landed alive. After storage the pH of fish from trip 1 dropped significantly. There were only minor increases or reductions for all the other trips.

While there were significant differences between trips for colour measurement at landing, there were no discernable relationships to either landed condition or sea temperature. The L* value increased after storage for all trips due to the normal loss of translucency of white muscle tissue that occurs when muscle protein is denatured by enzymes and metabolic acids. The cause

of significant differences in the amount or rate of change, however, was indeterminate. There was a loss of redness (a* value) during storage for all trips except 6, where there was an increase. Because of the higher proportion of dead landed swordfish, the blood pigments would have leaked out of the red muscle tissue of more swordfish caught on this trip. There was a loss in yellowness of the white muscle tissue during storage. The colour change from landing to the factory was similar for all trips. The rate of colour change was significantly higher for trip 1 probably because this trip had the shortest mean storage time. The factory grade and export score from the east coast catch varied between trips but did not appear to be directly related to landed condition, sea temperature or mean storage time.

Analysis of the changes in these parameters should identify whether the different mixture of fish condition and storage times in different media were significantly different between trips. Both the amount of change from landing till unloading at the factory and the rate of change per hour of total storage time were calculated. As Trip 3 contained only 3 swordfish with short storage times, this data was left out of the final analysis. Table 5 below shows the mean changes and significance for all trips except number 3.

Table 5. Mean quality measures for each trip minus trip 3 and their significance.

Parameter	Trip number						Significance
	1	2	4	5	6	7	
Δ K Value	23.8^{d}	47.4^{ab}	35.5^{bcd}	25.0^{cd}	49.9^{a}	40.9^{abc}	<0.001
Δ Lactate	166^{ab}	42^{b}	191^{a}	227^{a}	49^{b}	83^{ab}	<0.01
Δ Anterior pH	-1.41^{d}	-0.14^{abc}	0.17^{ab}	-0.55^{c}	0.26^{a}	-0.25^{bc}	<0.001
Δ Tail pH	-1.08^{c}	0.03^{ab}	0.24^{ab}	-0.18^{b}	0.46^{a}	0.17^{ab}	<0.001
Δ L* (change in lightness)	6.1^{a}	1.6^{b}	2.6^{ab}	6.8^{a}	1.5^{b}	5.8^{a}	<0.01
Δ a* (change in redness)	-0.53^{abc}	-0.90^{c}	-0.55^{bc}	-0.40^{abc}	0.40^{a}	-0.08^{ab}	<0.05
Δ b* (change in yellowness)	-0.54	-0.87	-0.42	-0.25	-0.94	-0.28	NS
Δ E* (colour difference)	6.94	5.45	6.69	8.36	4.79	6.21	NS
Δ Chroma	-0.12^{a}	-1.22^{b}	-0.69^{ab}	-0.31^{ab}	-0.16^{a}	-0.02^{a}	<0.05
Δ Hue	0.867	1.456	1.099	1.136	1.458	0.968	NS
Δ K Value/Hr storage	0.25^{ab}	0.16^{b}	0.18^{b}	0.11^{b}	0.38^{a}	0.23^{b}	<0.001
Δ Lactate/Hr storage	2.5^{a}	0.2^{b}	1.1^{ab}	1.2^{ab}	0.5^{b}	0.7^{b}	<0.01
Δ Anterior pH/Hr storage	-0.020^{a}	$--0.0002^{b}$	0.002^{b}	-0.001^{b}	0.002^{b}	-0.001^{b}	<0.001
Δ Tail pH/Hr storage	-0.012^{a}	0.001^{b}	0.001^{b}	-0.000^{b}	0.003^{b}	0.001^{b}	<0.001
Δ L*/Hr storage	0.101^{a}	0.009^{b}	0.007^{b}	0.030^{b}	0.015^{b}	0.038^{b}	<0.001
Δ a*/Hr storage	-0.017^{b}	-0.006^{ab}	-0.002^{ab}	-0.003^{ab}	0.005^{a}	-0.001^{a}	<0.01
Δ b*/Hr storage	-0.021^{b}	-0.006^{a}	-0.003^{a}	-0.002^{a}	-0.008^{a}	-0.004^{a}	<0.01
Δ E*/Hr storage	0.12^{a}	0.03^{b}	0.04^{b}	0.04^{b}	0.04^{b}	0.04^{b}	<0.001
Δ Chroma/Hr storage	-0.005	-0.008	-0.003	-0.003	0.001	0.000	NS
Δ Hue/Hr storage	0.020^{a}	0.008^{b}	0.006^{b}	0.005^{b}	0.013^{ab}	0.008^{b}	<0.05

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

There were significant differences between the parameters for each trip but only trip 1 was significantly different to all the other trips for a range of quality parameters. These were limited to the change per hour in pH and colour measurements. This may be due to the interruption half way through fishing to return a sick crewmember to shore. A loss of 3 days fishing has left a gap in the storage times for this collection.

One aspect not obvious in the analysis of the data by ANOVA was that while there is a large increase in K value after storage for some trips there is much less of an increase in lactate. The trips exhibiting the most increase in lactate had the lowest increase in K value. This condition is not consistent with the differences between live and dead landed swordfish presented in Table 6 below. This suggests that there may be some metabolic activity

occurring during storage some time after the swordfish had died. This trend is less apparent in the rate of change per hour data. There are obviously influences on the quality parameters that are not specific to any one trip.

5.6 Differences between live and dead landed swordfish

The quality parameters of all of the swordfish sampled were analysed by ANOVA to identify significant differences and the means and levels of significance are present in Table 6.

Table 6. Means and significance for swordfish when landed dead and alive.

Parameter	Alive	Dead	Significance
Numbers of swordfish	89	136	
Differences between sea and anterior temperature	-0.72 [b]	0.47 [a]	<0.001
Differences between sea and tail temperature	-0.09 [b]	0.80 [a]	<0.001
Landed K Value (%)	4.33 [b]	15.43 [a]	<0.001
Landed Lactate (µg/100g)	611 [b]	930 [a]	<0.001
Anterior Landed pH	6.61 [a]	5.92 [b]	<0.001
Tail Landed pH	6.27 [a]	5.71 [b]	<0.001
Landed L* value (lightness)	50.2 [b]	55.8 [a]	<0.001
Landed a* value (redness)	2.28 [a]	1.18 [b]	<0.001
Landed b* value (yellowness)	1.58 [a]	1.03 [b]	<0.05

Means followed by a different letter are significantly different at the stated level

Broadbill swordfish (*Xiphias gladius,* Linnaeus 1758) are large predatory fish that regularly descent to depths of 1000m or more (Carey and Robinson 1981). Their flesh is predominately 'white' muscle which provides energy for sudden bursts of activity (Gordon 1977). While they are not able to maintain a body temperature much above the surrounding water, their skin is a good insulator and they have a unique tissue that warms blood flowing to the brain and eyes when they are in cold water (Ward and Elscot 2000).

The live landed swordfish had higher body temperatures than the seawater at the surface (Table 6). Once they die they usually sink so that those landed dead have body temperatures lower than at the surface. This also means that you should hold live landed swordfish in the slurry tanks for longer so that they get to a core temperature below 5°C.

Lactate accumulation normally follows rigor mortis progress (Watabe et al., 1991). The data in Table 6 above shows measurements of K value and lactate become significantly higher for swordfish after they die due to cellular metabolism. Correspondingly the pH drops significantly after death due to the increase in acidic compounds such as lactate.

The measurement of lightness increases significantly after death due to the denaturation of muscle protein by enzymes and metabolic acids. The redness and yellowness become significantly lower after death due to drainage and breakdown of blood pigments. The level of significance is very high for all parameters except the b value (yellowness).

Because of the large number of swordfish sampled these means can be used as the baseline for all comparisons of quality. When these swordfish are unloaded at the end of the voyage most of the parameters retain their relationships, as shown below.

Table 7. Means and significance for swordfish landed dead or alive when unloaded at the factory.

Parameter	Alive	Dead	Significance
Factory K Value (%)	41.9 [b]	54.9 [a]	<0.001
Factory Lactate (µg/100g)	787 [b]	981 [a]	<0.001
Anterior Factory pH	6.17 [a]	5.82 [b]	<0.001
Tail Factory pH	6.23 [a]	5.82 [b]	<0.001
Factory L* value (lightness)	55.6 [b]	58.1 [a]	<0.001
Factory a* value (redness)	1.24	1.37	NS
Factory b* value (yellowness)	0.56	0.58	NS
Factory grade (East coast only)	6.52 [a]	6.05 [b]	<0.001
Export rating (Both coasts)	1.38 [b]	1.64 [a]	<0.001

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

Table 7 shows that when measured at the factory swordfish that were landed alive had a lower K value, lactate and lightness, a higher pH, received significantly higher grading scores and were much more likely to be exported. They were overall of better quality. The difference between the lactate of dead landed swordfish and those landed alive was greater than the increase that occurs during storage to either live or dead landed fish. Table 8 below shows the amount of change in particular quality parameters during storage of swordfish landed alive or dead.

Table 8. Mean changes and significance for swordfish landed dead or alive between landing and unloading at the factory.

Parameter	Alive	Dead	Significance
Δ K Value	38.9	40.2	NS
Δ Lactate	172 [a]	59 [b]	<0.001
Δ Anterior pH	-0.46 [a]	-0.10 [b]	<0.01
Δ Tail pH	-0.04 [a]	0.11 [b]	<0.001
Δ L* value (lightness)	5.24 [a]	2.36 [b]	<0.001
Δ a* value (redness)	-1.1 [b]	0.3 [a]	<0.001
Δ b* value (yellowness)	-0.9 [b]	-0.4 [a]	<0.05
Δ E* (colour difference)	7.13 [a]	5.22 [b]	<0.01
Δ Chroma	-1.03 [b]	0.003 [a]	<0.001
Δ Hue	1.27	1.15	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

The amount of change in K value due to storage is the same whether a swordfish is landed alive or dead. The storage increase in lactate is much larger for swordfish that were landed alive.

The storage increase in pH is lower for dead landed swordfish, partly due to lower starting levels of lactate and higher initial pH that live landed fish have, whereas fish that have died on the line have probably struggled for much longer generating only a little more lactate and many of them actually dropped in pH during storage which in turn results in lower mean pH change due to the storage. This aspect is also supported by the fact that the live fish had a larger drop in their pH after landing.

As would be expected the lightness (L value) increased more during storage for fish landed alive while there was a greater loss of redness and yellowness. These changes are

summarised by larger changes in colour difference and Chroma for live landed swordfish. To take account of the different storage times for individual swordfish these changes in measurements were adjusted to a per hour rate and the results are displayed in the Table 9.

Table 9. Mean changes per hour of storage and significance for swordfish landed dead or alive when unloaded at the factory.

Parameter	Alive	Dead	Significance
Δ K Value/Hr storage	0.22	0.26	NS
Δ Lactate/Hr storage	1.37[a]	0.51[b]	<0.01
Δ Anterior pH/Hr storage	-0.003	-0.002	NS
Δ Tail pH/Hr storage	-0.00002	-0.0001	NS
Δ L* value (lightness)/Hr storage	0.04[a]	0.02[b]	<0.05
Δ a* value (redness)/Hr storage	-0.01[b]	0.003[a]	<0.001
Δ b* value (yellowness)/Hr storage	-0.01[b]	-0.004[a]	<0.05
Δ E* (colour difference)/Hr storage	0.05	0.04	NS
Δ Chroma/Hr storage	-0.009[b]	0.002[a]	<0.01
Δ Hue/Hr storage	0.01	0.008	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

As would be expected the rate of K value change is similar for swordfish landed alive or dead. The rate of change in lactate during storage however is significantly higher for swordfish landed alive. This would be due to the fact that much more of the mitochondria would retain some metabolic activity producing lactic acid as a waste product as freshly killed swordfish go into rigor. Accompanying this are higher changes in most of the colour measurements.

5.6.1 Conclusion

There is a major difference in quality between swordfish landed alive and dead which carries though to unloading at the factory. To expedite the grading of fish at the factory swordfish landed alive should be marked in some way. This aspect alone is justification for adopting tagging of individual fish at the time of landing. One skipper operating out of Sydney marks his live landed swordfish with a cut to the caudal keel. This tissue would be firm enough to retain tags.

5.6.2 Recommendation

While it may be physically impossible for all swordfish to be landed alive, some thought should be given to the soak times and setting times prior to fishing so the proportion of fish landed alive can be increased.

5.7 Differences between pre rigor and in rigor landed swordfish

There was a higher proportion of the catch that was landed pre rigor than was landed alive. The changes characteristic of rigor mortis are a drop in pH, a conversion of glycogen to lactic acid, a loss of protein buffering capacity, a decrease in creatine phosphate, and a breakdown of ATP (Szczesniak & Torgeson 1965). Some of these changes can be seen in rigor data presented in Table 10 below.

Table 10. Means and significance for swordfish landed pre or in rigor.

Parameter	Pre rigor	In rigor	Significance
Numbers of swordfish	98	79	
Landed K Value (%)	7.15 [b]	16.90 [a]	<0.001
Landed Lactate (µg/100g)	736 [b]	928 [a]	<0.001
Anterior Landed pH	6.38 [a]	5.91 [b]	<0.001
Tail Landed pH	6.07 [a]	5.72 [b]	<0.001
Landed L* value (lightness)	51.8 [b]	56.4 [a]	<0.001
Landed a* value (redness)	1.97 [a]	1.11 [b]	<0.001
Landed b* value (yellowness)	1.56 [a]	0.91 [b]	<0.01

Means followed by a different letter are significantly different at the stated level

As few swordfish were appraised as being post rigor this aspect could not be evaluated statistically. While it might be expected that the results for rigor condition would mirror those observed between swordfish landed alive or dead, because some of the pre rigor fish were dead when landed the quality measurements were worse.

While the pre rigor results in Table 10 show that they were higher than live swordfish for K value, lactate and colour L* value and lower for pH and the colour a* and b* values, the in-rigor values were similar to those recorded for dead landed swordfish. The pattern of significant differences was similar to those present for live verses dead. There was little difference between measurements for dead and in rigor landed swordfish. Figure 10 shows are graphical comparison of colour measurements for rigor stage.

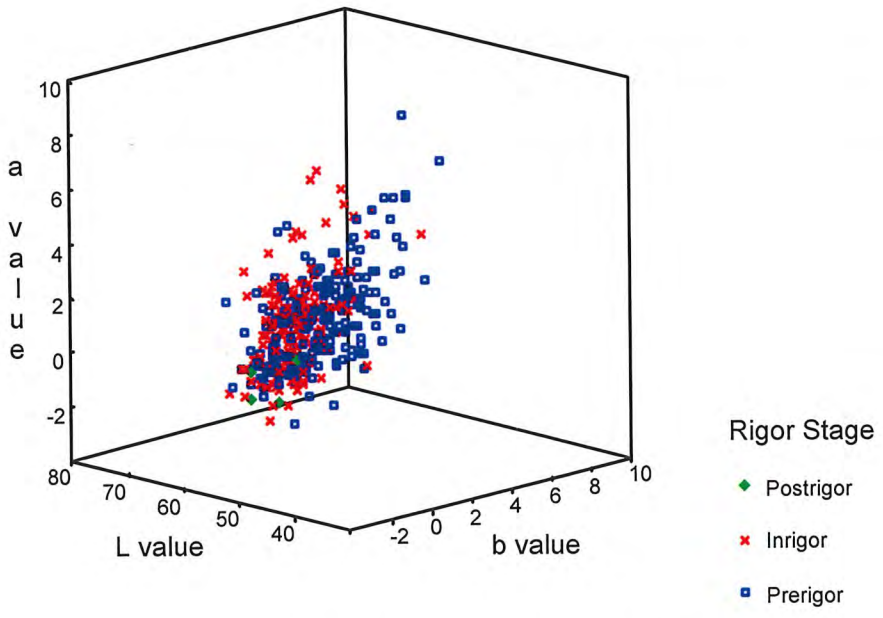


Figure 10. Minolta readings taken at capture for the different rigor stages on all trips.

The graph does not show any real separation of the collection due to rigor stage. The values for these parameters when measured at the factory was analysed by ANOVA with the outcomes present in Table 11.

Table 11. Means and significance for swordfish landed pre or in rigor when unloaded at the factory.

Parameter	Pre rigor	In rigor	Significance
Factory K Value (%)	43.7 [b]	56.9 [a]	<0.001
Factory Lactate (μg/100g)	876 [b]	969 [a]	<0.01
Anterior Factory pH	6.01	5.82	NS
Tail Factory pH	6.05 [a]	5.83 [b]	<0.05
Factory L* value (lightness)	56.8	57.8	NS
Factory a* value (redness)	1.31	1.38	NS
Factory b* value (yellowness)	0.77	0.51	NS
Factory grade (East coast only)	6.31	6.14	NS
Export rating (Both coasts)	1.48	1.60	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

There were fewer significantly different parameters for rigor condition. While the difference in K value and lactate had the similar trends the only other significant difference identified was for the tail pH. This parameter had a much higher level of probability. Again all of the factory measurements were worse for swordfish landed pre rigor than those recorded for live fish.

Unlike the live verses dead ratings there was no significant difference between the grades and export prospects for swordfish landed pre or in rigor. These results show that the quality of swordfish landed alive is much better and has more implication for fishers than those landed pre rigor. The change between these measurements and those recorded for landed swordfish and their significance when different are present in Table 12.

Table 12. Mean changes and significance for swordfish landed pre or in rigor when between landing and unloading at the factory.

Parameter	Pre rigor	In rigor	Significance
Δ K Value	37.7	41.3	NS
Δ Lactate	145 [a]	50 [b]	<0.01
Δ Anterior pH	-0.39 [a]	-0.09 [b]	<0.01
Δ Tail pH	-0.01 [a]	0.11 [b]	NS
Δ L* (lightness)	4.95 [a]	1.40 [b]	<0.001
Δ a* value (redness)	-0.71 [b]	-0.35 [a]	<0.001
Δ b* value (yellowness)	-0.71 [b]	-0.4 [a]	NS
Δ E* (colour difference)	7.10 [a]	4.36 [b]	<0.001
Δ Chroma	-0.78 [b]	0.10 [a]	<0.01
Δ Hue	1.24	1.08	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

As noted for the factory measurements there were fewer significantly different parameters for the amount of change. The quality of pre rigor swordfish was worse than swordfish landed alive because some of these were dead on landing. The pre rigor changes during storage for K value, lactate and anterior pH were smaller than those present for swordfish landed alive. The changes in tail pH and colour measurements were smaller. All the changes were smaller for the in rigor swordfish than those landed dead because they had been dead longer. Table 13 shows the analyses for the amount of change per hour of storage.

Table 13. Mean changes per hour of storage and significance for swordfish landed pre or in rigor between landing and unloading at the factory.

Parameter	Pre rigor	In rigor	Significance
Δ K Value/Hr storage	0.20 [b]	0.27 [a]	<0.05
Δ Lactate/Hr storage	1.15 [a]	0.47 [b]	<0.05
Δ Anterior pH/Hr storage	-0.002	-0.002	NS
Δ Tail pH/Hr storage	0.0003	0.0004	NS
Δ L* (lightness)/Hr storage	0.04 [a]	0.008 [b]	<0.001
Δ a* (redness)/Hr storage	-0.006 [b]	0.004 [a]	<0.01
Δ b* (yellowness)/Hr storage	-0.007 [b]	-0.005 [a]	NS
Δ E* (colour difference)/Hr storage	0.05	0.04	<0.05
Δ Chroma/Hr storage	-0.006 [b]	0.002 [a]	<0.05
Δ Hue/Hr storage	0.01	0.009	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

There were some differences for the amount of change per hour to that observed for live verses dead. The calculations were smaller for most pre rigor swordfish parameters while the in rigor calculations were similar to dead landed swordfish. This time the amount of K value and colour change (E*) per hour for pre rigor swordfish were significantly different to in rigor fish while the change in yellowness was not significant.

5.7.1 Conclusion

There is no major difference in quality between swordfish landed pre and in rigor which has any impact on the grade or export prospects. This condition should not play a role in sorting and handling the catch.

5.8 Differences between male and female swordfish sampled

It was difficult to determine the sex of the smaller swordfish landed during this study. Of the 193 swordfish that were sexed; there were more females (155) caught than males (38), similar to the study of Young *et al* (2003). Figure 8 on page 28 shows the different curves for male and female swordfish for orbital fork length in relation to the girth circumference. As mentioned earlier females had a slightly larger girth ($P<0.05$) than males of a similar orbital fork length.

There was no significant difference between the sexes for trip, season, orbital fork length, weight at shipment, whether landed alive or rigor stage. With only one exception there were no differences between the sexes for any quality parameter measured at landing, after unloading at the factory, for the total amount of change in these measurement or their change per hour of storage. The only difference found was that males had a slightly higher pH at the factory ($P<0.05$).

Table 14. Mean levels of male and female swordfish for significantly different parametes only.

Parameter	Male	Female	Significance
Girth	91.2 [b]	102.2 [a]	<0.05
Tail Factory pH	6.26 [a]	6.04[b]	<0.05

Means followed by a different letter are significantly different at the stated level.

5.8.1 Conclusion

There is no difference found between the sexes that directly impact on quality.

5.9 Differences between seasons for swordfish quality

Because of two bad trips from the west coast we have only one successful trip conducted in the spring of 2002. Initially it was included in the analysis, but it was excluded when trying to identify differences of quality over different parts of the year for the same region. The sea temperature was not available for the spring trip on the east coast (usually these were obtained from the skipper after the trip but unfortunately he had a computer failure) so that interpretations of the analysis are best kept to the three seasons from that same region, although some inference could be drawn for trunk temperatures at landing. The mean data can be seen in Table 15.

Table 15. Mean environmental and quality measures for each season and their significance.

Parameter	Spring	Summer	Autumn	Winter	Significance	Mean and significance
Geographic location	West&East	East	East	East		East only
Average sea temperature	21.8^{b}	25^{a}	24.5^{a}	20^{c}	<0.01	-
Sea & anterior temperature difference	0.3^{ab}	0.5^{a}	-0.2^{b}	-1.2^{c}	<0.01	-
Sea & tail temperature difference	0.5^{ab}	0.9^{a}	0.3^{b}	-0.6^{c}	<0.01	-
Proportion landed alive (%)	44	33	47	37	NS	51 NS
Landed K Value (%)	6.7^{b}	14^{a}	12^{ab}	7.4^{b}	<0.01	5.8^{b} <0.05
Landed Lactate (µg/100g)	789^{ab}	823^{ab}	727^{b}	934^{a}	<0.01	818^{ab} <0.01
Anterior Landed pH	6.11^{b}	6.13^{b}	6.48^{a}	6.08^{b}	<0.01	6.03^{b} <0.01
Tail Landed pH	5.75^{b}	5.92^{b}	6.19^{a}	5.87^{b}	<0.05	5.63^{b} <0.01
Landed L* value	53.3^{b}	56.1^{a}	50.3^{c}	52.3^{bc}	<0.01	52.9^{b} <0.01
Landed a* value	1.95^{ab}	1.07^{c}	1.39^{bc}	2.87^{a}	<0.01	2.0^{ab} <0.01
Landed b* value	1.82^{a}	1.20^{a}	0.46^{b}	1.66^{a}	<0.01	1.74^{a} <0.01
Factory K Value (%)	30.8^{c}	59.0^{a}	51.7^{ab}	43.0^{bc}	<0.01	30.8^{c} <0.01
Factory Lactate (µg/100g)	982^{b}	853^{c}	799^{c}	1125^{a}	<0.01	1045^{a} <0.01
Anterior Factory pH	5.27^{b}	6.20^{a}	6.26^{a}	6.21^{a}	<0.01	5.49^{b} <0.01
Tail Factory pH	5.28^{b}	6.19^{a}	6.37^{a}	6.21^{a}	<0.01	5.47^{b} <0.01
Factory L* value	60.1^{a}	57.4^{b}	56.0^{b}	54.9^{b}	<0.01	59.5^{a} <0.05
Factory a* value	1.22^{b}	0.99^{b}	1.35^{b}	2.32^{a}	<0.01	1.30^{b} <0.01
Factory b* value	1.22^{a}	0.31^{b}	0.19^{b}	1.25^{a}	<0.01	1.26^{a} <0.01
Factory grade (East only)	-	6.80^{a}	5.96^{b}	6.22^{b}	<0.01	6.21^{b} <0.01
Export rating (Both coasts)	1.32^{b}	1.61^{a}	1.56^{a}	1.52^{ab}	<0.05	1.32^{b} <0.05
Δ K value	24.4^{c}	48.9^{a}	39.7^{b}	35.5^{bc}	<0.01	25.0^{b} <0.01
Δ Lactate	193^{a}	46^{b}	73^{b}	191^{a}	<0.01	227^{a} <0.01
Δ Anterior pH	0.81^{a}	-0.08^{b}	0.21^{b}	-0.17^{b}	<0.01	0.55^{a} <0.01
Δ Tail pH	0.45^{a}	-0.26^{b}	-0.18^{b}	-0.24^{b}	<0.05	0.18^{a} <0.01
Δ L* value	6.4^{a}	1.5^{b}	5.6^{a}	2.6^{ab}	<0.01	6.8^{a} <0.01
Δ a value	-0.46	-0.21	-0.04	-0.55	NS	-0.4 NS
Δ b value	-0.42	-0.91	-0.27	-0.42	NS	-0.25 NS
Δ E value	7.59^{a}	5.1^{b}	6.15^{ab}	6.69^{ab}	<0.05	8.36^{a} <0.05
Δ K Value/Hr storage	0.20^{b}	0.29^{a}	0.24^{ab}	0.18^{b}	<0.05	0.11^{b} <0.01
Δ Lactate/Hr storage	2.1^{a}	0.4^{b}	0.6^{b}	1.1^{ab}	<0.01	1.21 NS
Δ Anterior pH/Hr storage	0.008^{a}	-0.001^{b}	-0.001^{b}	-0.002^{b}	<0.01	0.001^{a} <0.05
Δ Tail pH/Hr storage	0.004^{a}	-0.002^{b}	-0.001^{b}	-0.001^{b}	<0.01	0.001 NS
Δ L value/Hr storage	0.07^{a}	0.01^{b}	0.04^{a}	0.007^{b}	<0.01	0.03^{ab} <0.01
Δ E*/Hr storage	0.09^{a}	0.04^{b}	0.05^{b}	0.04^{b}	<0.01	0.04 NS
Δ remaining colour values/Hr storage					NS	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

There were significant differences between the seasons for sea temperature. Summer and autumn sea temperatures were higher than spring and winter, with the latter season having the lowest. The winter catch saw swordfish with significantly higher anterior and tail temperatures to that of the surface seawater. The autumn caught fish only had higher anterior temperatures. Swordfish (like other billfish) are able to increase their body temperature though specialised muscle tissue in the head region (Carey, 1982 and Block *et. al*, 1994). The core temperatures of the swordfish monitored during summer were higher, as shown by the temperature graphs and Tables in Appendix 1, so these fish took longer to chill to 0°C. There was even a difference of 5°C for internal starting temperatures during

chilling between a spring (October 2003) and a summer trip (February 2004). Obviously catches in the warmer months should be held longer in the initial chilling media than when it is cooler.

There was no difference between the seasons for proportion of the catch landed alive. As could be expected warmer seasons led to higher landed K values that carried though to the factory. Summer conditions (when the highest average sea temperatures occurred) resulted in significantly larger changes in K value overall and per hour of storage, with autumn following closely.

From viewing the raw data the lactate on landing appeared to be highest when the body temperature was higher than seawater. This may explain some of the contrasting outcomes seen in earlier analyses for K value with respect to lactate levels. Swordfish obviously have to expend more energy during winter resulting in higher lactate at landing. The catches during the warmer seasons had the lowest lactate measurements at the factory and consequently significantly smaller changes overall and per hour of storage. The season with the lowest lactate on landing accordingly had the highest pH measurements on landing. Even though lactate levels were not the highest during spring, this season had significantly lower pH measurements at the factory and the largest changes in pH overall and per hour. Autumn swordfish had the lowest lightness and yellowness of the landed colour measurements. Winter had the best redness measurements. This condition did not carry though to the factory however. Industry feedback is that swordfish appear to have better grades during the cooler seasons.

5.9.1 Conclusion

Swordfish caught during the warmer seasons may be of lower quality and will have shorter shelf life. There may be a need to reduce the load placed on cooling tanks during warmer conditions to increase the rate of cooling.

5.10 Differences between the different storage media used for swordfish

Chilling and storage systems have to cope with a lot of variables during fishing trips. Various numbers of fish of different size and shape and of different body temperatures are placed in holding tanks at irregular intervals. Three different storage systems operated by long line fishing vessels were evaluated by this project. As most vessels had limited wet hold space available, the catch placed into individual holds was usually composed of fish from two periods of setting and clearing of the long line. This meant that fish were kept in a particular fluid media for a period of rapid chilling and then removed and placed in another hold with a different media or the media was changed while the fish remained in that hold. This means that the analysis of the storage systems includes fish with varying combinations of one or two different treatments. As it was near impossible to take measurements of individual fish when being transferred from one hold to another (they were usually transferred in bulk and it was dangerous during rough seas) the quality parameters of the catch when landed at the factory provided the essential data and all interpretations are made about the total system used on the individual vessels rather than any combination.

To identify the most effective chilling media the temperature profiles of individually logged swordfish presented in the Appendix for each trip were analysed. The temperature profiles of some swordfish caught during Trip 6 show that there was an ongoing problem with the refrigeration equipment. While there is an initial delay in chilling when swordfish are first placed into the medium the drop in internal temperature follows a fairly linear relationship. All swordfish in ice slurry however displayed much longer delays of up to an hour.

The mean curves for large swordfish in these three media can be seen displayed in Figure 11 below.

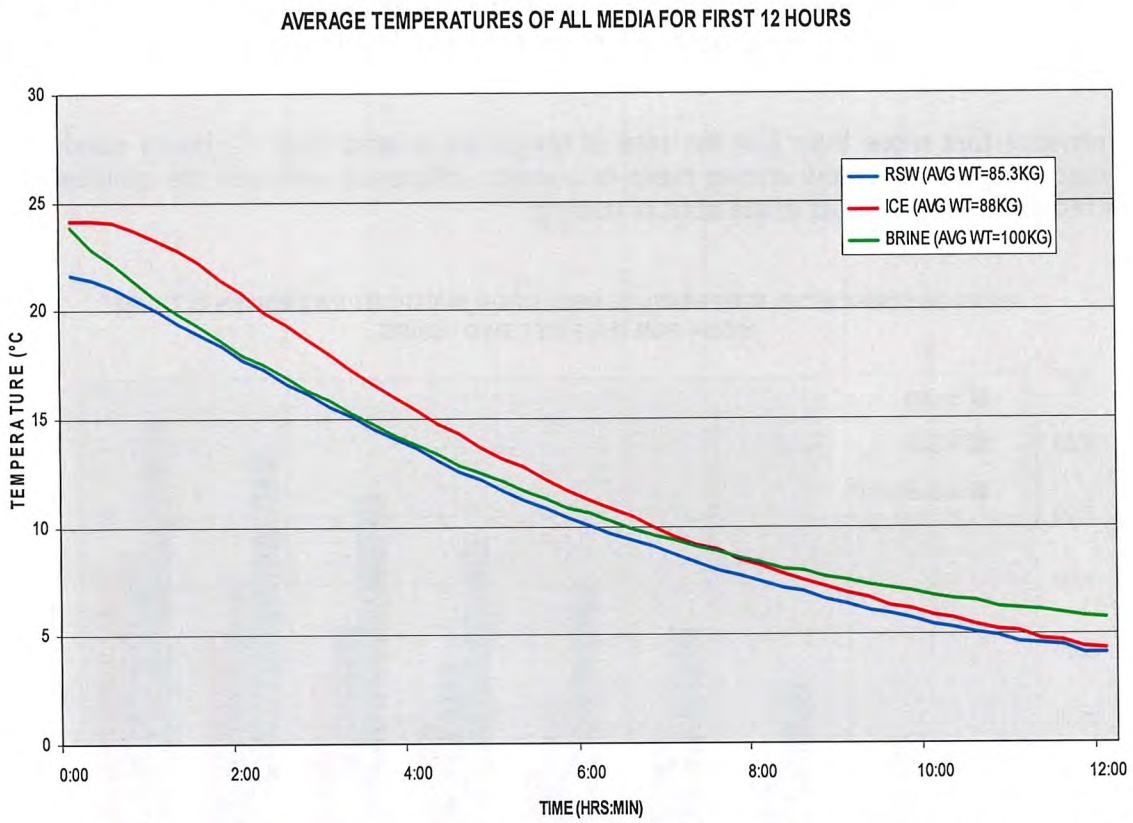


Figure 11. Mean temperature for export size swordfish stored in three different cooling media for the first 12 hours.

As the larger swordfish are more valuable and would cool at a slower rate than small ones only the temperature profiles of swordfish greater than 40kg were analysed. After about 12 hours in any of these media the rate of drop in temperature flattens out so only these hours of the logged temperatures were put into the model for analysis.

A 2 factor polynomial model showed even higher correlation than the linear model so this formula was also analysed. Table 16 below presents the analysis of both models with only the first factor being presented for the polynomial relationship. Further factors in the polynomial formula did not provide any better resolution of media cooling rates as these were much smaller values with no significant differences between them.

Table 16. Gradients, standard deviations and R^2 value for media cooling rates of swordfish >50kg.

Media	Linear gradients	Linear sd	Linear R^2	Polynomial factor *a*	Polynomial Sd	Polynomial R^2
RSW	-0.3438[a]	0.083	0.941	-0.602[a]	0.165	0.994
Ice slurry	-0.4477[b]	0.032	0.966	-0.755[a]	0.083	0.996
Brine	-0.3591[a]	0.054	0.992	-0.714[a]	0.268	0.992

Gradients and factors followed by a different letter are significantly different ($P<0.05$)

The significantly steeper gradient of the ice slurry in the linear model does suggest that this media is more effective at cooling over a 12 hour period (a period of prime importance in retaining quality) but it tends to disregard the delay in the drop in temperature at the start. A

polynomial model however does take into account the delay at the start of cooling so that the steeper gradient is negated by the initial delay in cooling by the ice slurry as accounted for by factor *a* in the polynomial equation resulting in no significant differences between the different media. The R^2 values obtained show they are highly representative of the data analysed.

It is obvious that more than just the rate of temperature drop over 12 hours needs to be analysed. Figure 12 below shows there is a major difference between the abilities of the three media to remove heat at the start of cooling.

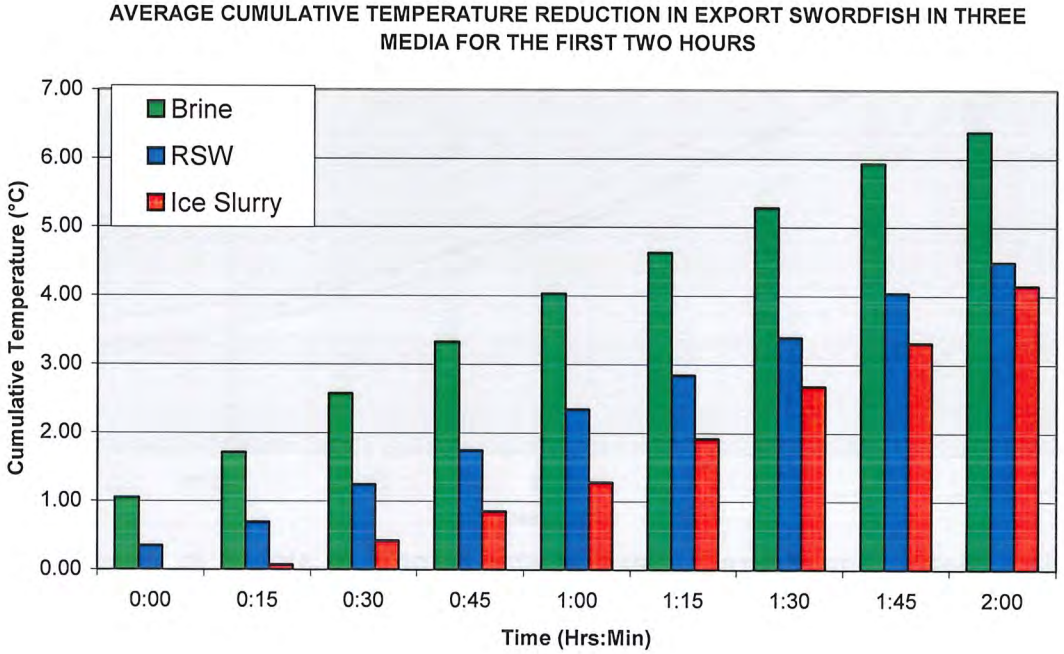


Figure 12. Mean cumulative temperature for export size swordfish stored in three different cooling media for the first two hours.

The brine removes the most heat right from the start while the ice slurry takes up to 30 minutes before it can even match the amount of heat being removed by the RSW. It is likely that, in the static ice slurry system, once the ice in direct contact with the fish melts the removal of heat by the melt water is less effective. It takes considerable time for convection currents to develop that will pass on heat to the ice further away from the surface of the fish. Eventually the ice slurry matches the other two media and then after two hours it is performing the best at removing heat from the swordfish trunk. After 8 hours all three media are removing the same amount of heat.

This means core temperatures of export size swordfish held in the ice slurry remain elevated for several hours. Figure 12 shows that the total heat removed by ice slurry for the first hour is much less than the other two media. Brine is the most efficient media for removing heat at a time when it is the most important for retaining quality.

A study of measured quality parameters for these media helps to further define which is the most efficient at producing the best quality swordfish. The analysis of the different parameters for the three types of media is present in Table 17 below.

Table 17. Means of quality parameters evaluated at unload and significance for three types of initial storage media.

Parameter	RSW	Ice slurry	Brine	Probability
Factory K value	37.4^{c}	50.8^{b}	60.4^{a}	<0.001
Factory lactate	1043^{a}	797^{c}	926^{b}	<0.001
Factory anterior pH	5.64^{b}	6.22^{a}	5.90^{b}	<0.001
Factory tail pH	5.89^{b}	6.21^{a}	5.68^{b}	<0.001
Factory L* value	57.2	56.4	58.0	NS
Factory a* value	1.87^{a}	0.83^{b}	1.53^{a}	<0.001
Factory b* value	1.20^{a}	0.30^{b}	0.35^{b}	<0.001
Grade	6.22	6.13	6.42	NS
Export score	1.57^{ab}	1.62^{b}	1.43^{a}	<0.05
Δ K value	30.2^{b}	43.3^{a}	44.4^{a}	<0.001
Δ Lactate	165.5^{a}	67.5^{b}	88.7^{b}	<0.05
Δ Anterior pH	-0.43	-0.20	-0.12	NS
Δ Tail pH	-0.25^{a}	0.11^{b}	0.16^{b}	<0.01
Δ L* value	3.81	3.95	2.65	NS
Δ a* value	-0.48	-0.44	0.22	NS
Δ b* value	-0.43	-0.54	-0.78	NS
Δ E* value	6.67	5.58	5.88	NS
Δ Chroma	-0.42	-0.19	-0.54	NS
Δ Hue	1.03	1.38	1.18	NS
Δ K Value/Hr storage	0.22^{b}	0.32^{a}	0.21^{b}	<0.01
Δ Lactate/Hr storage	1.55^{a}	0.47^{b}	0.66^{b}	<0.05
Δ Anterior pH/Hr storage	-0.007^{a}	-0.0006^{b}	0.0003^{b}	<0.001
Δ Tail pH/Hr storage	-0.0038^{a}	0.0009^{b}	0.0016^{b}	<0.001
Δ in most colour values/Hr storage	-	-	-	NS
Δ E* value/Hr storage	0.07^{a}	0.041^{b}	0.035^{b}	<0.01

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

While the temperature information can be examined at various time frames, the quality parameters are the result of the overall affect of both initial chilling as well as longer term ice or continued brine/ ice slurry storage. It should be kept in mind that this data is the mean for a range of swordfish conditions such as fish landed deal and alive, at different seasons, stored for different durations and from fish of different size. Only large swordfish are treated differently by holding in the chilling media for an extra day.

The analyses based on the samples taken at the factory show a mixture of relationships with each of the media resulting in a better outcome for individual parameters. Being an enzymic process (Ashie *et al.,* 1996), the accumulation of K value is larger for higher storage temperatures. Both the mean K value of swordfish after unloading and the amount of change in K value during storage were significantly higher for brine followed by ice slurry storage and ice slurry followed by ice storage. Starting levels for K value due to physiological condition at landing can eventually impact on factory levels so the amount of change is a better parameter for evaluating cooling systems.

The data presented in Table 17 demonstrates that swordfish chilled in ice slurry followed by ice storage have lower white muscle lactate than those stored in the other media, even though the factory K values were high. Change in K value at a constant storage temperature (this applies to all of the three systems investigated here when functioning normally) has been shown to be a linear relationship for fish (Bremner et al., 1988, Lakshmana et al., 1996).

At first glance the lactate levels obtained would appear to be in contrast with the K value results. Love (1979) demonstrated that lactate should increase due to degradation of glycogen and other metabolites while pH should drop. In Atlantic mackerel lactate appeared to decrease slightly in both muscle types with storage time (Fraser et al. 1968). Arthur et al. (1992) have reported lactate clearance after burst swimming in skipjack tuna but the authors were unaware of any data relating to this in swordfish. Enzymatic activity certainly continues after death in fish (Love, 1980), provided the substrate is present and the temperature remains optimum. One explanation for the difference in this study could be that while more ATP metabolism was occurring at higher storage temperature, other types of metabolic pathways may have also been operating effectively and one of these could have been the removal of lactate.

The conversion of lactate to pyruvate is reasonably well studied in tunas and other Scombrids (Dickson, 1989, Hansen and Dickson, 1994). A rapid removal of lactate would be considered advantageous for pelagic species (Dickson 1996) such as swordfish. Discussions with this author have provided the insight that tuna and some billfish white muscle tissue has a higher aerobic capacity than white muscle in other species and that levels of white muscle myoglobin in swordfish are equivalent to that found in southern bluefin tuna. Myoglobin serves as an intracellular storage site for oxygen. During periods of oxygen deprivation oxymyoglobin releases its bond with oxygen which is then used for metabolic purposes. More recent work by this author (unpublished) has indicated that tunas display a 'gear shift' when employing white muscle to swim at burst levels. The apparent aerobic qualities would appear to be present to hasten recovery from burst activity that was powered by anaerobic metabolism and resulted in the production of lactate.

In the light of our unexpected results it appears that swordfish do retain some of this activity after landing. If LDH, or a combination of similar acting enzymes, are proximal to available lactate in swordfish still at warmer temperatures, then clearance of lactate may result. It is unlikely that the type of experiments conducted by the authors mentioned above could be conducted on swordfish due to the difficulty of containing such a dangerous fish.

The ice slurry data had the higher pH at unloading and an overall increase in tail pH from landing. This is normally a result of delayed temperature reduction (Ashie *et al.,* 1996), confirmed by the temperature graphs in Appendix 3 and 8. The swordfish stored in brine and then ice slurry, while not of high pH on unloading do also show this increase in tail pH. This part of the swordfish is the narrowest and would be the most prone to temperature fluctuations.

There were no differences between the media for lightness (L* values) but the ice slurry seems to have led to swordfish with significantly less redness (a* value), something that graders usually score higher. This author is unsure whether this had any direct affect on the grade because of the different sites of the tissue involved.

When the grades of swordfish were analysed for the effect of the different storage media there were no significant differences present. Yet swordfish stored in brine were more likely to be exported. These contrary results are most likely due to the different mixture of live and dead fish at landing present for the different trips and the different storage times that each individual swordfish experienced.

To take into account some of these influences the amount of change in that parameter from the time of landing to the factory unloading was then analysed. No colour parameters were significantly different when the amount of change was analysed. The change in values was highest for lactate and tail pH in swordfish stored in RSW. Again there were contradictory outcomes probably due to the different mixtures of live/dead landed swordfish leading to some parameters being at worse levels at the start of and/or after storage.

To take account of the different storage times within each treatment a further level of analysis possible was to investigate the rate of change per hour of storage. This resulted in the same parameters being significantly different with the inclusion of the colour difference but in different patterns of relationship to the previous analyses.

The problem with salt water systems is that they can separate out into different layers due to density differences. Higher density salt water can hold more heat and if there is no cooling at the bottom much higher temperatures can develop than are present at the top. This is called a heat sink. For this reason circulation pumps should be installed to ensure there is even mixing within the holding tank.

It should be remembered that one of the data sets for brine includes swordfish exposed to fluctuating temperatures due to equipment malfunction. The individual temperature charts from Trip 6 (see Figure 29 to 31 in Appendix 7) show what may appear to be minor temperature increases within the first critical 12 hours of storage for several swordfish. This supports the admission by the skipper that the refrigeration system was not performing properly during that voyage, leading to a loss of freshness. The initial delay in cooling by the ice slurry shown in Figure 52 has also led to a loss of freshness. For this data set the RSW appears to be best overall. To take account of this heating effect the analyses were continued but without the data for trip 6. Unfortunately this leaves the brine treatment with data from only one trip while the others are composites of two trips. The analysis of the different parameters for the three types of media without data from trip 6 is present in Table 18 below.

Table 18. Means of quality parameters evaluated at unload and significance for three types of storage media without trip 6.

Parameter	RSW/ice	Ice slurry/ice	Brine	Probability
Factory K value	37.4^{b}	50.8^{a}	30.8^{b}	<0.001
Factory lactate	1043^{a}	797^{b}	1045^{a}	<0.001
Factory anterior pH	5.64^{b}	6.22^{a}	5.49^{b}	<0.001
Factory tail pH	5.89^{b}	6.21^{a}	5.63^{b}	<0.001
Factory CIE L* value (lightness)	57.2	56.4	59.6	NS
Factory CIE a* value (redness)	1.87^{a}	0.83^{b}	1.30^{ab}	<0.001
Factory CIE b* value (yellowness)	1.20^{a}	0.30^{b}	1.26^{a}	<0.01
Grade	6.22	6.13	6.21	NS
Export score	1.57^{ab}	1.62^{a}	1.32^{b}	<0.01
Δ K value	30.2^{b}	43.3^{a}	25.0^{b}	<0.001
Δ Lactate	165.5^{a}	67.5^{b}	227.3^{a}	<0.01
Δ Anterior pH	-0.43^{ab}	-0.20^{b}	-0.55^{a}	<0.05
Δ Tail pH	-0.25^{a}	0.11^{b}	0.18^{ab}	<0.01
Δ CIE L*	3.81	3.95	6.78	NS
Δ CIE a*	-0.48	-0.44	-0.40	NS
Δ CIE b*	-0.43	-0.54	-0.25	NS
Δ E* (colour difference)	6.67	5.58	8.36	NS
Δ Chroma	-0.42	-0.19	-0.31	NS
Δ Hue	1.03	1.38	1.14	NS
Δ K Value/Hr storage	0.22^{a}	0.32^{a}	0.11^{b}	<0.05
Δ Lactate/Hr storage	1.55^{a}	0.47^{b}	1.21^{ab}	<0.05
Δ Anterior pH/Hr storage	-0.007^{a}	-0.0006^{b}	-0.0012^{b}	<0.01
Δ Tail pH/Hr storage	-0.0038^{a}	0.0009^{b}	-0.0006^{ab}	<0.01
Δ in most colour values/Hr storage	-	-	-	NS
Δ E*/Hr storage	0.07^{a}	0.035^{b}	0.039^{ab}	<0.01

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

The removal of data from trip 6 led to much lower levels of K value (about half the previous level) of samples taken at the factory with the outcome this time of the ice slurry producing the worst of this quality indicator and the brine equal to the RSW. The ice slurry still led to the lowest lactates at the factory. This suggests that the higher initial temperatures of swordfish in ice slurry led to much greater reduction of lactate than was possible with the fluctuating brine tank temperatures as the lactate levels only show a small rise when this pool of data was removed.

Because of the higher lactate level, the anterior and tail pH means were lower for this analysis with ice slurry still exhibiting higher pH. There was no major change in the colour measurements or factory grade when trip 6 data was removed. The export score for the brine-stored swordfish did improve and it was still the best media that produced export quality swordfish.

Again there were lower increases in K value for brine and RSW yet larger increases in lactate. Unlike the previous analysis there were now significant differences ($P<0.05$) between the media for change in anterior pH with the ice slurry leading to the smallest change. This was because the K value on landing of fish to be stored in this media was already much higher than those placed in the other media. There were no real differences in the outcomes for change in tail pH, or colour measurements with trip 6 data removed.

There were however many changes in the levels of significance, all becoming lower, for the rate of change in most quality parameters per hour of storage. The brine was best able to control the rate of K value increase (remember an enzyme system dependant on temperature). Again this parameter is in contrast with the lactate change per hour with the ice slurry producing the lowest change rate. The outcome for change per hour of the anterior pH was not different but the rate of change of the tail pH increased to become positive. Only the rate of colour change per hour was significant for the different media with brine and ice slurry producing the lowest mean values. It is obvious that the minor increase in temperature that was detected during trip 6 had a much larger impact on the quality of swordfish than that suggested by just the temperature charts.

Because these two analyses of the catch included dead landed swordfish the varying times that these fish had struggled and then been dead may have muddied the overview for the different media. Only by looking at the quality parameters for swordfish landed alive (best starting quality) can the issue of best storage media be finally resolved. Table 19 following presents this analysis without data for swordfish landed dead or during trip 6.

Table 19. Means of quality parameters evaluated at unload and significance for only live landed swordfish stored in three types of storage media but without trip 6.

Parameter	RSW/ice	Ice slurry/ice	Brine	Probability
Landed K Value (%)	3.91	4.64	4.73	NS
Landed Lactate (µg/100g)	730[a]	541[b]	753[a]	<0.001
Anterior landed pH	6.55[ab]	6.75[a]	6.43[b]	<0.05
Tail landed pH	6.26[ab]	6.49[a]	5.86[b]	<0.001
Landed CIE L* value (lightness)	49.5	49.7	51.3	NS
Landed CIE a* value (redness)	3.61[a]	1.81[b]	2.33[ab]	<0.01
Landed CIE b* value (yellowness)	2.32[ab]	1.05[b]	2.44[a]	<0.01
Factory K value	35.0[ab]	44.1[a]	29.0[b]	<0.05
Factory lactate	1015[a]	672[b]	990[a]	<0.001
Factory anterior pH	5.88[ab]	6.41[a]	5.59[b]	<0.001
Factory tail pH	6.07[ab]	6.51[a]	5.60[b]	<0.001
Factory CIE L* value	56.2[ab]	54.6[b]	59.5[a]	<0.05
Factory CIE a* value	1.56	1.16	1.08	NS
Factory CIE b* value	1.25	0.38	1.40	NS
Grade	6.50	6.51	6.51	NS
Export score	1.36	1.43	1.15	NS
Δ K value	31.1[ab]	42.5[a]	24.2[b]	<0.01
Δ Lactate	284[a]	119[b]	238[ab]	<0.05
Δ Anterior pH	-0.67[ab]	-0.34[a]	-0.84[b]	<0.05
Δ Tail pH	-0.17	0.02	-0.26	NS
Δ in all colour values	-	-	-	NS
Δ K Value/Hr storage	0.21	0.20	0.11	NS
Δ Lactate/Hr storage	2.69[a]	0.89[b]	1.41[ab]	<0.05
Δ Anterior pH/Hr storage	-0.007[a]	-0.0013[b]	-0.0034[ab]	<0.05
Δ Tail pH/Hr storage	-0.0003	-0.0003	-0.0015	NS
Δ in all colour values/Hr storage	-	-	-	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

Now we are dealing with just those swordfish that had yet to go through rigor, starting levels were the lowest possible. While there were significant differences between the three groups of swordfish that went into the three different media there were none for K value. These differences were not consistent for any group destined for a particular medium. Lactate was much lower in swordfish to be stored in ice slurry while the tail pH was much lower in the group to be stored in brine. There were smaller differences between the groups for yellowness and redness.

As all three systems attempt to bring the internal temperature down to 0°C as quickly as possible, the rigor process of the swordfish should operate in similar ways resulting in quality differences, especially for K value, mainly due to the different temperature regimes experienced while in these media.

Due to the better quality of live landed swordfish all the mean quality values swordfish at the factory improved from the previous analyses but because of the lower number of replicates, the levels of significance mainly decreased or became not significant. While there was only a small numerical difference between the treatments, brine storage led to significantly lower K values than ice slurry while this latter media resulted in significantly lower lactate levels. The anterior and tail pH measured at the factory was still better for ice slurry stored swordfish. The factory L* value was the only parameter to become significant when previously not, although there was only a little difference between the numerical values. The factory redness and yellowness values became not significant. While there was numerical

improvement for both the grade and export ratings, none of the media was better than the other.

The amount of change in K value actually increased slightly for RSW from the previous model but it and brine storage still led to the least change. The change in lactate was still significantly higher for RSW and brine than ice slurry storage. The quicker drop in temperature by brine could have better control of any further increase in lactate than was able to be converted while in an ice slurry. Only change in the anterior pH exhibited significant differences with a similar outcome to the lactate change. None of the changes in colour measurement were significant for media type. The change in lactate per hour shows mixed significant differences with ice slurry and brine leading to the lowest changes. The change in anterior pH per hour mirrored the lactate. The change in colour difference per hour was not significant for this pool of data.

It is obvious that the initial delay in core temperature reduction during ice slurry storage does impact on quality but this is not expressed as lower factory grades or less chance of being exported. The impact on swordfish quality for fish that have been held at higher temperatures for more than several hours has already been shown by the previous analyses. Unfortunately the amount of replication is too small to analyse this cut of the data. The best that can be achieved is a comparison between trips 5 and 6 for live landed swordfish only presented in Table 20.

Table 20. Means of quality parameters evaluated at unload and significance for live landed swordfish stored in brine for trip 5 and 6.

Parameter	Trip 5	Trip 6	Probability
Factory K value	29.0[b]	56.6[a]	<0.05
Factory lactate	990[a]	682[b]	<0.001
Factory anterior pH	5.59[b]	6.82[a]	<0.001
Factory tail pH	5.60[b]	6.59[a]	<0.001
Factory L* value (lightness)	59.5	54.8	NS
Factory a* value (redness)	1.08	1.22	NS
Factory b* value (yellowness)	1.40[a]	-0.72[b]	<0.01
Grade	6.51	6.8	NS
Export score	1.15[b]	1.67[a]	<0.01
Δ K value	24.2[b]	52.4[a]	<0.001
Δ Lactate	238	100	NS
Δ Anterior pH	-0.84[a]	0.21[b]	<0.01
Δ Tail pH	-0.26	0.36	NS
Δ in all colour values	-	-	NS
Δ K Value/Hr storage	0.11[b]	0.40[a]	<0.05
Δ Lactate/Hr storage	1.41	0.77	NS
Δ Anterior pH/Hr storage	-0.0034	-0.0003	NS
Δ Tail pH/Hr storage	0.0015	-0.0015	NS
Δ in all colour values/Hr storage	-	-	NS

Means followed by a different letter are significantly different at the stated level. NS – Not significantly different

The comparison of both brine storage trips for live landed swordfish presented above shows that the quality values when the brine performed properly is much better. The impact of a higher starting temperature and a small increase in temperature during storage of 5°C resulted in a doubling of K value measurements while a reduction in lactate led to higher pH. While there was no difference for factory grade, swordfish that did not experience temperature increases were more likely to be exported. The only colour parameter that

contained significant differences was the b* value at the factory. The warmer storage led to loss of yellowness. The initial lag in cooling present during ice slurry led to better quality than swordfish held in the defective brine tank.

5.10.1 Conclusion

Holding swordfish at higher than sea temperature for more than a few minutes after landing will directly lead to a loss in quality. Static ice slurry will not chill swordfish as quickly as RSW or brine when first immersed. Once the heat exchange system gets going ice slurry can match the other two systems but it cannot recover that initial loss of freshness.

It is not possible to identify how much the influence of the highest starting temperatures for any of the catches had on brine chilled swordfish quality other than knowing that it did lead to less swordfish being landed alive and significantly higher landed K values (from Table 31 in Appendix 10). The later temperature increases due to machinery malfunction would have added to these higher levels resulting in the worst quality parameters of any swordfish measured at the factory. The elevation of temperature in the initial chilling media (above 5° for several hours) will also lead to lower quality. RSW and brine storage systems, when not operating ineffectively (when cooling coils in the wet holding tanks ice over preventing further cooling of the surrounding water, when compressors are operating under their best capacity due to being turned off for long periods, when the tanks are overloaded for the capacity of the system or due to mechanical problems), can preserve quality aspects much better than a static ice slurry.

One problem with any holding tank is that a heat sink can develop. This happens because waters with different density do not mix well. In RSW tanks, freshwater is removed from the seawater as it freezes to the cooling coils resulting in brine of a higher salinity which then sinks as it becomes denser. The body temperature of freshly landed fish that are introduced will cause some initial melting of the ice around the coils that will then float on top of the denser brine. Melting ice in an ice slurry tank behaves in a similar way. Most holding tanks on vessels are deeper than they are wide which restricts mixing even further, even during rough weather. The fish suspended vertically in the tank will also restrict water movement around the holding tank.

Just because ice is forming on the coils does not mean that the water around the fish is cold enough. It may be 5 degrees warmer. By turning off the refrigeration for long periods of time to stop icing, cooling will be much slower resulting in poorer quality.

5.10.2 Recommendation

Recirculating pumps with distribution outlets (spray bars) delivering water to each line of fish hanging in the tank should be present in all holding tanks regardless of chilling media used. Circulation will become more limited as the hold fills with fish. This applies both to RSW and brine. Start by putting the first fish in the centre of the chilling tank and place later landed fish towards the outside of the tank. Do not overfill a RSW tank and let fish lean against the coils or ice as they could become frozen.

5.11 Difference in swordfish quality due to storage time

The storage time on board the capture vessel for swordfish ranged from 1 to 15 days. As there was little effect for the type of storage media the analysis was based on total storage time when unloaded at the factory. Table 21 shows the levels of significance and whether there was any discernable trend in the data.

Table 21. Level of significance and trend of quality parameters for total storage time.

Parameter	Significance	Trend
Factory K value	<0.01	Increase as storage time increases
Factory lactate	NS	No trend
Factory anterior pH	<0.01	No trend
Factory tail pH	<0.01	No trend
Factory colour measurements	NS	No trend
Grade (east coast only)	<0.05	Decrease as storage time increases
Export score	<0.01	Less exported as storage time increases
Δ K value	<0.01	Increase as storage time increases
Δ Lactate	NS	No trend
Δ Anterior pH	NS	No trend
Δ Tail pH	<0.01	No trend
Δ in all colour values	NS	No trend

NS – Not significantly different

There were very few parameters that contained significant differences between different storage days and even less that exhibited trends that could have any real meaning for fishers. Where there were definite trends the data is presented as Figures 13 to 16.

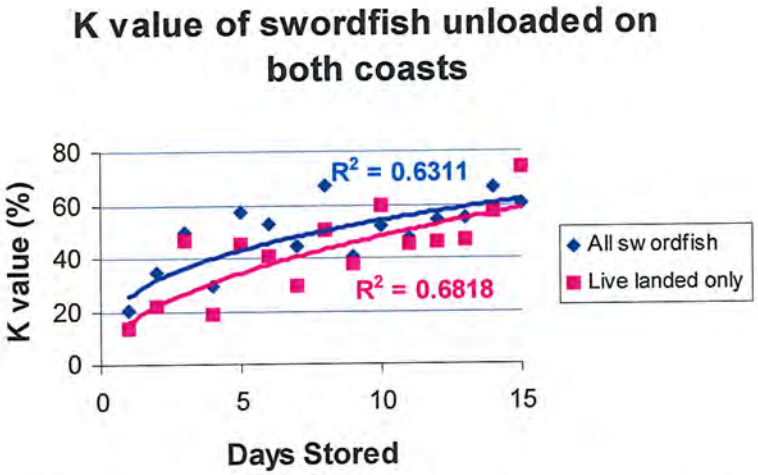


Figure 13. Mean K value of swordfish unloaded at the factory after some storage on the vessel.

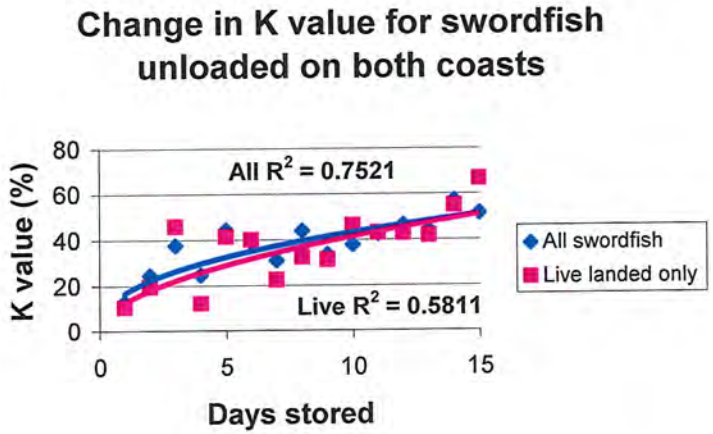


Figure 14. Change in K value of swordfish from landing to unloading after some storage on the vessel.

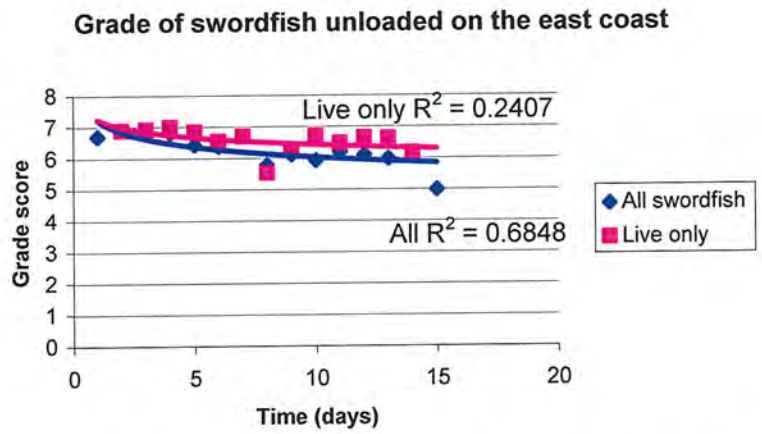


Figure 15. East coast factory grade of swordfish unloaded at the factory after some storage on the vessel.

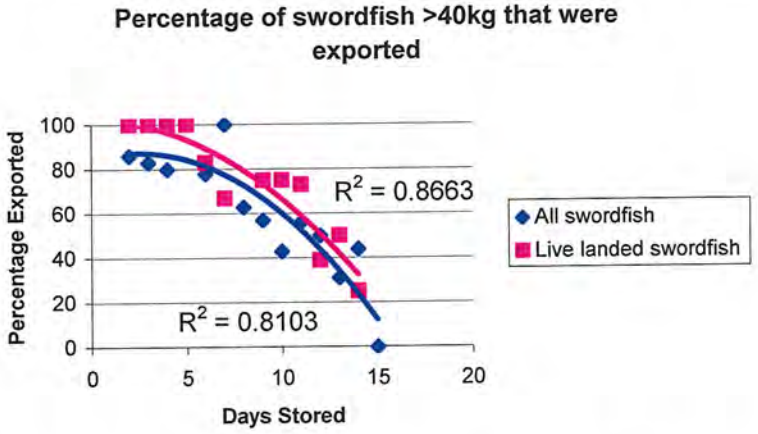


Figure 16. Percentage of >40kg swordfish exported from the factory after some storage on the vessel.

The graphs contain plots for both the parameter for all the catch and those for swordfish that were landed alive, showing the relationship for the different storage times. The mainstay of our quality measurements, K value, did show significant increases as storage time increased as well as the amount of change over that storage period.

The factory grade scored for swordfish on the east coast did drop as storage progressed, as did the export potential. As swordfish only larger than 40kg are generally exported only this particular pool of data has been presented in Figure 16. This graph shows that there is a dramatic drop in the proportion of the catch that can be exported as storage time increases. If there is a major difference between the profit levels for domestic and export swordfish (such as when the Australian dollar is low) then the revenue received from swordfish may fall if trips become too extended. After 10 days storage less than half the catch was exported.

Discussions with industry about this result has identified some of the constraints the long distance fleets operate under. They require large catches to "break even". When the catch is low they will extend trips fully knowing that the catch already in the hold will be of lower quality when finally unloaded. The smaller vessels operating shorter trips will continually produce better quality, and the owners state they are acutely aware of this aspect, and have been better equipped to survive periods when the Australian dollar is high. There will also be better profits from the resource if vessels conduct shorter trips. This situation may change if quotas are established for the industry.

5.11.1 Conclusions

The longer the storage time the lower the quality of swordfish at unloading. There will come a time when revenue will be lost if extended trips result in overly long storage times.

5.12 Microbiological testing of damaged tissue

Table 33 in Appendix 9 presents the total microbial (standard plate) counts and the psychrotrophic (cold loving bacteria) counts of swordfish flesh taken from a range of different types of damage commonly present on longline caught fish. These were large shark bites, cookie cutter shark bites or knife cuts.

5.12.1 Fresh wounds

Microbiological testing of a shark attached fish unloaded at the factory found very high total and psychrotrophs counts in the flesh within 10mm of the surface of the cut. The samples were taken after the skin had been removed for the area being sampled so the counts have originated from the movement of bacteria into the flesh directly from the exposed surface. Counts such as these would give concern if the flesh was not trimmed and sold for human consumption.

A further 10mm into the flesh, while the total counts had dropped, the psychrotrophs counts were still very high. The flesh between 20 and 30mm from the outer surface of the cut did show sufficient reduction in microbiological counts to be safe for consumption, as long as there was little further storage. The long term storage of swordfish on long line vessels, >10 days in ice, would have selected for the cold loving psychrotrophs. It is of no benefit to trim this tissue of before storage on the vessel because bacteria will enter from the skin into newly cut flesh during storage.

5.12.2 Old wounds

Even when the wound has started to heal there are bacteria present in the flesh. The two swordfish sampled with recently healed cookie cutter wounds that were covered in scar tissue still had moderate numbers of bacteria within the flesh adjacent to the wound.

5.12.3 Knife Cuts

Although of a limited sample size even the edges of knife cuts are highly contaminated. This is most likely because of the close presence of the guts when the incision is being made. These areas should be treated as the other types of damage.

5.12.4 Conclusion

There was no statistical difference between the different types of damage for microbiological count. There were significant differences ($P<0.01$) for the distance from the edge of the damage. The flesh at the edge of the damage had a significantly higher bacterial load. The further away from the edge the lower the bacterial count became. While there was no statistical difference between flesh that was 10 and 20mm away from the damage, there was a consistent reduction in the numbers by half a log count. Because of the rapid growth of bacteria their numbers are normally based in powers of 10. A reduction of more than one log is considered a significant improvement. Because these samples were 10mm wide, the transition zone for a significant drop in count may have been part the way through the second piece. To minimise the deterioration of swordfish flesh that consumers would encounter a conservative approach is required.

5.12.5 Recommendation

It is recommended that tissue 20mm wide should be removed from all damaged and cut faces when trimming swordfish for the domestic and export markets. One thing to remember is that the trimming only needs to be done prior to cutting into retail pieces. If the swordfish are trimmed before freighting and then there is subsequent storage then further trimming may need to be repeated at the receivers end.

5.13 Histamine evaluation

Of the 9 fish tested none had any measurable histamine present. Unless there is a major mishap with hauling the long line there is little chance of swordfish developing histamine under current industry practices. Histamine is only likely to develop if the fish are left on deck for extended periods of time and insufficiently iced during storage.

OBJECTIVE 2 DESIGN AND TRIAL MODIFICATIONS TO CURRENT METHODS TO ELIMINATE PROBLEM AREAS

The extensive sampling undertaken during the 7 voyages and 10 factory samplings has resulted in a large amount of data on various practices. All of the areas identified by industry at the start of the project (see Appendix 1) have been investigated as well as others identified while conducting the project. Many significant findings were addressed above under Objective 1 and did not need to be further trialed eg: do not stand on swordfish, trim 20mm of exposed surfaces, tag all fish caught etc. The only area where a possible modification of current practice could be trialed would be with the use of circulation on ice slurries. As the two other methods were shown to be already better than a static ice slurry those skippers with mechanical refrigeration saw no benefit from this type of further experiment. Seen as a low priority by industry it was apparent that there was no need for any further expenditure from the $24,678.95 remaining in the project budget just to substantiate this recommendation.

When all aspects of the data had been fully evaluated and presented, no industry representatives who attended the planning meetings for any final experiment were concerned about testing out the introduction of pumps into ice slurries. Also no feedback was returned from emailed reports of the data pertaining to this issue. One consequence of providing this data was that one of the ice slurry vessels that participated in the project has now been converted to a RSW system. Normally vessels using ice slurry do so because existing refrigeration systems break down when it is inconvenient to refit. This was the case with this vessel.

As for the few other ice slurry vessels currently operating, with the shrinking returns from longline fishing the owners are unlikely to spend much more either rebuilding the system or adding new equipment that would probably also break down at some time while at sea. To ensure that one more trip could be conducted within the time span of the project on the only aspect identified by this investigation as important enough to trial would have entailed the purchase of an expensive Capital Item not identified in the Contract. Even if an owner could be convinced to carry out the modification it would have had to wait several months until the vessel was due for a refit as spray bars would need to be attached as well as a pump.

As time had severely runout to fit in another trip (there had already been considerable delays to the experiments because of crew shortages), extract the samples obtained and then analyse the data before the submission of the draft final report was due, it was decided by the researchers to continue with more in depth data analysis and carry out extension activities at ports not previously visited and to return savings from the project to FRDC.

The key area of further in-depth analysis was the storage methods and the results of this are present in the discussion of Objective 1. The understanding about the ice slurry system gained from this analysis led to the final recommendation that the addition of a pump to an ice slurry tank would greatly improve the quality of freshly landed swordfish chilled by ice slurry.

Even if industry did want to investigate this aspect further, chances of getting this particular vessel that participated in the project to conduct this type of trial was limited. The researchers would have to convince the owner of the vessel that the expenditure required would be compensated by the unlikely chance of increased returns from better quality. As discussed earlier the main goal of most longline companies is to obtain large catches, often at the expense of quality.

Even if this trial was acceptable to the owner, the timing of another ice slurry trip would have to be delayed until after the end of this project because the particular vessel would need to undergo a refit to install pumps, spray bars and temperature monitors. To obtain sufficient data to investigate what amount of improvement could be attained, at least two trips would need to be conducted. The remaining budget and project deadline do not allow for this.

As both refrigerated brine and seawater currently provide better conditions for the initial chilling of swordfish (these can operate below 0°C) it seems unnecessary to spend any further time on proving that ice slurry (this can only reach 0°C if melted ice is replaced continually) can be more efficient. The K value results for ice slurry storage were 30% higher than the RSW system. Considering the refrigerated brine, when operating effectively, produced swordfish with K values half of that again of RSW stored swordfish it would seem to be more statistically appropriate to repeat an investigation of this system under proper operating conditions rather than the ice slurry. When the workshops were called industry did not show any interest in either scenario.

OBJECTIVE 3 TO DETERMINE IF RAPID SENSING NIR EQUIPMENT AND OTHER TECHNOLOGIES CAN BE DEVELOPED TO SCREEN FOR PARASITE INFESTATION

5.14 Jellied Flesh Syndrome

Myxosporea are parasites on different tissues and organs of cold-blooded vertebrates, mainly fish. The myxospidia *Chloromyxum musculoliquefaciens* has been detected in swordfish muscle (Konagaya 1983). Protein degrading enzymes (protease) can be readily extracted from parasitised swordfish muscle fibres. The jellification of the muscle texture is caused by the action of a cysteine protease which has a great ability to digest muscle myofibrils. The enzymes can have a high activity at room temperature. There are no external signs that a fish has been parasitised. The microscopic cysts reside close to the spinal column at the anterior end of the trunk and so are difficult to detect in a tail cut. Because swordfish are kept at low temperatures up until they are exported there is little chance for proteolysis to occur. Most parasitised swordfish are detected when being cut up for the retail market.

As background information about the incidence of jellied swordfish, industry indicated that the incidence could be as high as 5%. Early in the project information collected from some industry interviews (Table 22) suggested that there may be a size effect and that the fish exhibiting the condition were mostly small. If that is the case then it is unlikely to be a parasite-based artefact. Textural measurement (Instron Universal Testing Machine) is the appropriate method for investigating an age-associated defect. Other information obtained from fishers was that there are regions with high infection that are usually avoided when fishing. As the sighting of swordfish with this condition was rare it was hard to confirm the frequency or cause of the changes in swordfish. It would have been impossible to test a sensor that can identify parasitised swordfish at the factory if no samples were made available. A list of companies and their observations are contained in the table below.

Table 22. Industry comments on cause of jellied fish.

Company name	Observation
Catalano Seafoods	No size trends apparent
De Brett Seafood	Mainly small fish
Latitude Fisheries	No size trends apparent
Tohzai King	Possible localised phenomenon
Poulos Bros Group of Companies	Less than 1:500, no more than 4 or 5 in 3 years
De Costi Seafoods	More often in the past, not seen for couple years
Kabachi Seafoods	2yrs ago 1:200, now 1:1000
Claudios Seafoods	Never found
Sydney Fish Market	Rare, reason 18 months ago size limit <50kg

It appears that the problem has decreased in the last 2 years. While this may be due to climatic conditions some retails suggested that it was associated with a maximum size limit introduced by the Sydney Fish Market. Parasite numbers do show correlations with size of host so this limitation of swordfish over 50kg in weight may have led to less frequent incidences in fish coming through the Sydney Fish Market. Elsewhere the problem may have had a higher rate of frequency but it probably was still quite infrequent.

5.14.1 Methods

When swordfish with poor textural quality were identified they were shipped to the laboratory in Brisbane for evaluation. Here they were appraised using a number of chemical tests.

When the chemical and microscopic tests were finished the samples were then sent to the laboratory in Rockhampton. Sometimes these samples were quite old by the time they arrived for NIR evaluation and had to be frozen.

5.14.1.1. Preparation of samples

Twenty grams of the flesh was homogenised with an equal weight of water in a Waring blender (40s, high speed). Ten g of the homogenate was then centrifuged at 5000g for 30 minutes. One mL of supernatant was removed for protease activity assessment. Ten g of original homogenate was removed for total nitrogen evaluation. Twenty g was blended with an equal weight of 20% trichloroacetic acid (TCA) and then filtered through Whatmans No. 542 filter paper. Twenty mL of the supernatant was evaluated for total non-protein nitrogen while 0.1mL was used to determine peptide content.

5.14.1.2 Azocasein Assay

One mL of the supernatant was used to test for protease activity. The protease activity was measured using 0.17% azocasein as substrate. The procedure follows that of Jensen *et al.* (1980), and one unit of activity was defined as the amount of enzyme required to produce a 0.01 unit absorbance increase at 366nm per hour under the standard assay conditions.

5.14.1.3 Peptide Assay

The Dulley and Grieve (1975) modification of the Lowry *et al.* (1951) Folin-Ciocalteu protein determination assay was used for determine the amino acid content of the TCA extract and the results were expressed as mg/g tyrosine equivalents.

5.14.1.4 Total protein

Total protein (TP) was determined by the Kjeldahl method (AOAC, 1984) that evaluated total nitrogen (TN) and total non-protein nitrogen (TNPN). Total protein was thus determined by the formula:

TP (%) = (TN% - TNPN%) X 6.25

5.14.1.5 Proteolysis index

The proteolysis index (P.I.) was used to give an indication of the degree of protein breakdown that had occurred within the flesh. It was determined by the following formula:

P.I. = mg/g tyrosine equivalents / Total Protein%

5.14.1.6 NIR examination of swordfish tissue

Part of the samples received as being possibly parasitised were sent on to the laboratory in Rockhampton for Near infra-red spectroscopy (NIRS). There was no predefined NIR procedure for swordfish so various methods had to be trialed with the limited amount of material available. NIR has been in routine use for the assessment of a range of components in dry materials (e.g. protein in grains). Near infra-red is the area of the electro-magnetic spectrum between 700 and 2500 nm and concerns the bending and stretching of molecular bonds (C-H, N-H and O-H). These bonds are involved in most organic compounds, such as sugars, protein, lipids and water.

The presence of water, which also absorbs strongly in the near infra-red has limited the use of NIRS for assessment of quality of fresh produce. However, recent improvements, namely, the massive increase in computing power of modern PCs and the development of software capable of carrying out the complex statistical mathematics has made the technique applicable to high moisture products such as fresh fruit. Further, recent improvements in fibre optic and sensor technology have made the technique applicable to an in-line, commercial food processing operations.

Scanning of the samples was undertaken in transmission mode (Figure 17) using a 100 watt tungsten halogen light source and two Zeiss spectrometers (MMS1 and InGaAs). These two spectrometers are photodiode array (PDA) instruments. The Zeiss MMS1 has 256 silicon (Si) diodes covering an area from 306nm to 1100nm at approximately 3.3nm intervals. The InGaAs PDA has 128 indium gallium arsenic diodes covering 800nm to 1700nm at approximately 6.6nm intervals.

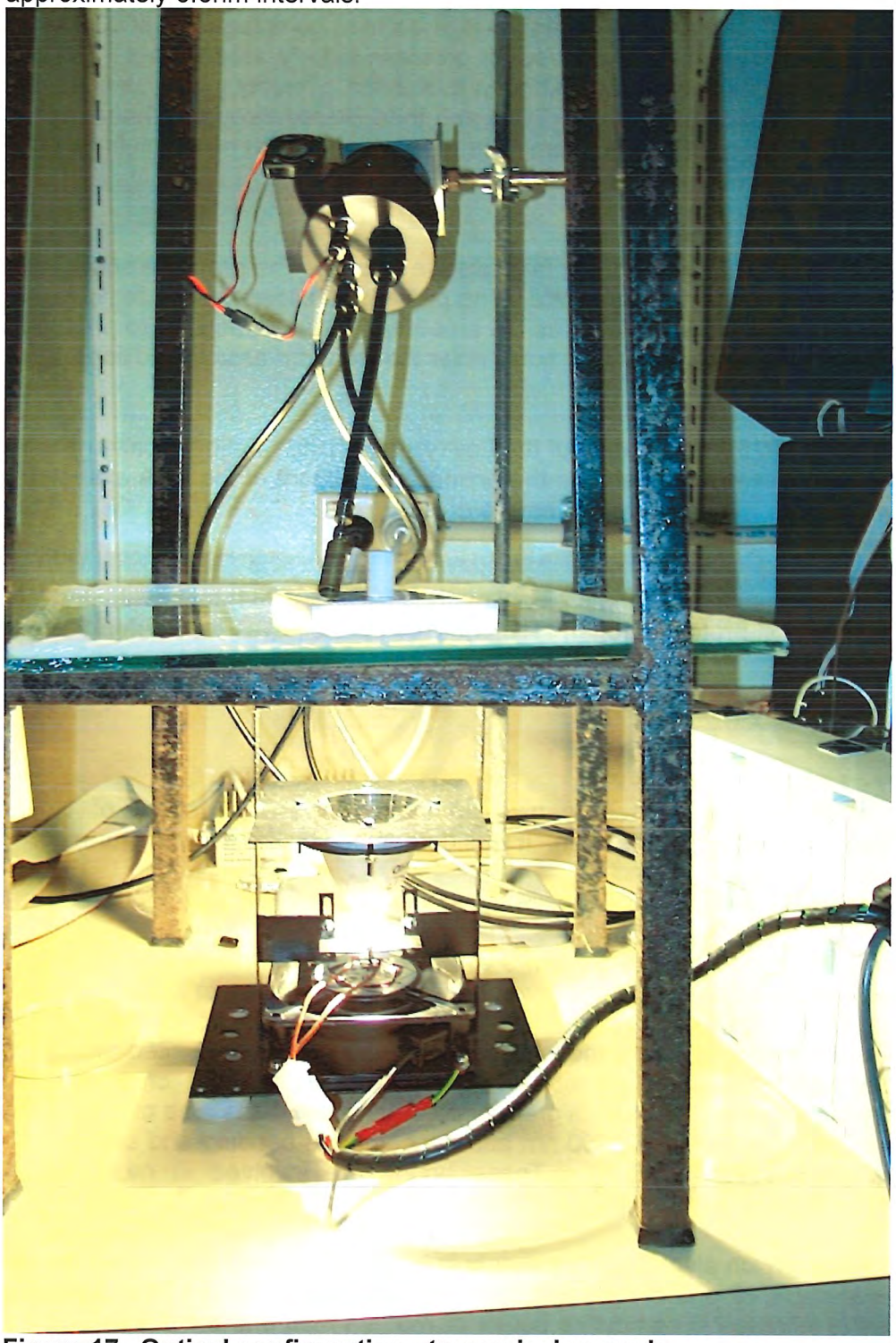


Figure 17. Optical configuration - transmission mode

The samples of fish (in polyethylene bags) were presented to the above instruments alternatively skin and flesh side towards the light source. Nine spectra were taken per skin and flesh side using a plastic template with 10mm diameter holes (Figure 18).

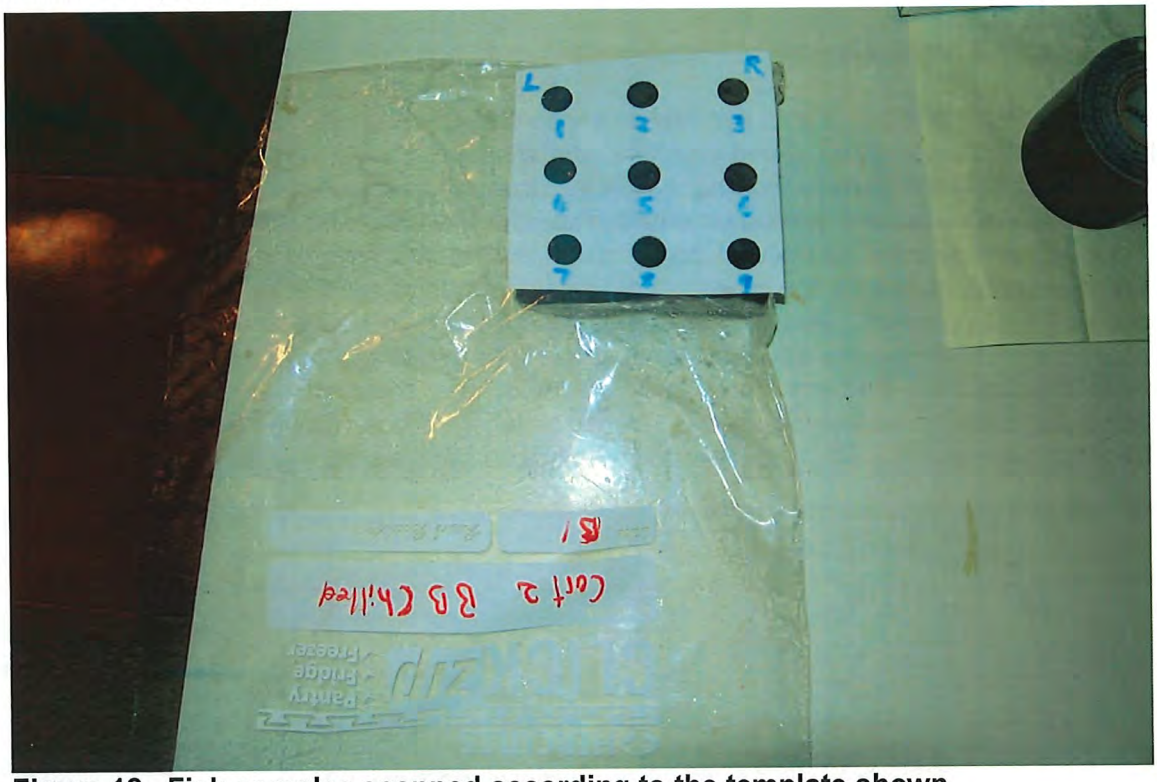


Figure 18. Fish samples scanned according to the template shown

5.14.2 Results

During the first year only two suspected "jellied" fish were identified and supplied by industry. At the end of the project only four sets of possibly parasitised swordfish had been obtained, two from WA and another two from Mooloolaba. This suggested a very low level of incidence for this condition.

5.14.2.1 Possible parasitised swordfish No.1

The first possible parasitised swordfish supplied by the factory at Mooloolaba was a juvenile. These small fish are normally not kept by vessels so there has been no NIR work carried out. The flesh did not contain any parasite cysts when evaluated by Professor Bob Lester under a microscope. No protease activity was present in this speciman, even though their presence has been identified overseas as a consequence of the parasite infestation in swordfish (Konagaya, 1982).

Conclusion

This swordfish did not display any attributes which would help with Objective 3.

5.14.2.2 Possible parasitised swordfish No.2

A shipment was sent to the laboratory from Latitude Fisheries Ltd, Geraldton, WA on 12/12/2002, comprising a swordfish which industry had thought to be parasitised and an uncontaminated control fish. It was sent on to Rockhampton for NIR testing. As samples had been very rare up to this time it was difficult to set up a reliable NIR method that could be used routinely. In all 432 spectra were taken. Further work would involve chemometric analysis of the spectral data to ascertain if near infra-red spectroscopy can differentiate between contaminated and uncontaminated samples through the skin of the fish.

As subsequent microscopic examination of the scanned samples showed no evidence of parasite contamination and protease activity testing identified no active proteases, no further chemometric analysis was undertaken.

Conclusion
This swordfish did not display any attributes which would help with Objective 3.

5.14.2.3 Possible parasitised swordfish No.3
In November 2003 a second jellied fish was identified from WA. When inspected at the Brisbane laboratory the texture was quite different from all previous samples. Being of low quality it had been originally graded as only suitable for the domestic market, however there had been no indication of a textural problem present at the time of grading. Only after delivery to and processing by the customer did it become apparent that considerable textural deterioration had occurred. At the customer's factory the skin had been removed and the loin had been cut into pieces and left standing at room temperature for some time. It was then that the condition became noticeable. When it was detected the researchers were contacted and the fish was shipped to Brisbane. After a further day of freighting the tissue had become even worse. The material had to be frozen before shipping to Rockhampton.

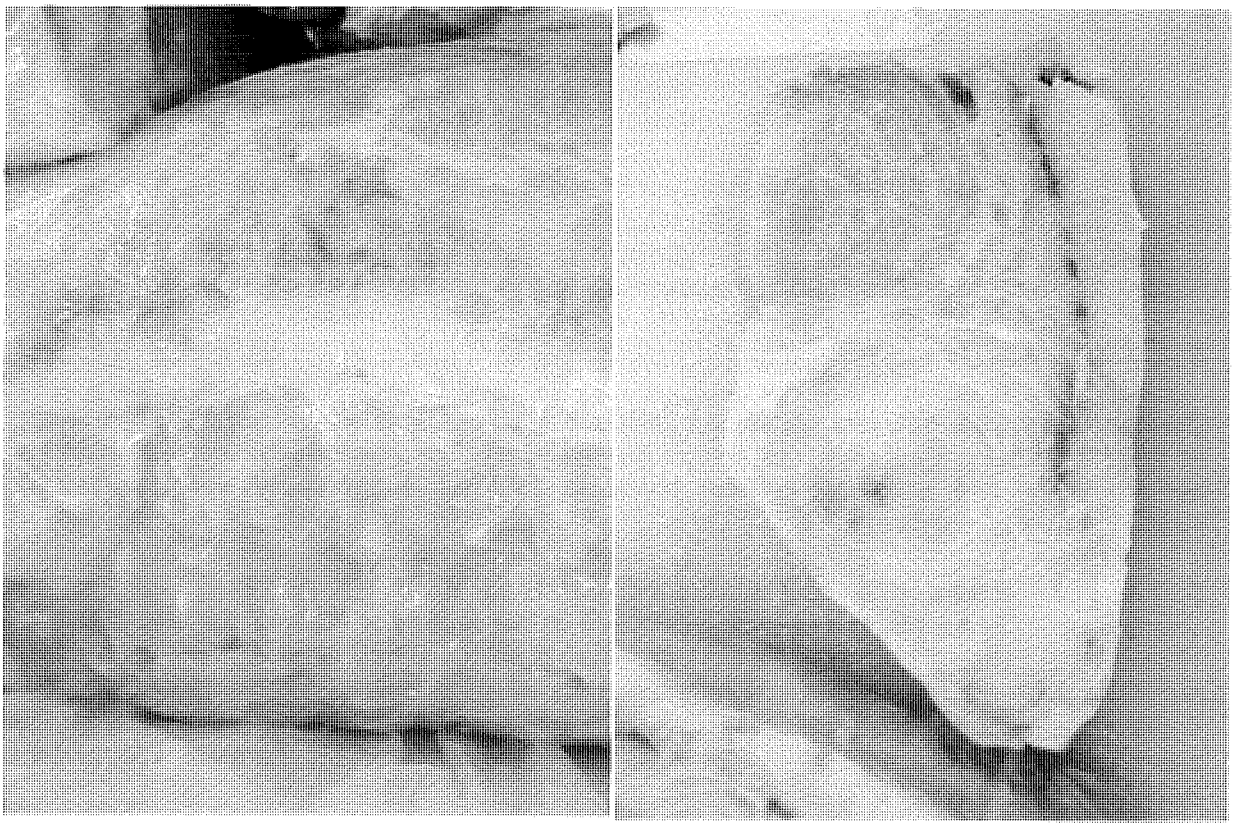


Figure 19a & b. Swordfish loin and cutlet of parasitised swordfish No.3 exhibiting softening of texture caused by proteolysis.

A representative cutlet was sampled at three sites, from the worst affected tissue close to the vertebral column, going outward through progressively less damaged tissue to the skin where the tissue was most intact due to less proteolytic enzymes being released to digest the muscle tissue. There is almost total digestion present in the mushy core of the flesh that lies close to the vertebral column. This is where the majority of parasites tend to reside. Figure 19 shows intact flesh of the dorsal region of a swordfish loin (a) and a cutlet (b), while the central section shows significant digestion and loss of texture. Figure 20 is a photograph of a cutlet with severe proteolysis that was located close to the spinal column. The damage decreased towards the outer and dorsal region and pitting is visible where only individual parasites had been present.

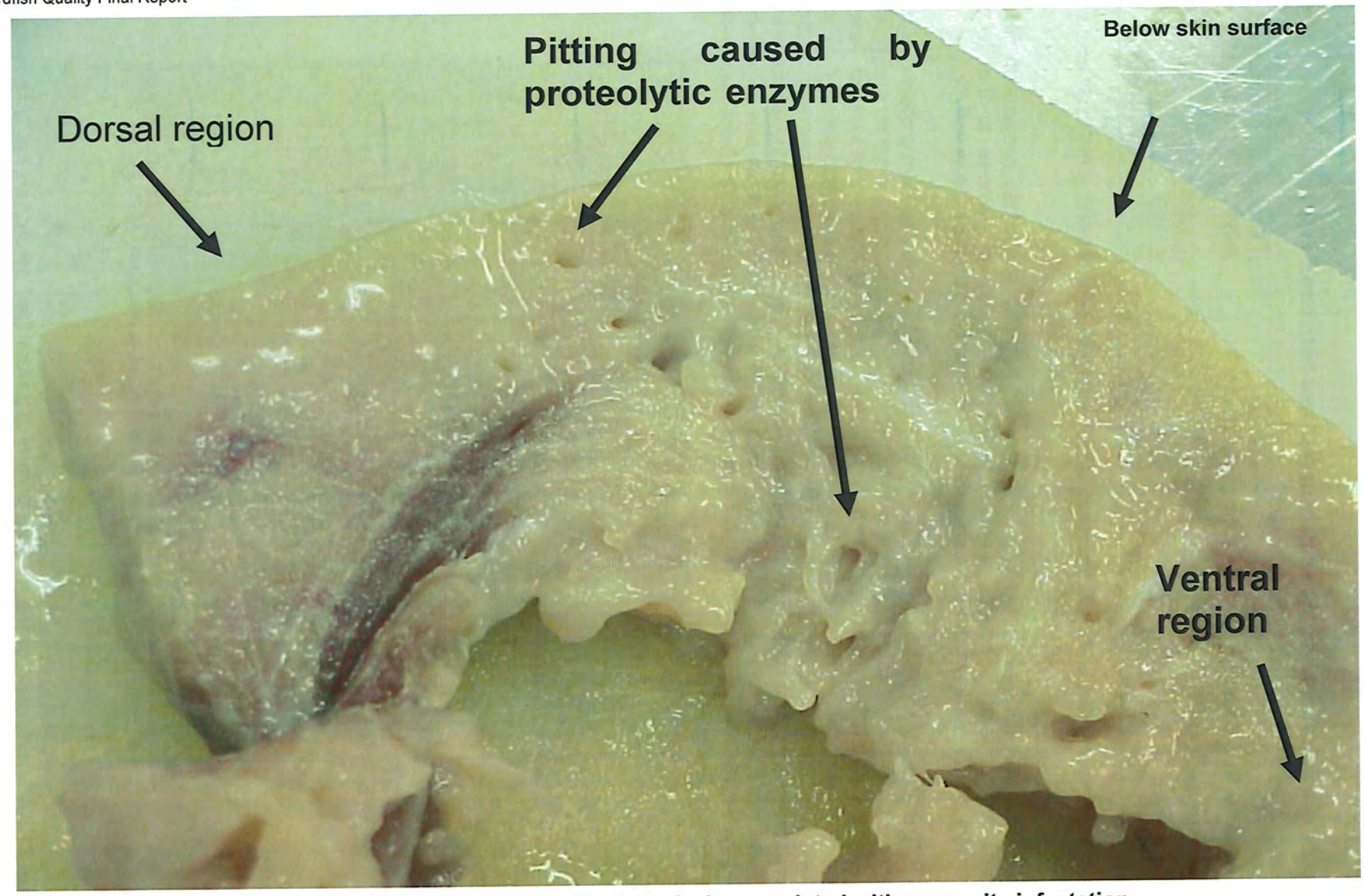


Figure 20. Cutlet of swordfish exhibiting pitting caused by proteolysis associated with a parasite infestation..

Table 23 contains the results from the chemical tests conducted and the Proteolysis Indices that were calculated from the data.

Table 23. Chemical profile of the highly parasitised fish from Geraldton.

Sample position	Protease activity (units/g)**	Peptides (mg/g tyrosine equivalents)**	Total Protein (%)**	Proteolysis Index**
Mushy core	14.3[a]	2967[a]	13.756[a]	216[a]
Half way to skin	0.4[b]	979[b]	16.706[b]	59[b]
Near skin	0.2[b]	709[b]	17.137[b]	41[b]

Measurement means followed by a different superscript are significantly different at the ** 1% level or * 5% level.

The protease activity was concentrated about the region that is in close association with vertebral column and is directly responsible for the amount of damage to the flesh (Konagaya, 1982). Away from the mushy tissue there was almost no protease activity.

While there appears to be a progressive drop in free peptides released from protein due to protease activity related to distance away from the damaged core, there were no statistical differences between the three sites for this measure. Table 23 shows that level of Total Protein was significantly reduced ($P<0.01$) by the protease activity that was present. The resultant Proteolysis Index was significantly higher ($P<0.05$) for this site than any tissue closer to the skin. When sectioned and stained histologically, cysts similar to those known to be *Kudoa* were present. Figure 21 shows a section of a muscle fibre from this swordfish stained by H&E. An individual plasmodia can be seen in the center of a cleared zone of digested muscle tissue.

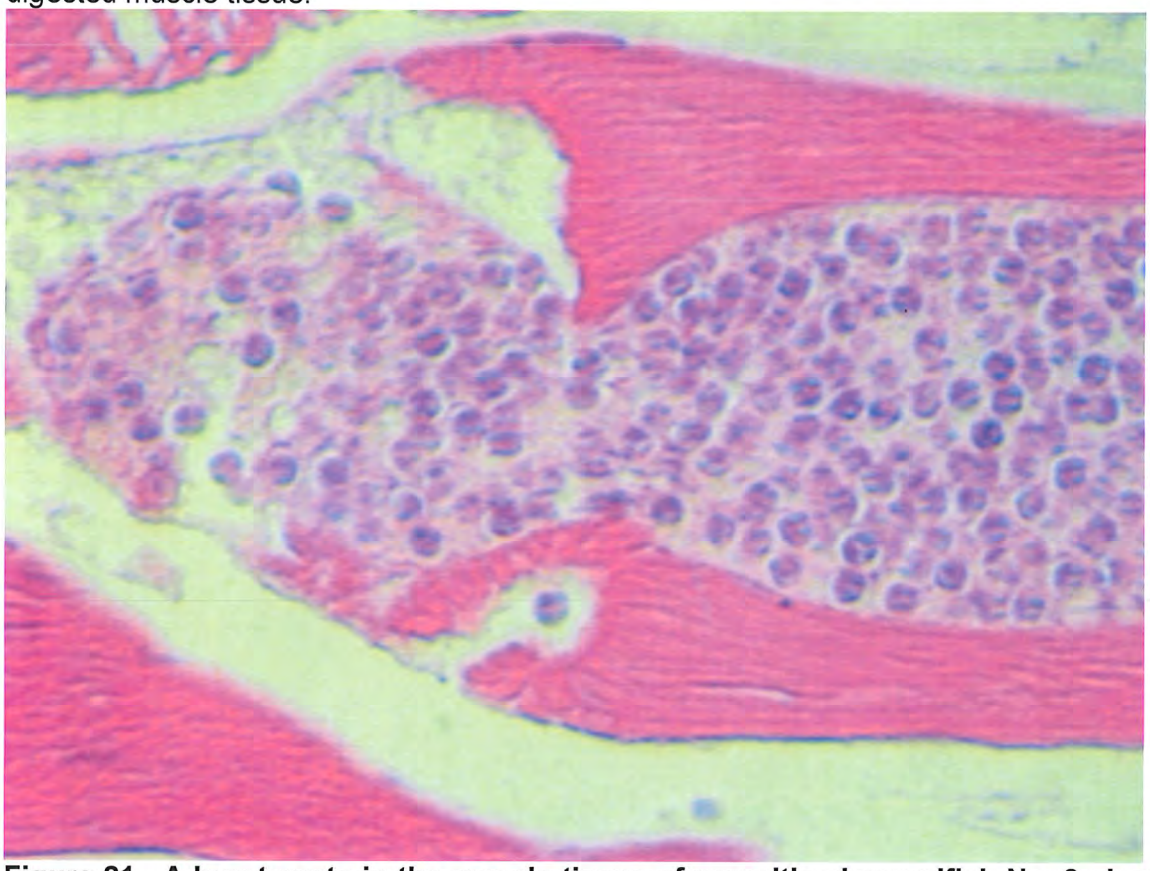


Figure 21. A burst cyste in the muscle tissue of parasitised swordfish No. 3 showing clearing around an individual plasmodium.

The NIR samples consisted of flesh all from the one swordfish. One sample was labelled sound (varying degrees of parasitic contamination) and another as fully 'mushy' tissue. The samples were scanned in transmission mode on two Zeiss photo-diode array spectrometers (Si and InGaAs) after thawing to 10° C in a refrigerator. The spectral windows used were 700 to 1050 nm, and 800 1700 nm for Si and InGaAs, respectively. The flesh was cut into approximately 120mm square blocks of 25mm thickness. Scanning was undertaken using the template (refer Experiment 1) except the samples were without skin and scanned on one side only. The parasitic infestation increased from the dorsal area (skin removed) to the gut cavity with spectra taken through the gradient of infestation (parasite levels increased from external (skin) to internal (gut cavity)). Thus scanning was confounded with increasing level of parasite contamination. The software packages 'The Unscrambler', (vers. 7.8) and 'WinISI', (vers. 1.5) were used for the chemometric analysis. For this qualitative (discriminant) analysis raw absorbance and 2nd derivatised data were used.

In all 95 spectra were taken (Table 24). These comprised 36 spectra visually sound and 59 spectra exhibiting substantial tissue breakdown ('mushy'). However, because of the inconsistent nature of the flesh integrity, which affected the optical density and caused saturation of instrument detectors, 23 spectra had to be discarded (data were unusable).

Table 24. Spectra of extensively and partly damaged swordfish tissue undertaken.

Sample	Spectra	
	MMS1	InGaAs
Block 1	9	9
Block 2	9	9
Block 3 'Mushy'	19	22
Block 4 'Mushy'	9	9
Total	46	49

The results for the discriminant analysis were similar for both instruments and data pre-treatment. As can be seen in Figures 22 and 23, separation of 'mushy' from visually sound could be achieved, but without separation within the visually sound.

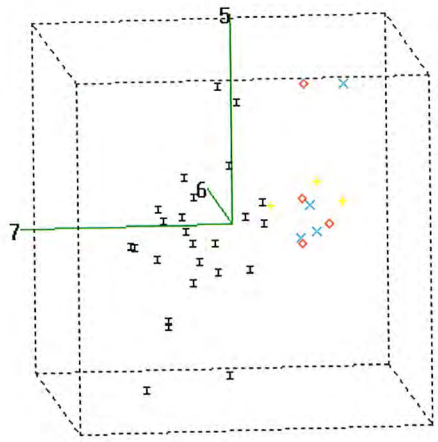


Figure 22. 3-D plot of scanned samples using principle components 5, 6, and 7 of absorbance data with the Zeiss InGaAs. Samples visually sound denoted by coloured symbols and 'mushy' denoted by black symbol.

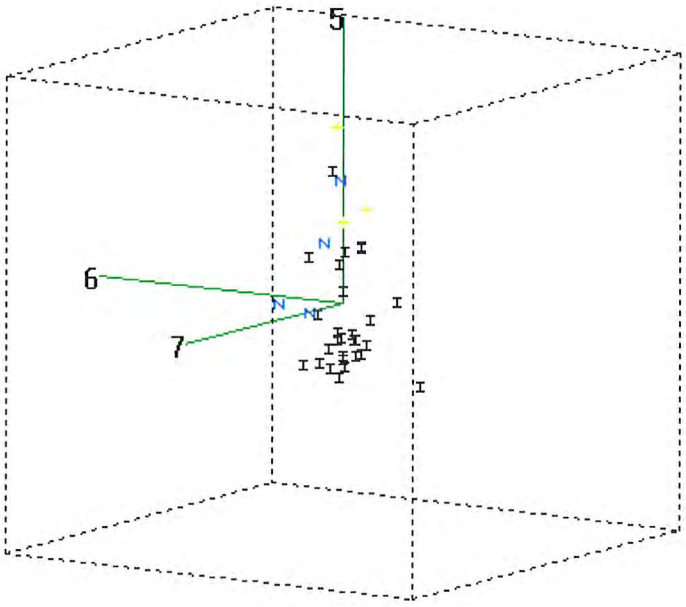


Figure 23. 3-D plot of scanned samples using principle components 5, 6, and 7 of absorbance data, with the Zeiss MMS1. Samples visually sound denoted by coloured symbols and 'mushy' denoted by black symbol.

For this investigation all samples originated from a single animal with parasitic data considered as the only changing variable in the scanned matrix. Other parameters, e.g. muscle type and muscle composition, having a random correlation to the feature of interest may have been unknowingly modelled. Without a scientific basis this assumption is probably flawed, however the use of large data populations (animal numbers) could give better insight into this issue.

Conclusion

Any future work should utilise numerous samples across a large number of animals (30 - 50), so as to incorporate the inherent variability between individuals. It is recognised that the cost and logistics of sample acquisition may be prohibitive. These conditions are unlikely to be met given the low incidence of detection.

5.14.2.4 Possible parasitised swordfish No.4

A swordfish from the last trip appeared to have a very soft texture when graded at the Mooloolaba factory. It was initially queried as possibly infested with *Kudoa* when landed. It had an old large shark bite that had removed a large portion of the muscle on the left side which had subsequently healed, as well as large numbers of scars from cookie cutter sharks. While it easily gave way with finger pressure to the skin it was not falling apart like the swordfish from WA. The fish was graded as domestic until we pointed out the condition and then it was decided to dispose of it. After being cut in half through the belly region samples were then taken back to the laboratory for evaluation. This time four positions within the dorsal loin were sampled. Figure 24 shows holes in the trunk where the samples were taken.

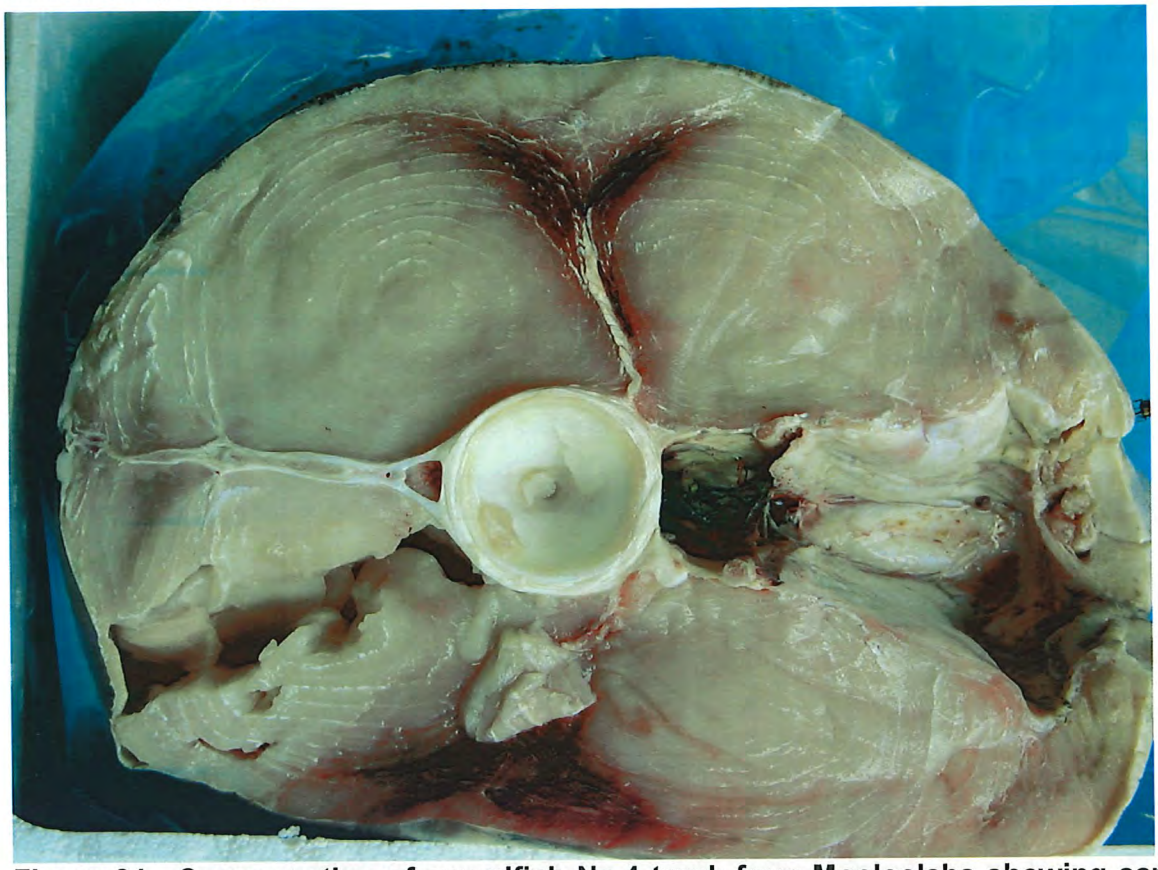


Figure 24. Cross section of swordfish No.4 trunk from Mooloolaba showing sample sites for chemical analysis.

The same chemicals tests used previously on "possible parasitised swordfish 1, 2 and 3" were carried out on this specimen. To find out whether the enzymes could withstand freezing duplicate samples were frozen and thawed at a later stage (long after the NIR evaluation had been completed) for a second protease assay. Table 25 below presents the results of the various chemical analyses.

Table 25. Chemical profile of the highly parasitised fish from Mooloolaba.

Sample position	Protease activity (units/g)	Peptides (mg/g tyrosine equivalents)	Total Protein (%)	Proteolysis Index	Protease activity after thawing (units/g)
Near the vertebrae	1.45	770	14.9	51	0
Quarter way to skin	1.2	730	16.9	43	0
Half way to skin	1.3	670	13.7	49	0
Near the skin	1.5	655	14.3	46	0

There was no portion of the cutlet that held any significant levels of protease activity. The levels were slightly higher than the low levels encountered in "possible parasitised swordfish number 3". There were no differences between sample sites for protease activity or peptides. The level of peptides present in this swordfish is less than was present in the undamaged tissue of the previous jellied swordfish. The amount of total protein present was similar for all sites but they were mainly lower than that seen near the skin of the previous swordfish. The Proteolysis Indicies were similar to the undamaged tissue of the previous parasitised swordfish and there were no significant differences between sites.

After freezing and thawing what little protease activity that had been present was gone. There is obviously some mechanism required to start the release of proteases. Most proteases normally require initial activation before they can be utilized. In this case the trunk was kept chilled throughout handling and sampling and was then frozen in an IQF tank. There was obviously no opportunity for the initial activation of any proteases to occur due to the cold temperature encountered up to the first protease evaluation and then the freezing of the remaining sample. Some enzymes, such as collagenases, do not survive freezing which would explain the absence of any activity present in the thawed tissue.

The flesh from this swordfish was cooked in a microwave oven using the high setting for 1.5 minutes (a normal setting for fish). When tasted there was no discernable difference in texture to that of a normal swordfish. Figure 25 shows a portion that was microwave cooked. Note that even the connective tissue is intact after cooking.

Figure 25. Cooked portion of parasitised swordfish No.4 from Mooloolaba

When sectioned and stained histologically, cysts similar to those produced by *Kudoa* could be observed (Figure 26). Nearly all of the cysts observed were intact and no clearing of muscle tissue was apparent. This was an unexpected outcome considering parasites and protease activity had been detected in the previous swordfish. This time there was no protease activity present and there had been no loss of texture. It may be that the fish was sampled a lot earlier than the one sent from WA and it had been kept at low temperature that even though the parasite was present in all tissue samples, there had not have been any protease activation, even in the near vicinity of the parasite. The lower levels of muscle protein may have been due to the weakened state that this fish would have been in while it was recovering from its wounds. Many species of fish use their muscle protein as an energy source when under nutritional stress, especially when migrating and spawning (eg. mullet and salmon).

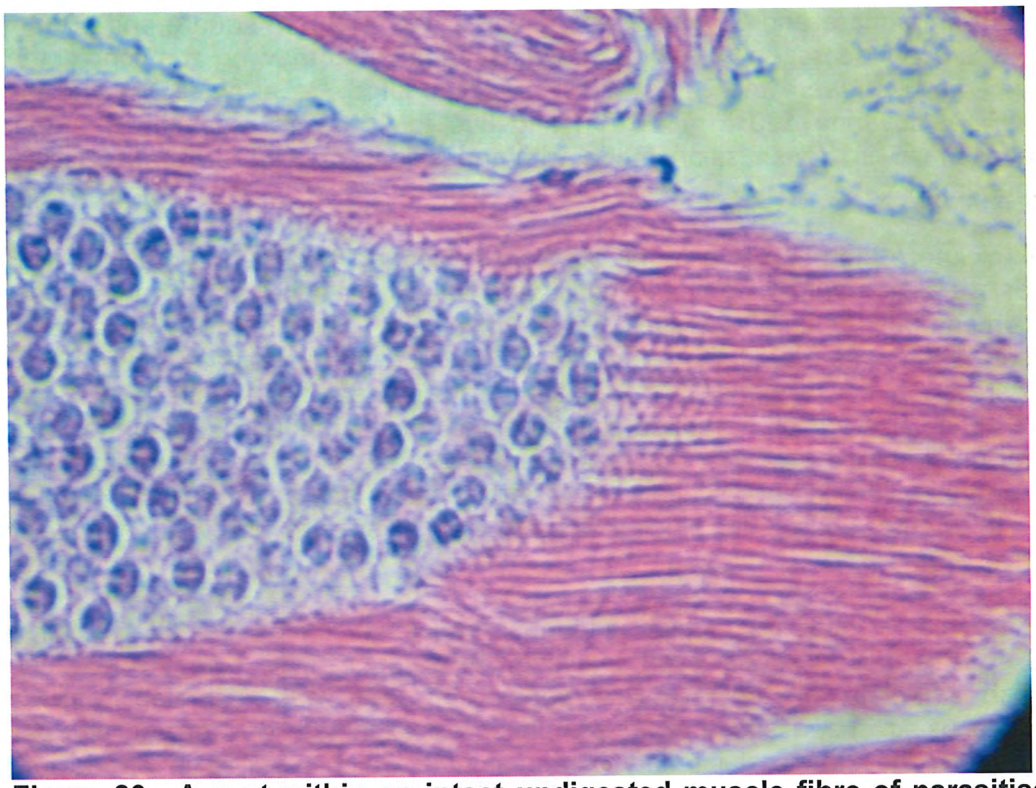


Figure 26. A cyst within an intact undigested muscle fibre of parasitised swordfish No.4 containing plasmodia.

For the NIR evaluation a sample of frozen swordfish flesh was tested, although it is anticipated that in a 'real world' situation this technology would be of practical benefit to the industry when used on fresh chilled product. The sample of approximately 20 Kg was from the one animal and was a transverse section of the trunk (Figure 27). Two blocks of flesh with skin on were removed from the above sample while frozen.

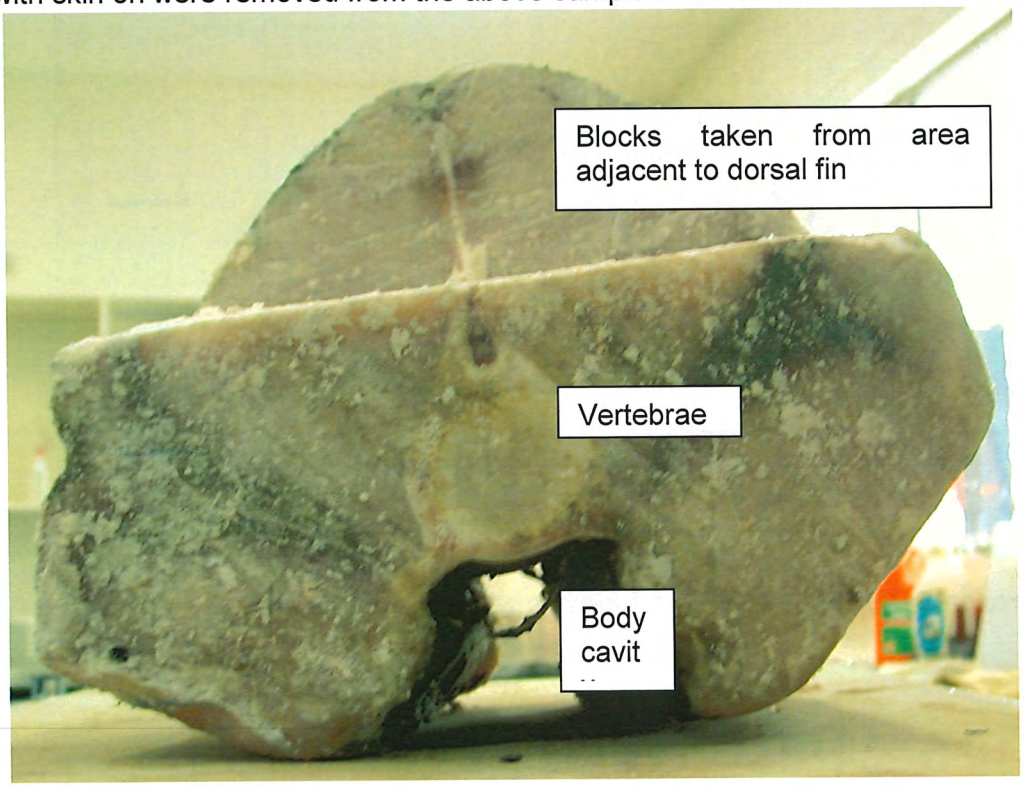


Figure 27. Swordfish sampling for light penetration experiment.

Block 1 was 100 mm square and 80 mm deep. Block 2 was 100 mm square and 40 mm deep. Block 1 was scanned frozen while block 2 was scanned after thawing at a constant 5° C. The instruments used were the Zeiss MMS1 silicon photodiode array (PDA) and the Zeiss InGaAs PDA, covering 400 to 1100 nm and 800 to 1800 nm respectively. Both samples were scanned in transmission mode with the skin side towards the 100 Watt tungsten halogen lamp.

Starting at full thickness the flesh side of the block was scanned and then approximately 5 mm thick slices were sequentially removed until transmitted light saturated the instrument detectors (silicon and InGaAs detectors used). A template with nine 6mm holes machined in a 30 mm square pattern was manufactured from a 100 x 100 x 10 mm square acrylic block. The spectra were acquired sequentially in a raster format at each thickness level. The bifurcated fibre optic cable, which permitted simultaneously optical data acquisition for both instruments, was maintained at 5 mm above the surface of the sample. Instrument data acquisition parameters were integration time of 250 milliseconds and an average of 4 scans per spectrum. In total 90 spectra for block 1 (frozen) and 54 spectra for block 2 (thawed) were taken.

Using Microsoft Excel ® both percentage and absorbance values of the NIR radiation (average of 9 spectra per thickness level) reaching the detectors was computed. Since 'fresh chilled fish' samples were not available, penetration depth was estimated from the experimental data using frozen and thawed samples. As expected the freezing process greatly compromised the structural integrity of the sample which resulted in erratic and unusable data (Figures 28 and 29). Thus the flesh in a thawed state exhibited greatly differing optical characteristics from the frozen. Therefore the focus in this report will be on the frozen results.

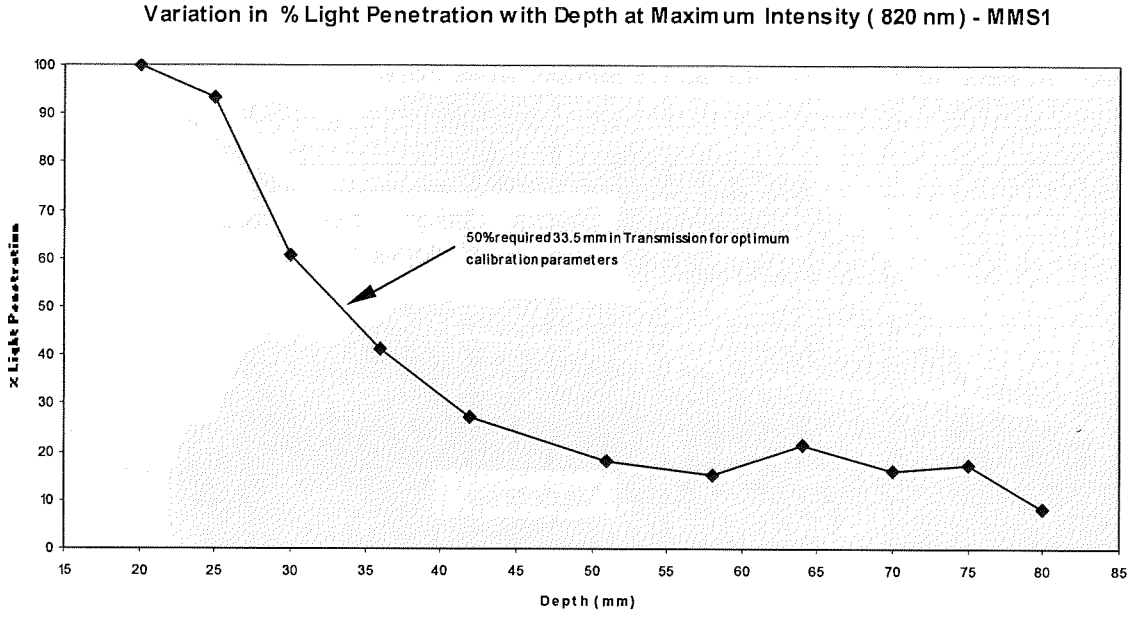


Figure 28. Frozen Swordfish - MMS1 % Light Penetration at 820 nm.

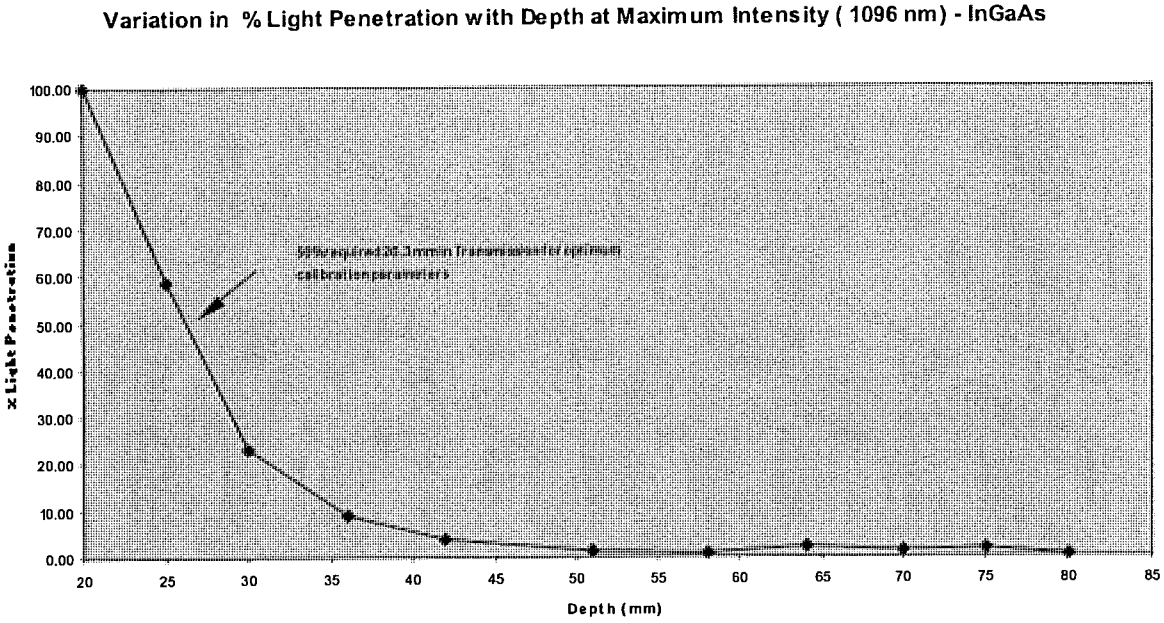


Figure 29. Frozen Swordfish - InGaAs % Light Penetration at 1096 nm.

A wavelength, chosen at peak intensity for each instrument (MMS1 820 nm and for the InGaAs 1096 nm), was used to determine the percentage of NIR energy reaching the instrument detectors through the fish flesh. The results are presented in Figures 30 and 31.

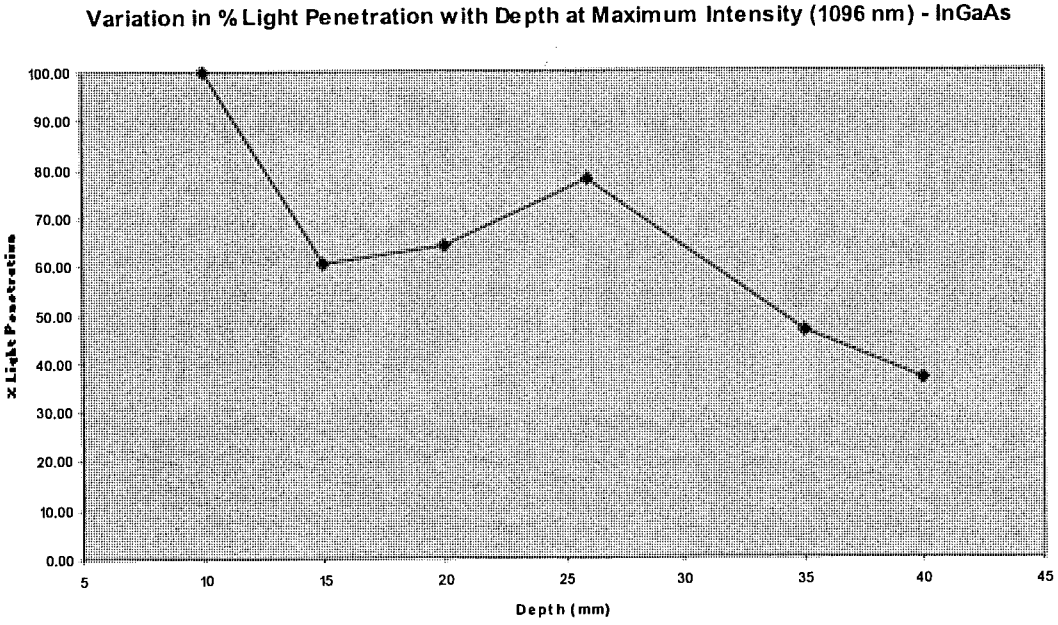


Figure 30. Thawed (5°C) Swordfish - InGaAs % Light Penetration at 1096 nm.

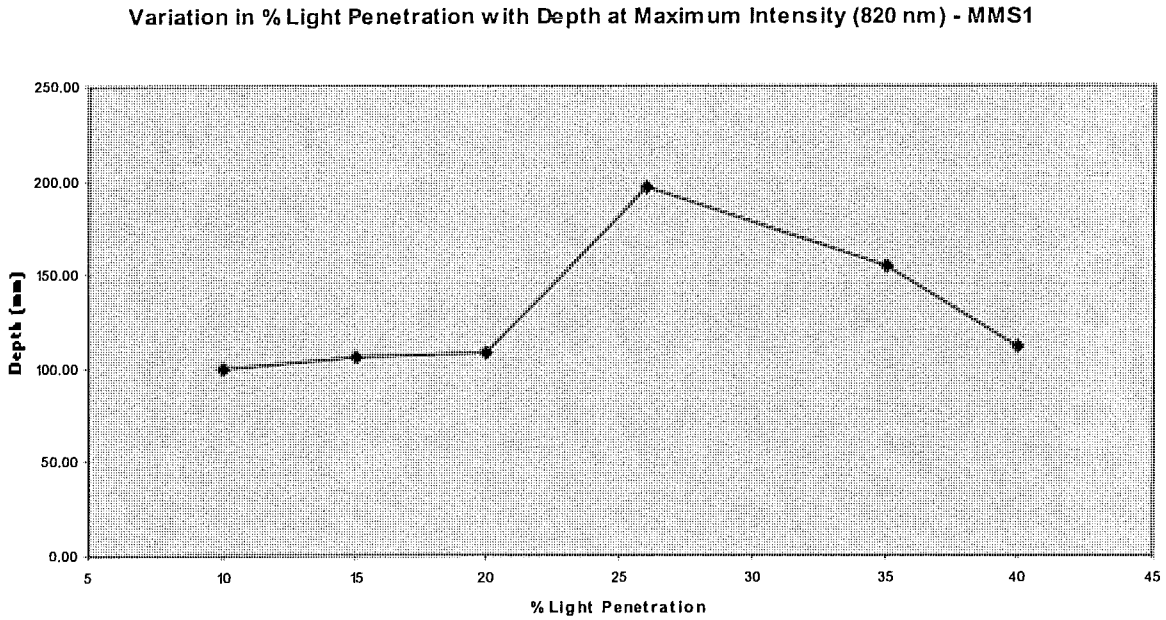


Figure 31. Thawed Swordfish - MMS1 % Light Penetration at 820 nm.

In transmission mode the depth of effective penetration of NIR energy was approximately 33.5 mm for the MMS1 and 26.3 mm for the InGaAs instruments. This was determined at the level of 50% of the effective energy and is seen as sufficient energy to produce useable spectra for qualitative and quantitative analysis. It is well documented in literature that an optical window exists in biological material from approximately 800 to 1,000 nm which permits good penetration due to low absorptivity. Penetration depth could be increased by a higher intensity light source, however the heat load on the sample would have to be considered. However, in practical use of this technology to analyse large intact fish trunks, reflectance mode would be the only optical mode possible.

Conclusion

The frozen swordfish flesh demonstrated that the penetration of NIR energy was still only a small percentage of the total depth of the fish. However, the optical characteristics of fresh chilled swordfish in regard to depth of penetration would be different to both frozen and thawed but not expected to offer any significantly better depth of penetration of NIR energy.

This particular swordfish had been stored for 12 days before unloading. The lack of protease activity and protein breakdown even when numbers of a parasite were present in the muscle tissue suggests that some activation process, other than warming or freeze/thawing, is required before texture changes are initiated.

5.14.3 Conclusion about NIR

The NIR measurements show that the penetration ability of the set-up is insufficient for assessment of whole fish trunks and that the light intensity cannot be increased without causing heat damage (parboiling) of the sample.

Parasitised swordfish exhibiting textural loss have only been identified after they have left the processing factory. It is likely that the cold storage systems used by the vessels and the factories are effective in keeping the muscle tissue cold enough to limit significant protease activity and thus prevent any textural changes that could be detected at the time of grading. Even when some proteolysis has occurred it could only be detected at such an early stage if samples were taken from the anterior portion.

5.14.4 Other testing equipment trailed to detect parasitic infestation

By the second milestone the other equipment offered for trial by Sastek did not arrive from New Zealand until much later in the project. It was hoped that it may have become available in the second year but the lack of positive samples made it difficult to trial any other equipment anyway.

The type of technologies that could be used to identify parasitised swordfish may have to rely on samples of flesh containing the parasite, preferably taken from the site of maximum concentration (usually close to the vertebrae). PCR equipment can give the type of rapid results needed when packing an export shipment of swordfish but the price per test compared with the amount of savings from parasitised swordfish not being shipped may be prohibitive for this industry.

5.14.5 Conclusion about rapid sensing

Only one swordfish was obtained during the life of the project that had lost textural quality. It has been determined from the experiments conducted, the low incidence of jellied swordfish detected over a two year period and the cost of detecting these few individuals using expensive complex equipment of any type that the application of any rapid sensing system is unfeasible for the longline fishing industry. Thus this objective has been met.

OBJECTIVE 4 TO PROVIDE INFORMATION THAT WILL CONTRIBUTE TO A BAR CODING SYSTEM FOR TRACKING SWORDFISH

The previous sections have already discussed the differences between live and dead landed swordfish. As this difference carries though to the factory there would be advantages for both fishers and processors if these individuals can be identified within the sales details for that catch. To ensure there will be some aspect of traceability for later product problems swordfish should be tagged when landed. This section provides information on tracking options for the longline industry.

Tracking the catch will assist skippers in developing better fishing practices and see when they may start to lose value from their catch due to extensive storage times. It will help fishers avoid areas containing fish of low quality or are more frequently parasitised because individual swordfish can be routinely identified as coming from specific geographic locations. Even if there are no outstanding problems with quality skippers will know that if they try new techniques at sea they easily can see how these impact on quality back at port.

5.15 Bar code reader

5.15.1 Limitations

The insurance complications for borrowing this expensive device and the limited number of characteristics (less than half of what this project was evaluating) that could be recorded for each fish prevented taking it to sea for any routine project work. The Sastek bar-code tracking device on loan was shown to Graham Wilkinson and Erica Starling of Indian Ocean Fresh. They were both impressed by the system and looked forward to being able to implement such a system onboard the vessel(s) in the future that would assist with their traceability issues.

As the device is part of a larger factory weighing and labelling system for export packaging, it could be used at sea to record the information that is currently being written down by skippers as fish are landed. It would assist fishers and factory processors improve their traceability as well as help identify seasonal, regional and operational changes that have an impact on quality that were not observed during the short time of this project.

5.15.2 Costs

When told of the cost of the Sastek bar-code tracking device Erica did suggest that at $7000 per hand piece, some of the smaller fisherman would have reservations of using such a system. Unfortunately as the company insists that the unit should be sold as an integrated factory system worth more than $100,000 it is up to individual fishers to seek manufacturers capable of producing hand held units if required.

5.15.3 Tags

As the cost of the bar coded tag reader used by the Sastek system is prohibitive for most fishers it would be up to industry to obtain suitable tags elsewhere. Tags similar to those used by salmon growers are suitable. Here are a few web sites of companies with tags:
http://www.nationalband.com/nbtlives.htm
http://www.sunshinetechnologies.com.au
http://www.alltheindustrials.com/search.aspx?q=Tags&referrer=adwords&keyword=tags&camp=MATHANDLING-ATI&group=Tags&rd=1&brand=
http://www.i-man.com.au/website/index.cfm?tid=5&cat id=6
http://www.paxar.com.au/solutions_paxar_gl_info.htm

OBJECTIVE 5 PRODUCE BEST PRACTICE MANUAL FOR INDUSTRY

The manual developed for handling and processing swordfish is present in Appendix 10. A DVD version is also being prepared.

6 BENEFITS AND ADOPTION

Both the longline industry and the consumer will benefit from adopting this research. Factories will be able to select batches of swordfish which will have higher quality and longer shelflife to sell into premium markets while the general quality of the catch should also improve. This outcome was anticipated in the original application.

Unfortunately the project has not been able to assist industry in providing a guarantee of parasite free fish unless costly technology such as PCR equipment is obtained. The author knows of an aquaculture farm that currently uses this type of technology to monitor its prawns for viruses. This technology may not be as prohibitive as first perceived as only the shipping factory would need to use such equipment rather than each capture vessel.

It is likely that many of the recommendations made by this report, because of their simplicity, will be implemented by industry in the future, probably at the time of refit.

7 FURTHER DEVELOPMENT

Further research is required to develop a rapid sensor for parasitised swordfish. The isolation of Kudoa and other parasite markers that can be used for PCR or Elisa detection will assist in the development of a seafood friendly device. This will enable industry in identifying parasitised swordfish thus preventing them from being sold.

These methods can give answers within the time available at the factory. An application for funding of this work through the SIDF program of Seafood Services Australia may be prepared for submission by December 2004.

8. PLANNED OUTCOMES

The information produced by this project will directly contribute to FRDC Programs 2, 3 and 7. The industry manual will assist with the training of current and new staff. The project has identified ways to improve storage practices on longline vessels that will result in overall quality improvements. It has suggested ways to improve tracking swordfish which will increase efficiency of the grading process. Some companies already use a marking system for their fish. Tracking systems will then assist industry in incorporating traceability as part of their production process.

The project has identified reasons that made the NIR ineffective and have recommended a suitable for alternative.

9. CONCLUSIONS AND RECOMMENDATIONS

Approximately 40% of the swordfish catch examined was landed alive. Live landed swordfish have better quality than those landed dead and this carries right though to unloading at the factory. Their measurable quality parameters indicate they will have a longer shelf life, they look better, receive higher grading scores and are more likely to be exported. All swordfish should have the spinal cord treated in the same way as tuna, regardless of whether landed dead or alive.

To expedite the grading of fish at the factory swordfish landed alive should be tagged with a label that incorporates a bar code or identification system. This aspect alone is justification for tagging individual fish at the time of landing. While it may be physically impossible for all swordfish to be landed alive, some thought should be given to hook types fished with, the soak times for bait and when to set the long line prior to fishing, so the proportion of fish landed alive can be maximised. There is also a major difference in quality between swordfish landed pre and in rigor. While this carries through to the factory it has no impact on the grade or export prospects. Overall rigor condition has less impact on quality than live landed swordfish because some pre rigor swordfish are dead on landing. Unlike live landed swordfish, this condition need not play a role in the sorting and handling the catch.

While there are more females caught there is no difference between the sexes for quality. Swordfish caught during the warmer seasons may be of lower quality and will have shorter shelf life. There may be a need to reduce the load placed in cooling tanks during warmer conditions to increase the rate of cooling.

Swordfish quality deteriorates immediately after death so they should be chilled to 0°C as soon as possible. Holding swordfish at higher than sea temperature for more than a few minutes after landing will directly lead to a loss in quality. Even an increase of temperature during the initial rapid chilling period (above 5° for several hours) will lead to lower quality. Freshly landed swordfish should not be packed directly under ice unless they can be re-iced every two hours. A chilled water system is more efficient at cooling. Swordfish being generally larger than tuna need longer in the chilling tanks. Always hold large swordfish (>50kg) in an ice slurry or chilled seawater tank for no less than 48 hours before packing in ice. Take only swordfish smaller than 50kg out after 24 hours of storage.

Of the three rapid chilling systems investigated; ice slurry, refrigerated seawater (RSW) and brine (seawater with extra salt added), the latter was most effective in prolonging quality. Each system does have it own problems. Chilled water held in tanks can build up large numbers of bacteria so they should be flushed and filled with clean water before the next days catch is introduced. A sanitising agent may be used to reduce the bacterial load. While it is understood that vessels use a cooling system because of their individual design some improvements can be made to existing tanks. Here are some recommendations.

- **Ice slurry**

  While melting ice has a greater ability to absorb heat than chilled water, we found that there is a delay of over an hour before the core temperature starts to drop in swordfish stored in ice slurries. This is due to the immediate melting of the ice that is in direct contact with the swordfish which is then followed by a slower rate of heat transfer through this melted water from the surrounding ice. The addition of a recirculating pump and spray bar will speed up the chilling rate for ice slurry. This will also result in the need to add ice more frequently than current practice. Temperature monitors should be fitted to assist skippers in identifying when to add more ice.

- **Refrigerated brine and seawater**

Refrigerated brine chilling systems have the best capacity of producing quality swordfish. This is due to the ability of brine to absorb heat quicker than the other systems. Brine chilling tanks usually operate from external heat exchange units rather than metal coils that can ice up. They also have pumps that move the water from the tank through the heat exchange system and back into the tank providing some mixing of the media. Temperature monitors and alarms are usually set up in the wheelhouse so that the skipper can continually monitor the operation of the compressor system, but it not fitted or working properly problems can develop. The compressor attached to both these storage systems can operate ineffectively at times.

It is only freshwater that freezes onto the coils leaving higher levels of salt in the water. This happens when the compressor is run for too long and/or there is limited water movement within the tank (when overfull). Once ice has formed the heat can no longer be removed from the water. Some vessels even have plates covering the coils so that fish do not freeze to the coils. The ice and these covers can further restrict circulation causing even slower cooling of the surrounding water when it is most needed. Also layers of warmer higher density water (saltier water is denser and resists mixing) can form on the bottom if no circulation system is present, slowing the cooling rate of or even warming large swordfish that hang down lower in the tank. Running the compressor more frequently for less time and installing circulating pumps that moves the bottom water over the coils will reduce the build up of ice and chill swordfish quicker. Another alternative is to have the holding water run through a heat exchange unit, removing the coils all together. If there is any trouble with the compressors at any time ice should be added to the tanks.

Swordfish should not be stood on while packing fish in the hold with ice. This will damage the flesh and lead to poorer yields for the customer. Place only the small swordfish on the top when the layers are deeper than two levels of fish. Do not leave swordfish at the dock for more than 5 minutes without a covering of ice. Warming will lead to deterioration during shipping.

There is a loss of swordfish quality as storage time progresses. This results in lower grades for fish at the factory and thus fewer being exported. After 10 days of storage less than half the catch is exported. While there is the need to cover the initial cost of each trip and the main imperative for skippers may be the volume of catch, there may come a time when they will start to loose income because of poor quality. Any flesh of swordfish that exhibits some form of damage or was cut during cleaning should be trimmed by at least 20mm to remove the bacterial contamination that occurred during handling and storage.

Swordfish exhibiting textural loss caused by Kudoa have only been identified after they have left the processing factory. It is likely that the cold storage systems used by the vessels and the factories are effective in keeping the muscle tissue cold enough to limit significant protease activity and thus prevent any textural deterioration that could be detected at the time of grading. NIR penetration ability is insufficient for assessment of whole fish trunks. Light intensity cannot be increased without causing heat damage (parboiling) of the sample. Other less damaging technology, such as ultrasound, will also have to rely on some textural quality deterioration already being present and could prove too expensive for seafood industry use. The type of technology that could be used to identify parasitised swordfish before any textural changes have occurred may have to rely on testing samples of flesh containing the parasite. A sample will have to be taken from close to the vertebrae where there is maximum concentration. PCR equipment can give the type of rapid results needed when packing an export shipment of swordfish but the price per test may not be cheap enough for individual vessels to use.

10 REFERENCES

AOAC, 1984. Kjeldahl method for determination of protein in seafood. 24.027, 2.055-2.057.

Australian Standard 1991. AS 1766.1.4 Food Microbiology - General procedures and techniques – Colony count – Surface spread method.

Arthur, P. G., West, T. G., Brill, R.W., Schulte, P. m. and Hochachka, P.W. 1992. Recovery metabolism of skipjack tuna (*Katsuwonus pelamis*) white muscle: Rapid and parallel changes in lactate and phosphocreatine after exercise. Canadian J of Zool/Revue Canadienne de Zoologie 70(6): 1230-1239

Ashie, I.N.A, Smith, J.P. and Simpson, B.K. 1996. Spoilage and shelf-life extension of fresh fish. Crit. Rev. Food Sci. Nutrit. 36 (1&2): 87-121.

Block, B.A. and Finnerty, J.R. 1994. Endothermic strategies in fishes: a phylogenetic analysis of constraints, predispositions, and selection pressures. Env. Biol. Fish. 40: 283-302.

Bremner H. A., Statham, J.A. and Vail A.M.A. 1988. Nucleotide Catabolism: Influence on the storage life of tropical species of fish from the North West Shelf of Australia. J Food Sci 53(1): 6-11.

Carey, F.G. 1982. A brain heater in the swordfish. Sci. 216 (4552): 1327-1329.
Carey, F.G. and Robinson, B.H. 1981. Daily patterns in the activities of swordfish, *Xiphias gladius,* observed by acoustic telemetry. Fish. Bull. 79 (2): 277-292.

Dickson, K. A. 1989. Why are some fishes endothermic? Interspecific comparisons of aerobic and anaerobic metabolic capacities in endothermic and ectothermic scombrids: no. 8, 389.

Dickson, K. A. 1996. Locomotor muscle of high-performance fishes: What do comparisons of tunas with ectothermic sister taxa reveal? Comp. Biochem. Physiol. Pt A: Physiol. 113(1): 39-49.

Dulley, J.R. and Grieve, P.A. 1975. A simple technique for eliminating interference by detergents in the Lowry method of protein determination. Anal. Biochem. 64: 136-141.

Dyer,W.J. and Hiltz, D.I. 1969. Nucleotide degeneration in frozen swordfish muscle. J. Fish. Res. Bd. Canada 26:591-603.

Fraser, D.I., Pitts, D.P. and Dyer, W.J. 1968. Nucleotide degeneration and organoleptic quality in fresh and thawed mackerel muscle held at and above ice temperature. J. Fish. Res. Bd. Canada 25(2): 239-253.

Goodrick, G.B., Thomas, P.T. and Paterson, B.D. 2002. Effect of husbandry and handling techniques on the post-harvest quality of farmed southern bluefin tuna. Final Report for FRDC Project No. 97/364 (SBT Aquaculture Subprogram Project 4, Aquaculture CRC).

Gordon, M.S. 1977. Animal physiology: Principals and adaptations. Macmillan, New York: 117.

Haard, N.F. 1992. Technological aspects of extending prime quality of seafood:A review. J. Aquat. Food Prod. Techn. 1(3/4):9-27.

Hansen, M. and Dickson, K. A. 1994. Aerobic and anaerobic capacities in locomotor muscle of tunas and ectothermic scombrid fishes." The Physiologist 37: A-73.

Hiltz, D.F. and Dyer, W.J. 1971. Octopine in postmortem adductor muscle of the sea scallop (*Placopecten magellanicus*). J. Fish. Res. Bd. Canada 28:869-874.

Izquierdo-Pulido, M.L., Hatae, K. and Haard, N.F. 1992. Nucleotide catabolism and changes in texture indices during ice storage of cultured sturgeon, *Acipenser transmontanus*. J. Bio0chem. 16 (3): 173-192.
Malcolm 1996 and 2000 AFMA Logbook Program

Jensen, S.E., Fecycz, I.T., Stemfeg, G.W., and Campbell, J. N. 1980. Demonstration of a cell associated inactive precursor of an exocellular protease produced by *Pseudomonas aeruginosa*. Microbiology 26: 87-93.

Konagaya, S. 1982. Histological observations of the jellification process of myxosporidia-infected swordfish meat. Bulletin of the Tokai Regional Fisheries Research Laboratory, 108:47-57.

Lakshmanan, P. T., Antony, P. D. and Gopakumar, K. 1996. Nucleotide degradation and quality changes in mullet (*Liza corsula*) and pearlspot (*Etroplus suratensis*) in ice and at ambient temperatures. Food Control 7(6): 277-283.

Love, R.M. 1970. The chemical biology of fishes. Academic Press, London.

Love, R. M. 1979. The post-mortem pH of cod and haddock muscle and its seasonal variation. J. Sci. Food Agric., 30(4): 433 438.

Love, R. M. 1980. The chemical biology of fishes. Vol. 2: Advances 1968-1977, with a supplementary key to the chemical literature. Academic Press; London UK.

Lowry, O.H., Rosenbrough, N.J., Farr, A.L., and Randall, R.J. 1951. Protein measurement with the Folin phenol reagent. J. Biol. Chem. 193: 265-275.

Nichols, P.D, Virtue, P., Mooney, B.D., Elliott, N.G. and Yearsley, G.K. 1998. Seafood the Good Food: The Oil Content and Composition of Australian Commercial Fishes, Shellfishes and Crustaceans FRDC/CSIRO Publishing.

Punt, A.E., Campbell, R.A. and Smith, D.M. 2001. Evaluating empirical indicators and reference points for fisheries management: application to the broadbill swordfish fishery off eastern Australia. Mar. Freshwater Res. 52:819-82

Ruello, N. 1998. A Study Of Seafood Consumption In Perth And The Development Of A Guide To Targeted Promotion, FRDC Report 98/342
Slattery, S.L., Dionysius, D.A., Smith, R.A.D. and Deeth, H.C. 1989. Mushiness in the blue swimmer crab, *Portunus pelagicus* (L). Food Australia 41, 4:698-703 & 709.

Sullivan, P. 1998. The location of *Kudoa* sp. in swordfish trunks. Postgraduate research project PA305 Uni. Qld.

Jones, C. 1999. Identification of *Kudoa* from dolphinfish and swordfish using morphological and molecular techniques. Postgraduate research project Uni. Qld.

Szczesniak, A.S & Torgeson, K.W. 1965. Methods of meat texture measurement viewed from the background of factors affecting tenderness. Adv. Food Res. 14:33-165

Thyholt, K and Isaksson, T. 1997. Differentiation of frozen and unfrozen beef using near-infrared spectroscopy. J. Sci. Food Agric. 73:525-532.

Watanabe, S., Kamal, M. and Hashimoto, K. 1991. Postmortem changes in ATP, creatine phosphate, and lactate in sardine muscle. J. Fd. Sci. 56 (1):151-153.

Ward, P and Elscot, S. 2000. Broadbill swordfish: status of world fisheries. Bureau of Rural Sciences Report, Canberra.

Young, J., Drake,A., Brickhill, M., Farley, J. and Carter, T. 2003. Reproductive dynamics of broadbill swordfish, *Xiphias gladius*, in the domestic longline fishery off eastern Australia. Mar. Fre. Res. 54:315-332.

11 Intellectual property issues arising

None

12 Staff

The following staff at Innovative Food Technology, Queensland Department of Primary Industries and Fisheries participated in the project at some stage assisting with the collection of samples and information.

Steve Slattery	Andrew Forrest	Bob Fitzpatrick
John Nagle	Paul Exley	Darren Leighton
Reg Reeves	John Mayze	Mel Kippen

APPENDIX 1 Industry steering committees.

Planning meeting with WA Pelagic and Longline Association and other Industry individuals.

Attendees

Steve Slattery	Centre for Food Technology, QDPI
Erica Starling	Latitude Fisheries
Jean Menzies	Challenger TAFE
Gordon Duzevich	Sealanes
Kim Palmer	Partridges
John Minutillo	Lobster Australia
Jodi Earnshaw	Lobster Australia
Louis Lynch	Seafresh
Gary Bevan	Bevans WA
Fan Chung	Catalano Seafoods
Geoff Diver	WA Pelagic and Longline Association
Kim Leighton	WA Health Department
Lex Kingdom	Westuna
Ian Doughty	Laister Consultants

Findings

After discussion the following methods were determined as having high priority and should be included in the grant application methods section.

1. Determine whether fish alive or dead at landing have different quality.
2. Impact of storage in Seawater ice, Freshwater ice and RSW on quality to be evaluated. A minimum of 20 fish per treatment required.
3. Parameters to record for each fish sea temperature, weather conditions, deck temperatures, fish temperature, handling times, body lengths at capture and weights on landing, pH, sex and gonadal condition, bite damage (rating), old wounds, whether fish are transhipped and time/temperatures.
4. Sample for K value, lactate, otoliths on landing. Apply tag to fish to be tested. Sample K value, lactate, temperature and pH after unloading and when possible after transhipping.
5. Identify parasitised (jellied) fish at the factory and send for testing using NIR equipment.
6. Sample wounds 25mm and 25cm from centre of damage for microbiology.
7. Design industry manual similar to Codex Code of Practice for industry.

Planning meeting with East Coast steering committee.

Attendees

Steve Slattery	Innovative for Food Technology, QDPI&F
Bob Lester	Parasitology Dept, University of Queensland
Brad More	" (possible project staff member)
Bruce Williams	Sastek Pty Ltd
Rod Fitzgerald	Prime Fish
Sue Jones	"
Mark Bazzo	De Bretts
Garth Evans	
Hans Jusseit	East Coast Tuna Boat Owners Assoc.

Findings

The methods section from the FRDC contract and the additional aspects recommended by the WA component of the steering committee were discussed. The biological aspects listed at the WA meeting were considered important additions. This meeting identified no new aspects.

Following the progression of rigor was discussed but as the fish are stored for up to 10 days this would have little impact on the quality at the processing end as rigor would have resolved before landing. It was noted that the factories on the east coast never received in rigor fish. The bayonet sampler designed for tuna was demonstrated and the possible sites for sampling were discussed. The sampler is capable of removing tissue while leaving the site of entry and exit appear intact on tuna. It may be more obvious on swordfish because there is no recess for the dorsal fin to retract into. The cut is usually sterilised before and after sampling so there will be little contamination of the surrounding tissue.

There was a preference by industry for sampling the tail region but this site would not yield information about parasite infestation. Bob Lester stated that the parasites are concentrated about the spinal column in the anterior muscle rather than the tail. It was also identified by previous tuna research that the tail region gave quite different chemical quality results to the head. The anterior region provides the bulk of the flesh so sampling for quality parameters should be from material representative of the majority of the edible portion. The dorsal fin of swordfish is normally removed exposing some of the tissue so a cut here should create less concern for buyers. The flesh that the operculum covers behind the gills may also be suitable as much of this tissue is trimmed off.

The different types of equipment to be trailed for identification of parasitism and how they operate were described to the meeting. As the NIR equipment has not yet been purchased by Food Technology (the expenditure had been approved at that stage), the collection of samples for this component of the project could be delayed. It was decided to ask Jock Young of CSIRO in Hobart about further biological aspects that may need to be recorded. He requested that we collect dorsal fins from all our catch and roe from the females. He indicated he would use these samples in his current project.

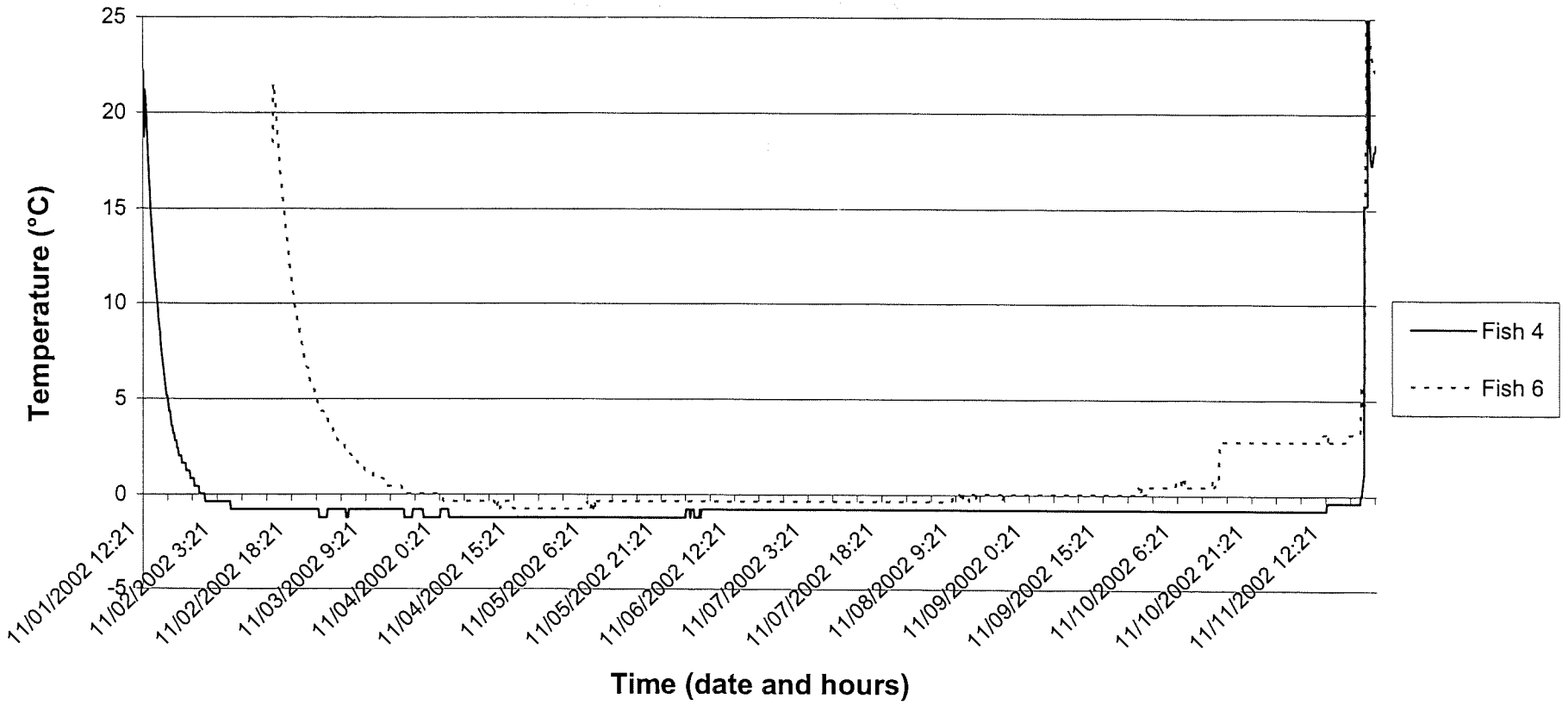
APPENDIX 2 Raw data, internal temperatures and colour measurements of fish caught for trip 1.

Table 26. Physical data collected for swordfish caught during trip 1.

Departed from Geraldton on Discovery III owned by Latitude Fisheries, catch trucked back to Geraldton from Carnarvon.														
Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
1/11/2002 8:45	10	20.8	2	2	0	0	0	0	0	1040	700	?	19.7	20.3
1/11/2002 9:00	10	20.8	2	2	0	0	0	0	0	1950	1230	?M	19.3	18.8
1/11/2002 10:15	10	20.8	1	1	1	0	0	1	s	1690	?	?	20.6	20.0
1/11/2002 11:10	10	20.8	2	2	0	0	0	0	0	1470	920	?	20.4	20.4
2/11/2002 11:00	9	21.2	1	1	0	0	0	0	0	1205	740	?	21.8	21.3
2/11/2002 11:20	9	21.2	1	1	0	0	0	0	0	1610	1100	?	21.4	21.3
2/11/2002 11:44	9	21.2	2	2	0	0	0	0	0	950	600	?	20.3	20.3
2/11/2002 12:11	9	21.2	1	1	0	0	0	12	s	2200	1380	?	21.3	20.9
2/11/2002 14:54	9	21.2	2	2	1	0	0	6	s	2160	2150	?	19.0	18.1
6/11/2002 9:00	5	22.6	2	1	10	0	10	0	d	1910	m	F	23.1	22.7
6/11/2002 9:15	5	22.6	2	1	1	0	0	9	s	1585	1020	?	23.3	23.1
6/11/2002 13:57	5	22.6	2	3	0	0	0	0	0	1300	810	?	22.1	22.0
8/11/2002 8:39	3	22.7	2	2	0	0	0	0	0	2110	1290	F	21.0	20.6
8/11/2002 14:39	3	22.7	2	2	1	1	1	0	s	2430	m	?	21.0	21.8
9/11/2002 11:49	2	23.1	1	1	3	3	0	3	s	1940	1270	?F	24.0	24.0
9/11/2002 13:30	2	23.1	2	2	10	10	10	1	d	2160	1140	?F	24.0	24.0
10/11/2002 9:05	1	21.9	2	2	0	0	0	0	0	910	530	?	21.3	21.3
10/11/2002 9:17	1	21.9	2	2	4	0	0	4	s	1730	1060	?	22.0	21.2
10/11/2002 10:00	1	21.9	1	1	3	0	0	3	s	1610	950	?	22.4	22.0
10/11/2002 10:15	1	21.9	2	2	1	0	0	1	s	1230	830	?	21.8	21.5
10/11/2002 10:56	1	21.9	1	1	0	0	0	0	0	2160	m	F	22.3	22.1
10/11/2002 11:21	1	21.9	2	2	0	0	0	0	0	920	500	?	21.8	21.3
10/11/2002 13:20	1	21.9	2	2	1	0	0	1	s	1280	760	?	21.6	21.8

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some ?=missing data, Fork Length and Girth diameter in cm F=female and M=male

Figure 32. Temperature of swordfish during storage and unloading for trip 1.



APPENDIX 3 Raw data, internal temperatures and colour measurements of fish caught for trip 2.

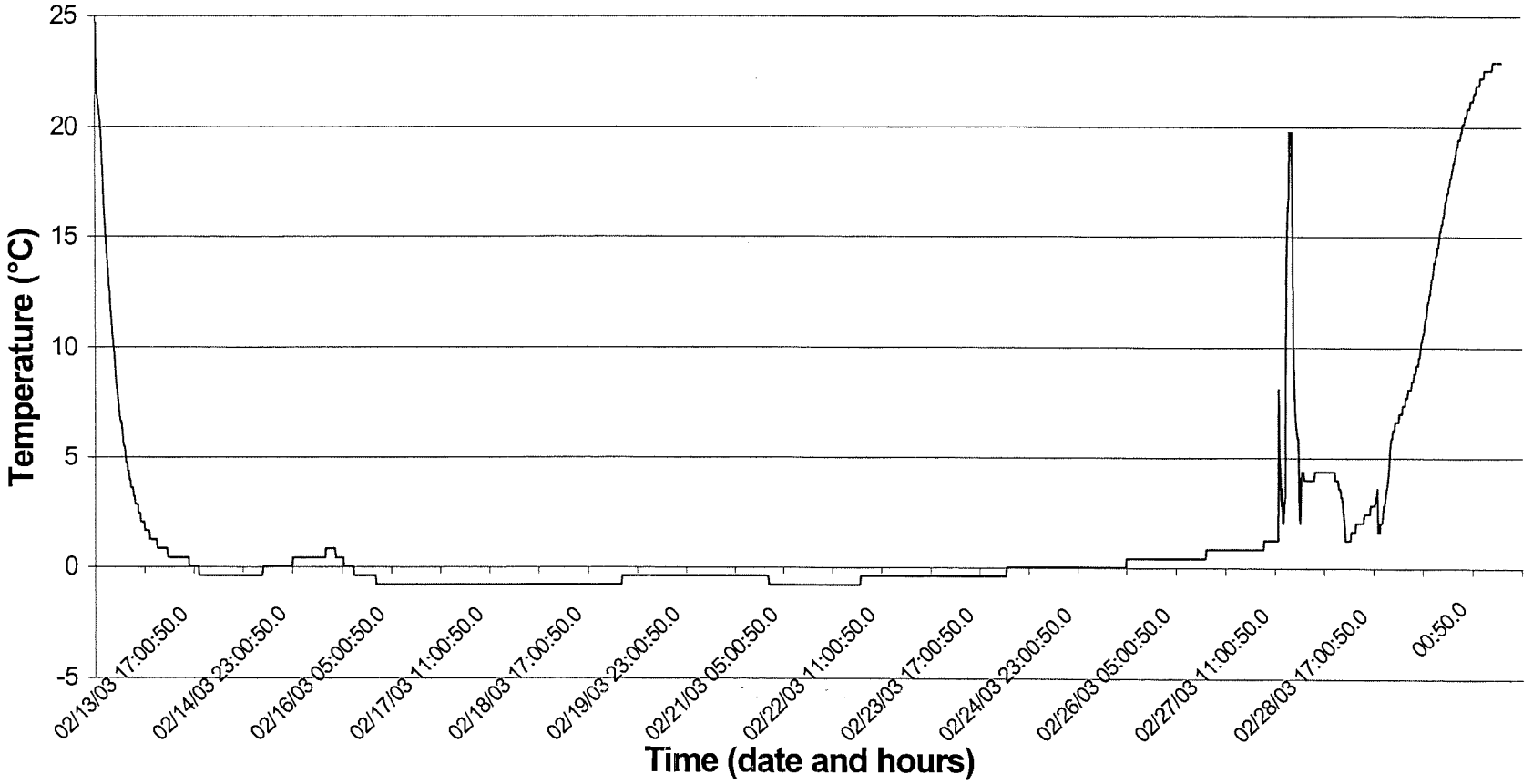
Table 27. Physical data collected for swordfish caught during trip 2.

Departed on Ocean Odyssey owned by Tasman Bluefin from Mooloolaba and returned to Mooloolaba.														
Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
12/02/2003 8:01	15	23.4	1	1	0	0	0	0	0	80	45	?	19.9	21.9
12/02/2003 8:47	15	23.4	2	2	1	1	0	0	0	129	80	F	19.1	18.9
12/02/2003 9:48	15	23.4	1	1	1	0	0	4	0	98	65	F	24.1	18.9
12/02/2003 10:28	15	23.4	2	1	0	0	0	2	0	121	76	?	21.3	21.8
12/02/2003 10:30	15	23.4	2	2	1	5	0	7	s	170	107	F	21.1	21.1
12/02/2003 12:10	15	23.4	2	2	1	2	0	3	s	173	110	F	20.1	19.7
15/02/2003 6:45	12	22.4	1	1	1	2	1	4	s	209	119	F	20.9	21.3
15/02/2003 7:50	12	22.4	2	3?	0	0	2	0	0	174	117	F	22.8	21.8
15/02/2003 7:28	12	22.4	2	1	0	0	0	2	s	145	97	F	22.8	22.4
15/02/2003 8:07	12	22.4	1	1	0	0	0	0	0	184	124	?	23.4	22.3
15/02/2003 8:26	12	22.4	1	1	0	0	0	0	0	207	126	F	23.1	22.8
15/02/2003 8:54	12	22.4	1	1	0	2	0	9	s	185	110	F	21.8	21.8
15/02/2003 9:00	12	22.4	2	2	0	0	0	0	0	185	104	F	22.7	21.7
15/02/2003 9:56	12	22.4	1	1	0	1	0	0	0	191	124	?	22.8	21.9
15/02/2003 10:17	12	22.4	1	1	0	0	0	0	0	153	94	F	23.1	21.8
15/02/2003 10:57	12	22.4	1	1	0	2	0	0	0	210	125	F	22.8	21.7
15/02/2003 11:38	12	22.4	2	1	1	1	0	3	s	148	92	M	21.3	21.3
15/02/2003 12:19	12	22.4	2	2	0	0	0	3	s	145	105	F	20.9	21.6
15/02/2003 13:57	12	22.4	1	1	0	0	0	3	s	171	98	F	22.5	22
16/02/2003 6:15	11	22.9	2	2	0	0	0	5	s	141	96	?	21.8	22
16/02/2003 6:58	11	22.9	2	2	1	2	0	2	s	144	95	F	21.7	21.7
16/02/2003 8:22	11	22.9	1	1	1	2	0	6	d+s	174	95	M	23.3	23.3
16/02/2003 9:05	11	22.9	2	2	0	0	0	8	s	196	126	F	20.3	20.3
16/02/2003 9:54	11	22.9	2	2	0	0	0	7	s	176	113	F	21.9	21.8
16/02/2003 10:49	11	22.9	2	2	0	0	0	0	0	140	85	F	21.7	22
16/02/2003 10:57	11	22.9	2	2	1	2	0	3	s	148	88	M	21.4	21
17/02/2003 7:21	10	22.8	1	1	0	2	0	3	s	177	113	M	25.2	23.7
17/02/2003 8:41	10	22.8	2	1	1	3	0	6	s	185	111	M	22.2	22.7

Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
17/02/2003 10:23	10	22.8	1	1	1	2	0	7	s	174	104	F	23.4	22.9
17/02/2003 11:21	10	22.8	2	2	1	2	0	0	0	148	86	F	21.6	21.6
18/02/2003 7:12	9	23.1	1	1	1	0	0	10	s	181	113	M	23.4	23.7
21/02/2003 11:30	6	23.6	1	1	0	0	0	5	s	184	103	?	24.9	24.8
21/02/2003 12:35	6	23.6	2	1	0	0	0	7	s	143	94	F	21.8	22.7
21/02/2003 12:43	6	23.6	2	2	1	3	0	15	s	204	120	F	19.6	19
23/02/2003 8:35	4	25.1	1	1	0	3	0	4	s	169	94	M	24.8	25.1
25/02/2003 8:35	2	24.8	2	2	0	2	0	7	s	139	87	F	26.4	23.9
25/02/2003 9:42	2	24.8	1	1	0	0	0	12	s	162	95	M	24.8	24.8
25/02/2003 12:57	2	24.8	1	1	0.0	1	0	6	s	163	97	F	25.8	25.5

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some ?=missing data, Fork Length and Girth diameter in cm
F=female and M=male

Figure 33. Temperature of swordfish during storage and unloading for trip 2.



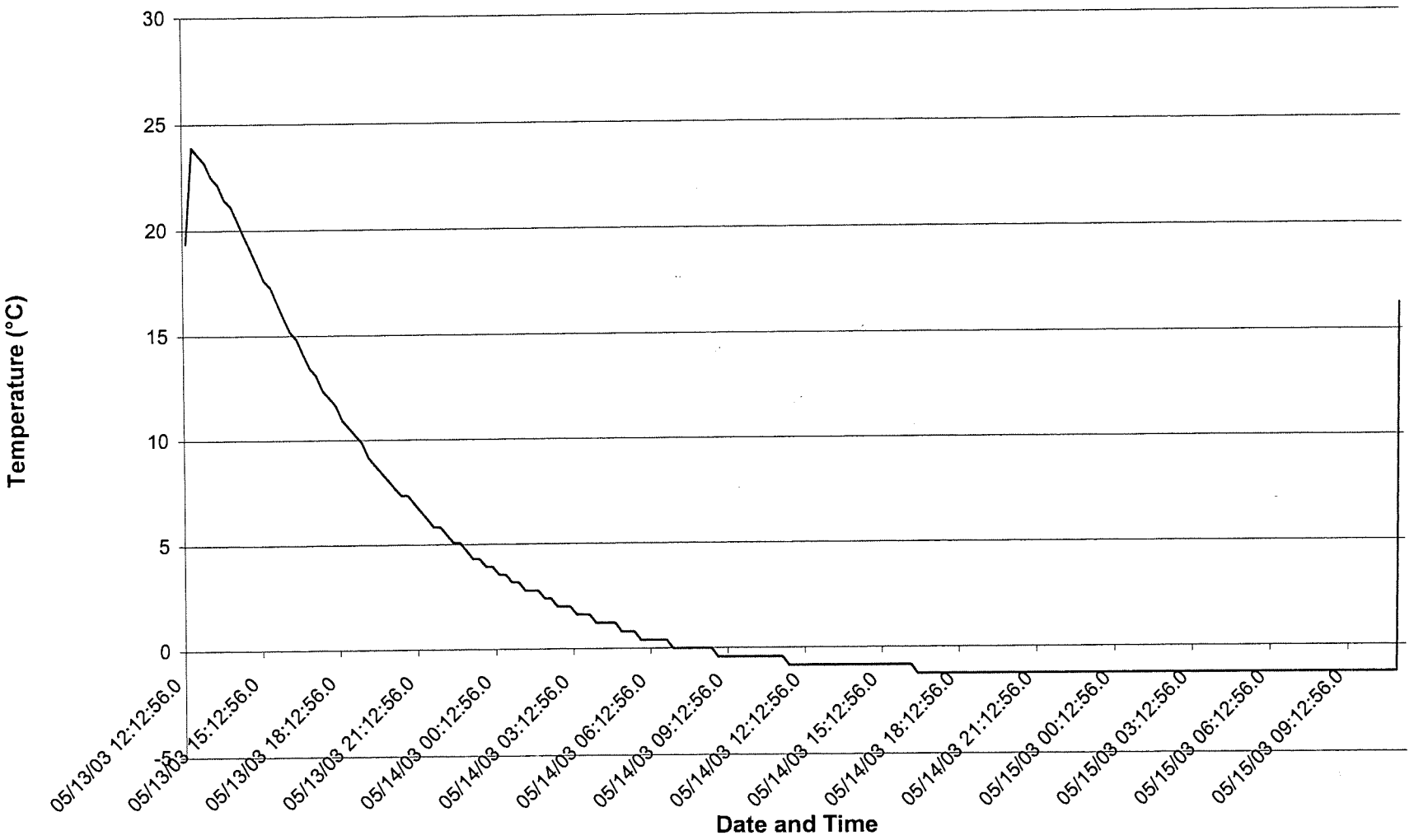
APPENDIX 4 Raw data, internal temperatures and colour measurements of fish caught for trip 3.

Table 28. Physical data collected for swordfish caught during trip 3.

Departed on 34 South owned by Latitude Fisheries from Fremantle and returned early to Fremantle due to bad weather.														
Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
12/05/2003 20:10	2	23.9	2	1	0	0	0	0	0	125	73	F	22.6	22.7
12/05/2003 20:30	2	23.9	2	1	0	0	0	0	0	155	95	F	22.6	22.4
14/05/2003 9:57	1	23.9	2	1	0	0	0	0	0	193	113	?	23.5	22.6

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some ?=missing data, Fork Length and Girth diameter in cm F=female and M=male

Figure 34. Temperature of swordfish A during storage and unloading for trip 3.



APPENDIX 5 Raw data, internal temperatures and colour measurements of fish caught for trip 4.

Table 29. Physical data collected for swordfish caught during trip 4.

Departed on Ocean Wanderer owned by Tasman Bluefin from Mooloolaba and returned to Mooloolaba.

Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
7/07/2003 9:53	15	21.4	2	1	?	3	0	0	0	118	74	F	21.4	20.4
8/07/2003 7:51	14	19.2	1	1	0	0	0	0	0	138	90	F	21.6	20
8/07/2003 8:57	14	19.2	1	1	0	0	3	0	0	150	101	F	21.8	20.7
8/07/2003 12:43	13	19.2	1	1	0	2	0	0	0	210	122	F	21.2	19.9
9/07/2003 13:20	13	19.4	1	1	0	0	0	6	cc	183	100	M	21.2	19.5
9/07/2003 14:06	13	19.4	2	2	1	6	1	20	cc	204	128	F	20.3	19.6
10/07/2003 9:50	12	19.7	2	2	1	2	0	3	cc	149	94	M	19.5	19.6
10/07/2003 10:30	12	19.7	2	1	1	4	0	6	cc	151	97	F	19.8	20.1
11/07/2003 7:17	11	19.8	1	1	1	2	0	6	s	175	101	F	21.8	21.6
11/07/2003 8:05	11	19.8	2	1	1	3	0	15	s	183	134	F	21.3	20.9
11/07/2003 8:36	11	19.8	1	1	0	0	0	10	s	160	102	F	23	21.7
11/07/2003 11:07	11	19.8	2	1	0	0	0	12	s	140	85	F	20.6	20.3
11/07/2003 12:52	11	19.8	2	1	1	4	0	7	s	178	120	F	20.3	19.7
12/07/2003 8:10	10	19.8	2	1	0	0	0	4	s	148	83	F	21	20.4
12/07/2003 9:40	10	19.8	2	2	0	0	0	9	s	137	83	F	20.8	20.4
13/07/2003 7:18	9	19.9	2	1	0	0	0	6	s	148	92	F	21.4	21
13/07/2003 7:33	9	19.9	1	1	1	1	0	9	s	204	121	M?	22.1	21.4
13/07/2003 8:20	9	19.9	2	1	0	0	0	0	0	122	71	M	21.4	21
13/07/2003 10:20	9	19.9	1	1	1	0	0	6	s	167	105	F	22.8	21.4
13/07/2003 11:22	9	19.9	2	1	0	0	0	0	0	128	65	M	20.6	20.6
13/07/2003 11:50	9	19.9	2	2	1	0	0	10	s	157	107	F	20.8	20.4
2/01/1900 12:00	9	19.9	2	1	0	0	1	6	s	188	118	F	20.8	20.7
13/07/2003 13:52	9	19.9	2	2	1	0	0	5	s	165	104	F	20.4	20.3
16/07/2003 9:25	6	19.9	1	1	0	0	0	7	s	172	102	F	22.1	21
16/07/2003 11:52	6	19.9	1	1	0	1	0	10	s	214	125	F	21.2	20.5
16/07/2003 15:04	6	19.9	2	2	1	1	0	8	s	195	123	F	20.3	20.1
18/07/2003 8:28	4	21.2	1	1	1	1	0	7	s	159	105	F	22.8	21.1
18/07/2003 12:40	4	21.2	2	2	1	1	0	8	s	184	117	F	19.5	19.5
20/07/2003 9:51	2	21.2	2	2	1	1	0	20	s	172	173	F	21.7	21.9
20/07/2003 10:15	2	21.2	2	2	0	0	0	6	s	98	92	F	21.5	21.2

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some ?=missing data, Fork Length and Girth diameter in cm F=female and M=male

Figure 35. Temperature of swordfish A during storage and unloading for trip 4.

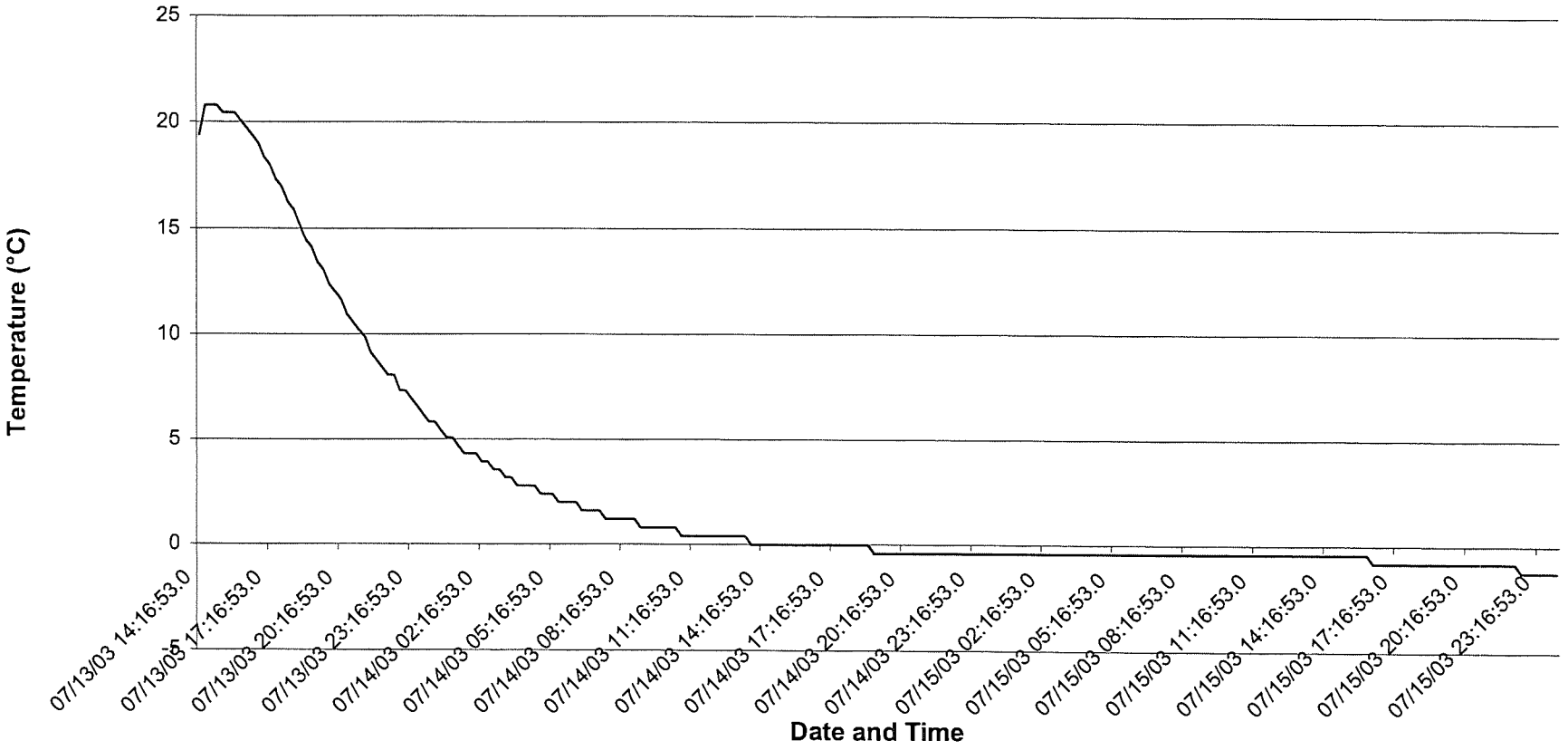


Figure 36. Temperature of swordfish B during storage and unloading for trip 4.

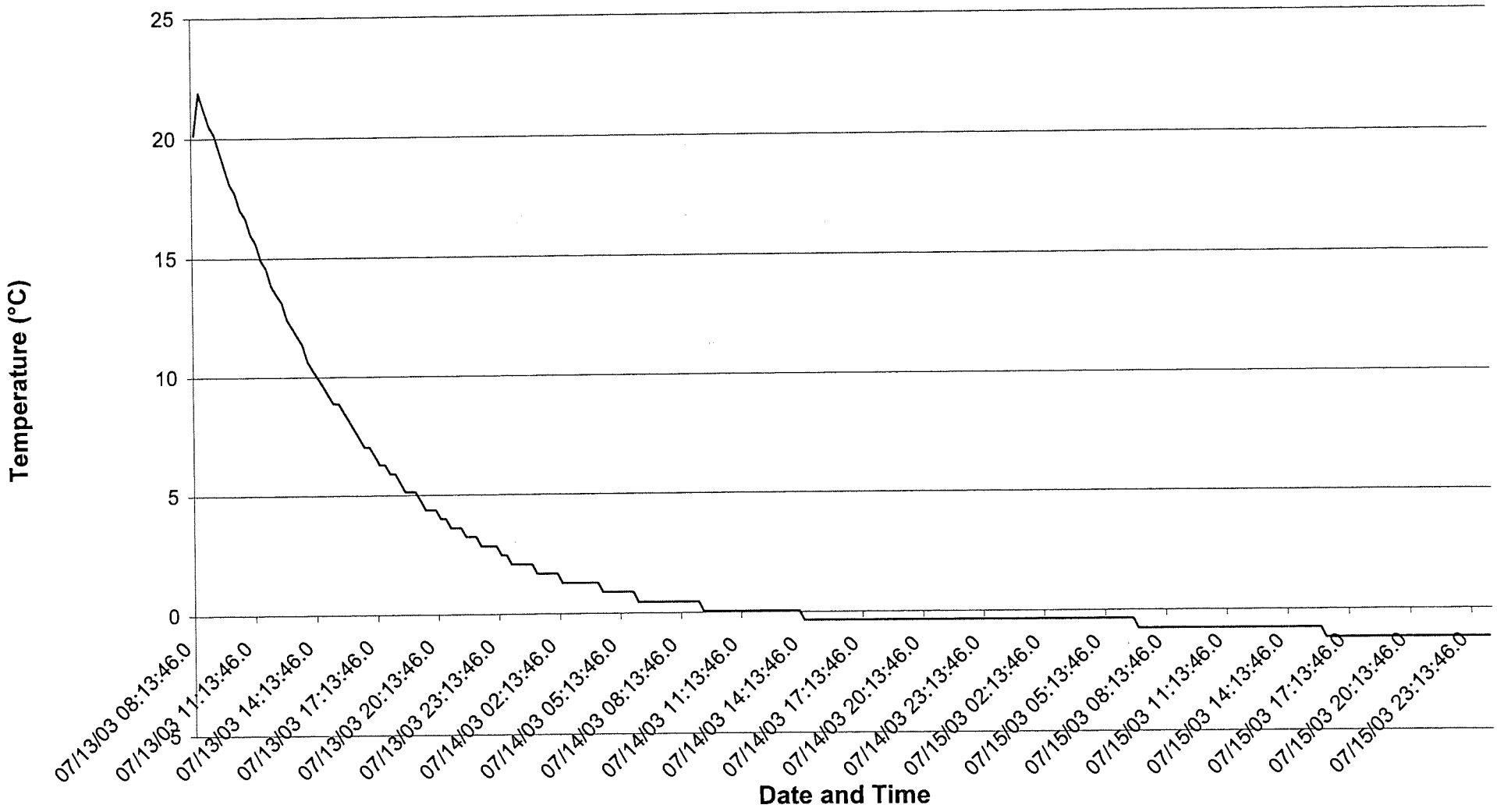


Figure 37. Temperature of swordfish C during storage and unloading.

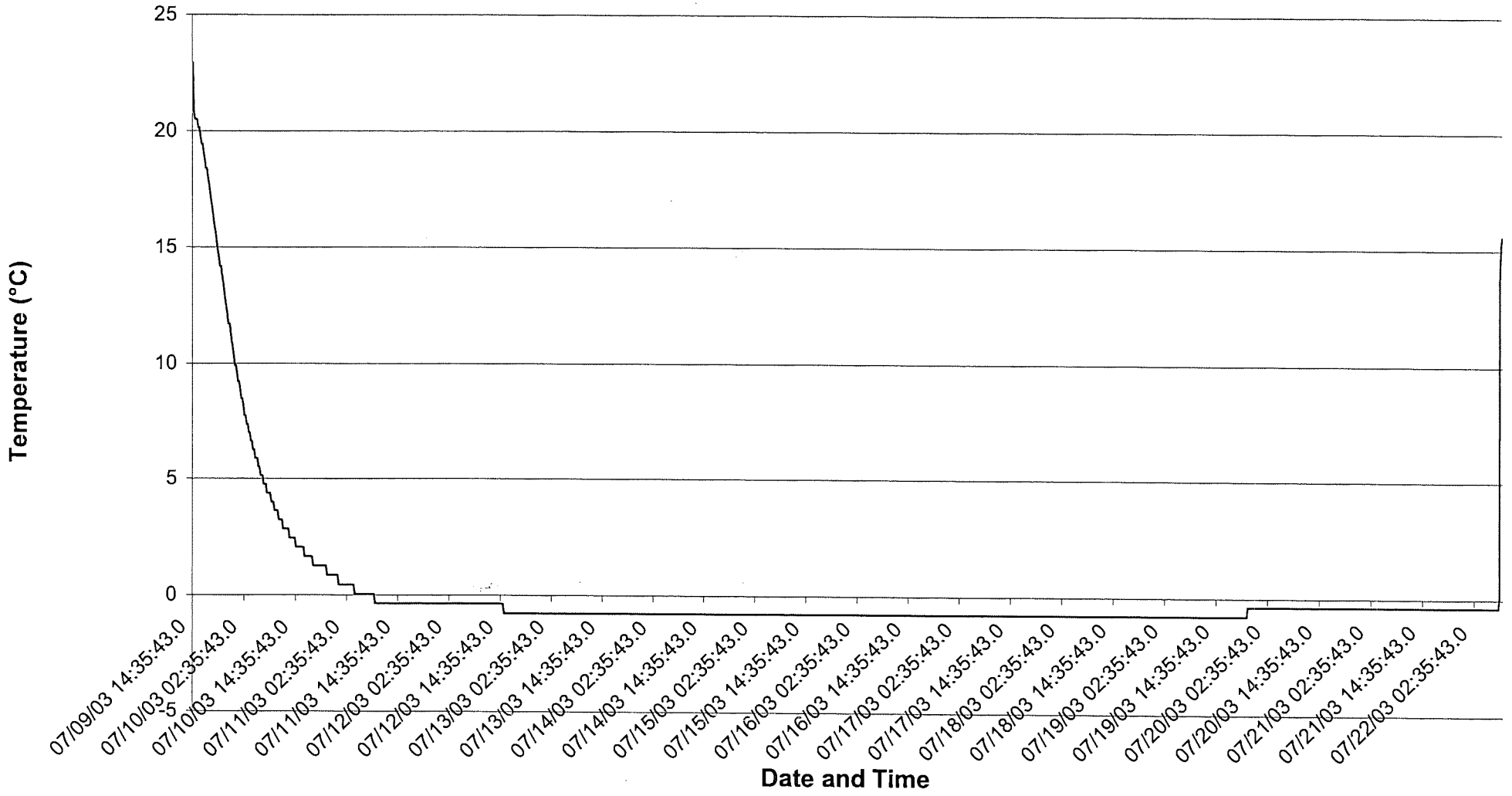
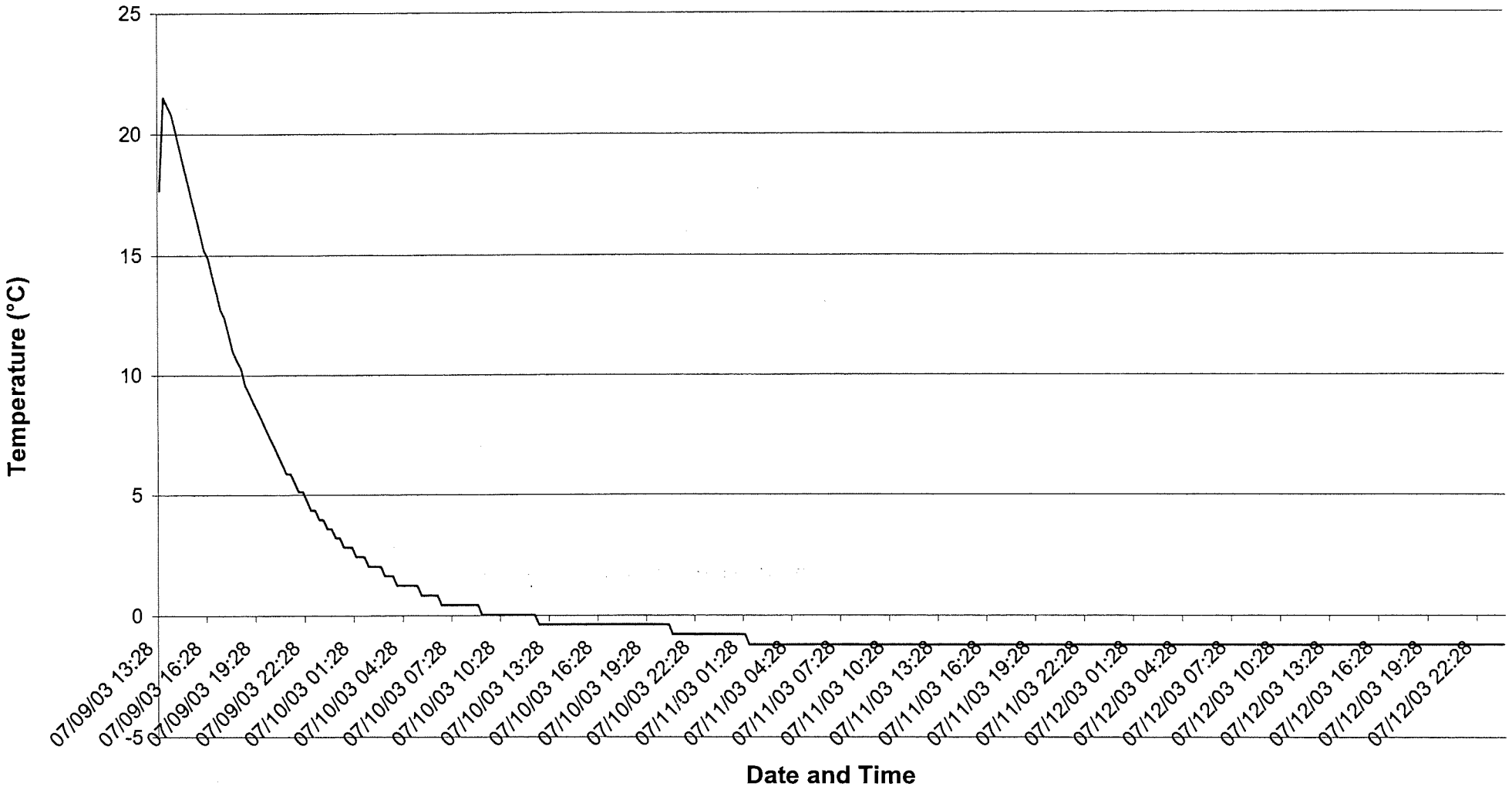


Figure 38. Temperature of swordfish D during storage and unloading for trip 4.



APPENDIX 6 Raw data, internal temperatures and colour measurements of fish caught for trip 5.

Table 30. Physical data collected for swordfish caught during trip 5.

Departed on Ocean Dawn owned by Tasman Bluefin from Mooloolaba and returned to Mooloolaba.														
Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
3/10/2003 10:29	15	?	2	2	1	3	0	5	s	101	70	F	22.3	21.9
5/10/2003 7:43	13	?	2	2	0	0	0	3	s	164	103	F	21.5	20.9
5/10/2003 8:25	13	?	2	2	1	1	0	2	s	135	90	F	21.6	20.9
5/10/2003 8:47	13	?	2	1	1	1	0	3	s	123	73	F	21.5	20.9
5/10/2003 9:54	13	?	2	1	0	0	0	3	s	122	79	F	21.6	21.3
5/10/2003 11:13	13	?	1	1	1	1	0	0	s	140	86	F	22.9	22
5/10/2003 11:50	13	?	1	1	1	2	0	>20	s	238	149	F	22	22
6/10/2003 6:41	12	?	2	1	1	1	0	13	s	170	101	F	21.6	20.9
6/10/2003 9:10	12	?	1	1	1	1	0	6	s	180	105	F	22.2	21.8
6/10/2003 10:40	12	?	2	1	0	0	0	5	s	116	73	F	20.9	21.2
6/10/2003 11:06	12	?	2	2	1	2	0	>20	s	192	120	F	21.1	21.1
6/10/2003 11:30	12	?	2	1	1	3	0	6	s	147	84	F	22.6	21.2
6/10/2003 11:51	12	?	1	1	1	1	0	10	s	187	107	F	21.7	21.1
6/10/2003 12:32	12	?	2	2	1	6	0	>20	s	160	98	F	21.2	20.8
6/10/2003 12:54	12	?	2	1	0	0	0	4	s	137	89	F	20.9	20.7
7/10/2003 7:03	11	?	1	1	1	3	0	2	s	137	85	F	21.8	21.2
7/10/2003 7:40	11	?	1	1	1	2	0	4	s	177	104	F	21.5	21.1
7/10/2003 8:14	11	?	1	1	1	4	0	12	s	165	102	F	21.3	21.3
7/10/2003 8:38	11	?	1	1	0	0	0	15	s	152	97	M	21.8	20.9
8/10/2003 6:56	10	?	1	1	1	1	0	6	s	158	98	F	21.8	21.3
8/10/2003 8:37	10	?	2	2	1	1	0	0	s	126	81	F	21.2	20.7
8/10/2003 10:15	10	?	1	1	0	0	0	5	s	181	99	M	22.4	71.6
8/10/2003 13:46	10	?	2	1	0	0	0	0	s	127	65	F	20.8	20.8
9/10/2003 7:49	9	?	1	1	0	0	0	0	s	125	82	F	22.1	21.8
9/10/2003 8:11	9	?	1	1	1	2	0	>20	s	207	135	F	21.6	21.6
10/10/2003 7:38	8	?	1	1	0	0	0	4	s	126	86	F	22.7	22.2
10/10/2003 8:17	8	?	1	1	1	2	0	8	s	141	88	F	21.8	22

Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
10/10/2003 12:34	8	?	2	1	0	0	0	>20	s	194	124	F	21.3	21.8
10/10/2003 14:23	8	?	1	1	0	0	0	3	s	141	89	F	21.9	22.1
10/10/2003 15:29	8	?	2	1	1	1	0	>20	s	223	143	F	21.2	21.2
11/10/2003 8:32	7	?	1	1	1	1	0	>20	s	215	130	F	22.6	21
11/10/2003 15:44	7	?	1	1	0	0	0	>20	s	220	122	F	22.1	21.1
13/10/2003 9:19	5	?	1	1	0	0	0	9	s	165	84	M	20.9	20.1
14/10/2003 11:47	4	?	1	1	0	0	0	>20	s	204	133	F	20.9	20.6
15/10/2003 9:44	3	?	1	1	0	0	0	>20	s	197	128	F	20.6	20.6
15/10/2003 14:05	3	?	2	2	1	2	0	>20	s	205	132	F	20.5	20.2
15/10/2003 15:49	3	?	2	2	1	1	0	>20	s	193	126	F	20.3	19.9
16/10/2003 9:57	2	?	2	1	0	0	0	2	s	141	85	F	20.6	20.6

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some ?=missing data, Fork Length and Girth diameter in cm

Figure 39. Temperature of swordfish A during storage and unloading for trip 5.

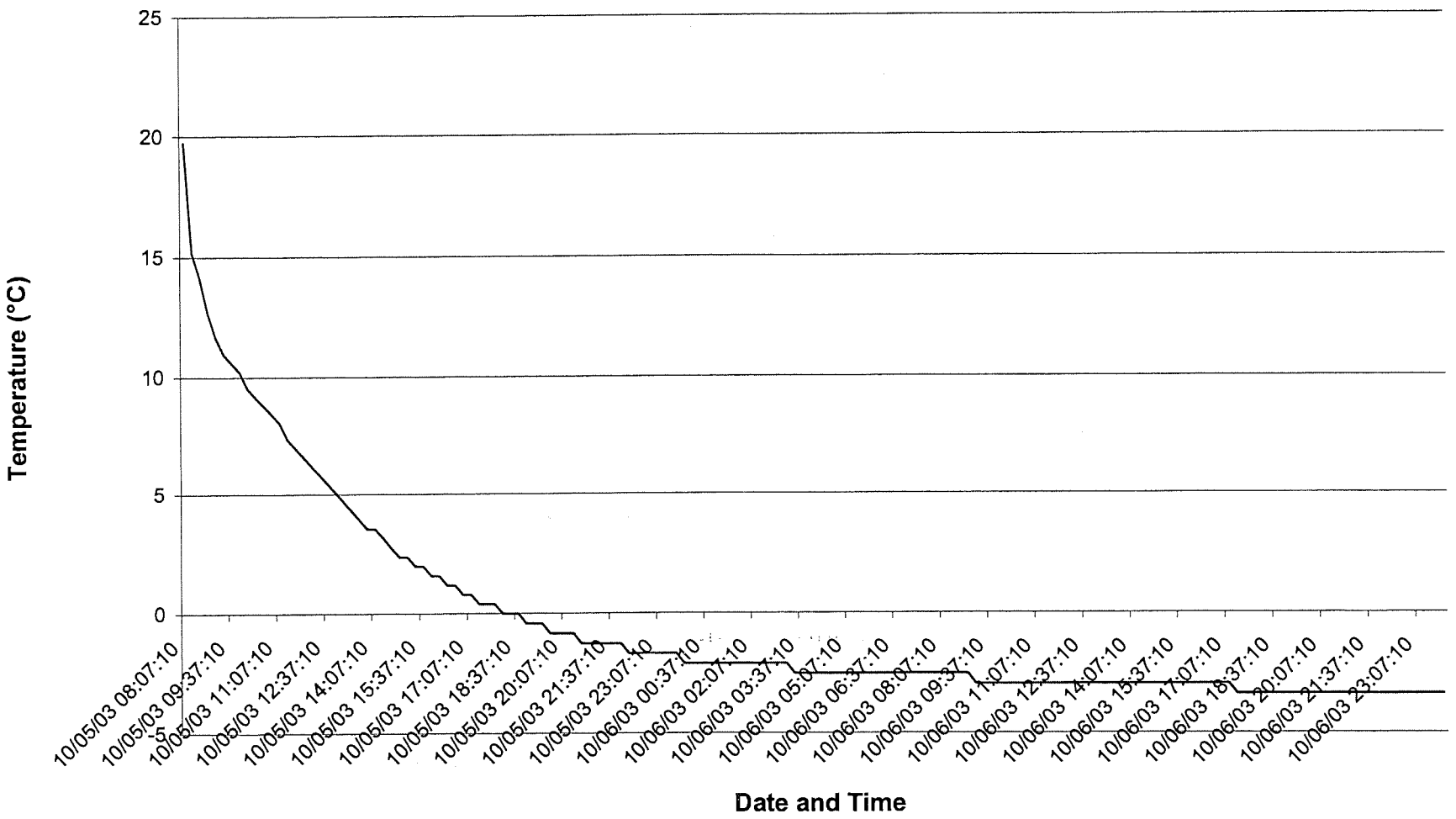


Figure 40. Temperature of swordfish B during storage and unloading for trip 5.

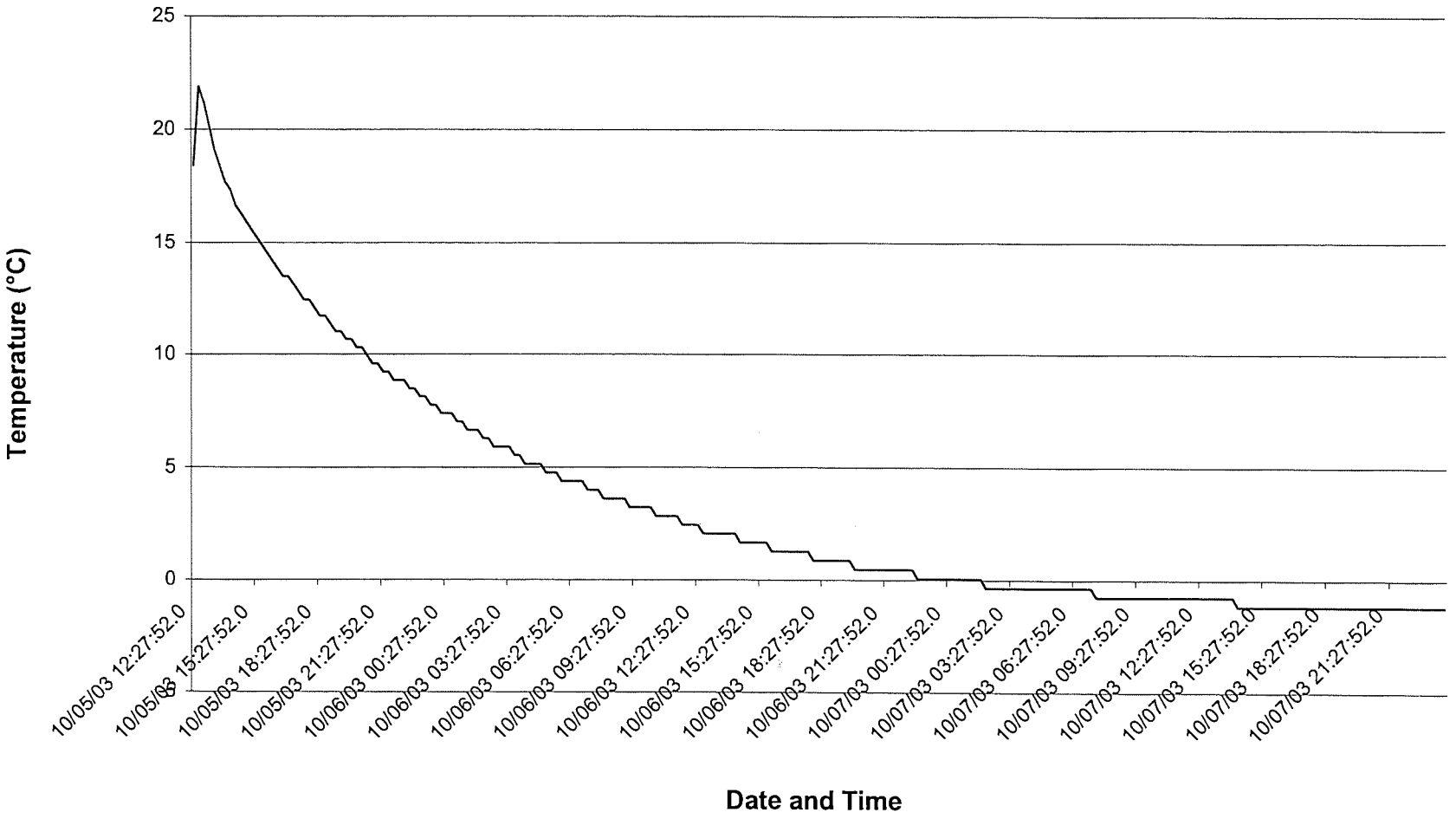


Figure 41. Temperature of swordfish C during storage and unloading for trip 5.

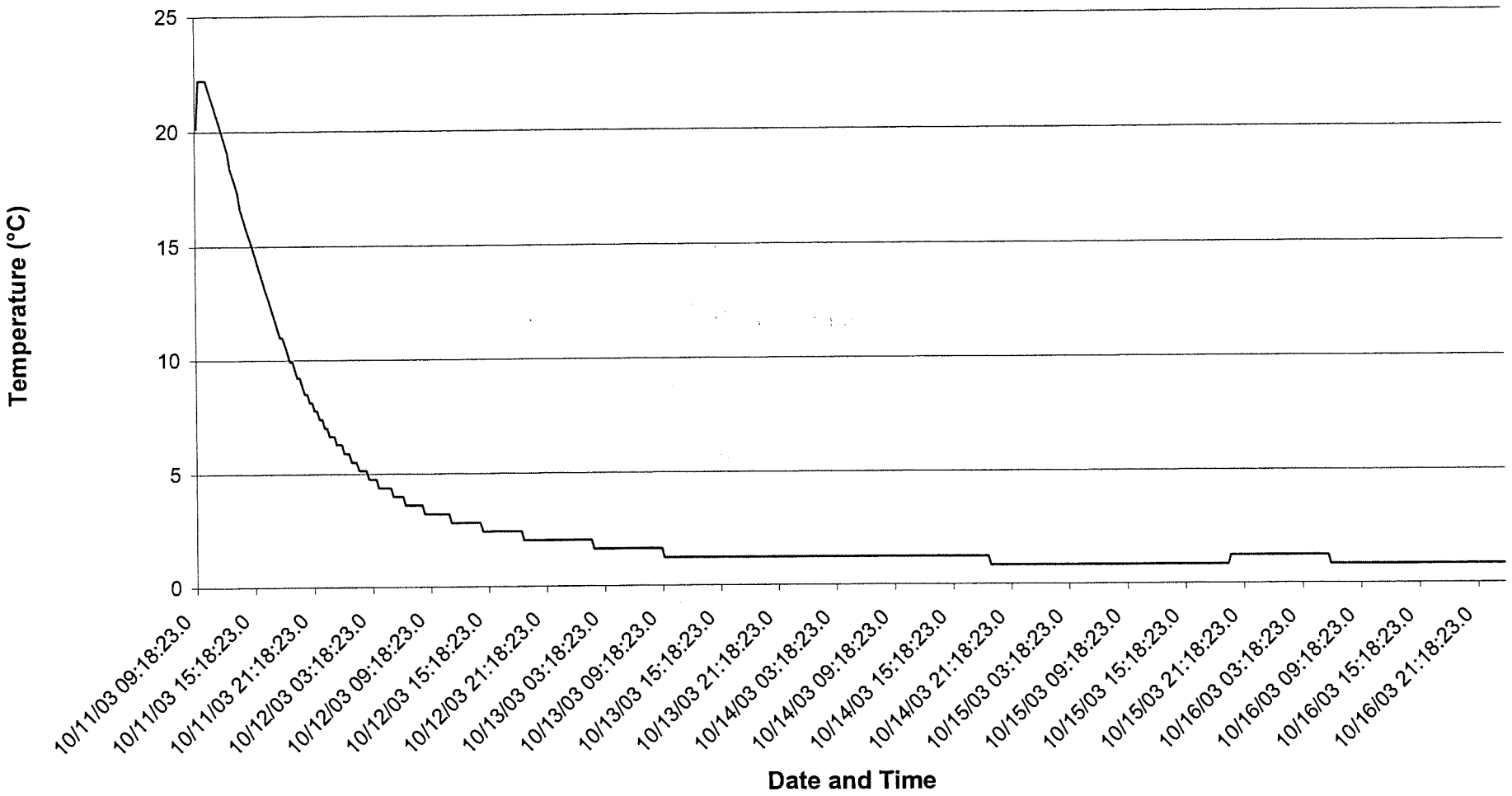
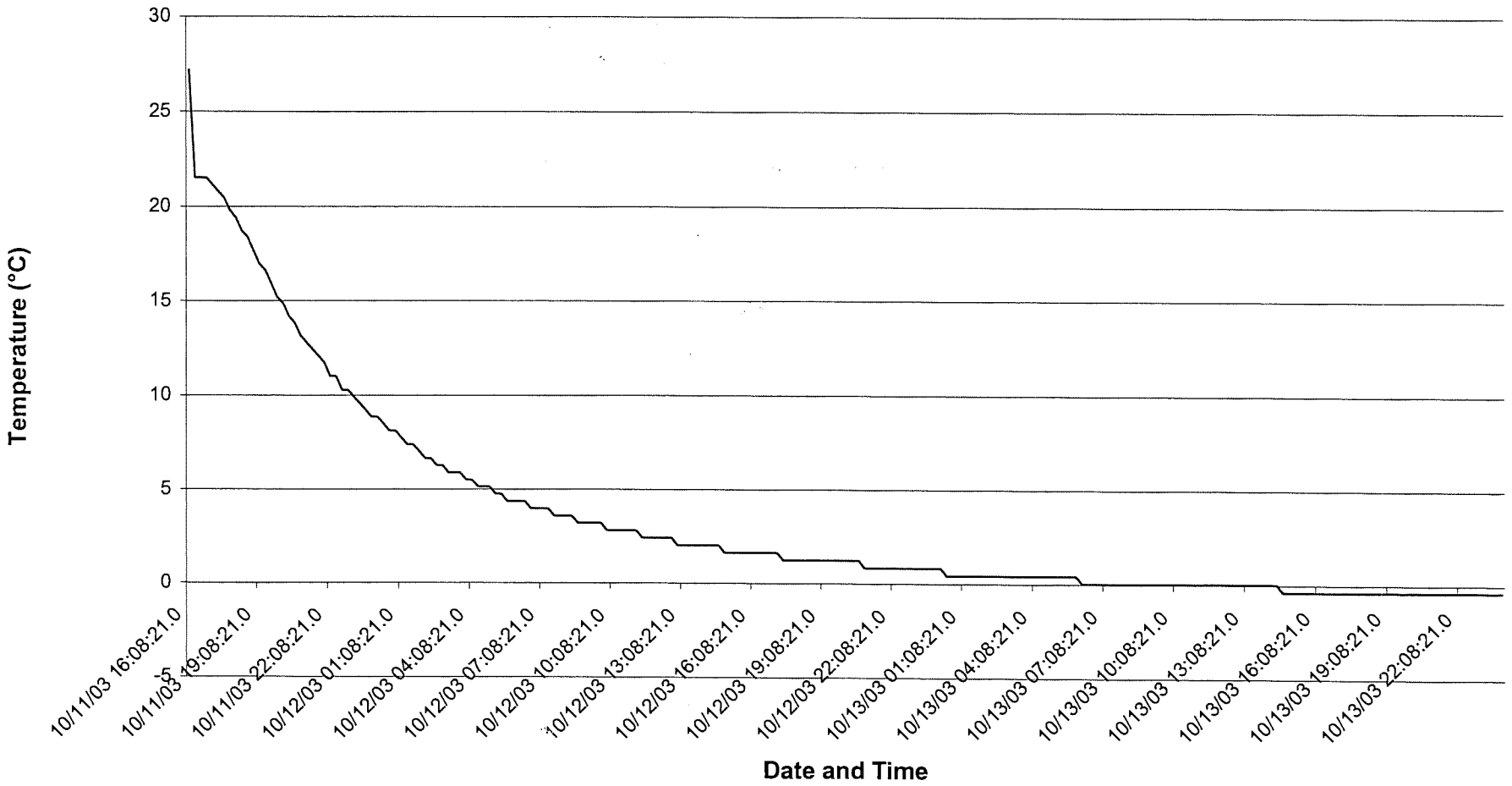


Figure 42. Temperature of swordfish D during storage and unloading for trip 5.



APPENDIX 7 Raw data, internal temperatures and colour measurements of fish caught for trip 6.

Table 31. Physical data collected for swordfish caught during trip 6.

Departed on Ocean Dawn owned by Tasman Bluefin from Mooloolaba and returned to Mooloolaba.														
Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
2/02/2004 9:03	14	25.2	2	2	1	5	0	>50	cc	186	108	M	22.8	22
2/02/2004 9:15	14	25.2	2	1	1	0	0	>50	cc	165	99	F	25.2	24.7
2/02/2004 10:33	14	25.2	2	1	0	0	0	>12	cc	147	94	F	23.4	23.4
2/02/2004 12:14	14	25.2	2	2	1	9	0	>12	cc	173	108	F	25.2	26.2
2/02/2004 13:01	14	25.2	1	?	1	4	0	>20	cc	179	101	F	26.2	25.2
3/02/2004 7:38	13	25.1	1	?	1	2	0	>20	cc	154	90	M	24.8	24.5
3/02/2004 10:02	13	25.1	1	?	0	0	0	15	cc	134	70	M	24.8	25.4
3/02/2004 13:49	13	25.1	1	?	1	3	0	4	cc	141	86	F	25.2	24.5
3/02/2004 14:38	13	25.1	1	?	0	0	0	1	cc	122	68	F	24.6	23.4
3/02/2004 14:57	13	25.1	2	2	1	1	0	10	cc	169	99	F	21.3	22.5
4/02/2004 8:28	12	24.3	2	2	1	2	0	4	cc	134	74	M	24.6	24.1
4/02/2004 8:40	12	24.3	2	2	1	2	0	10	cc	143	85	F	24.6	24.1
4/02/2004 10:29	12	24.3	2	1	0	0	0	15	cc	149	94	F	24.9	24.1
4/02/2004 12:36	12	24.3	2	2	1	3	0	5	cc	163	107	F	24.7	23.4
6/02/2004 11:13	10	26.8	2	2	1	2	0	>50	cc	189	111	F	23.7	24.3
8/02/2004 8:45	8	26.8	2	2	0	0	0	10	cc	130	79	M	27.3	27.1
8/02/2004 10:02	8	26.8	2	2	1	1	0	>50	cc	209	142	F	27.1	27.1
8/02/2004 11:41	8	26.8	2	2	0	0	0	>12	cc	157	103	F	27.2	26.7
8/02/2004 12:28	8	26.8	2	1	0	0	0	7	cc	122	45	F	27	26.7
8/02/2004 14:03	8	26.8	2	2	0	0	0	22	cc	179	105	F	26.5	25.9
8/02/2004 14:57	8	26.8	2	2	1	1	0	>20	cc	157	94	M	24.7	24.5
9/02/2004 11:07	7	26.9	2	2	1	4	0	>20	cc	196	120	F	23.8	22.8
9/02/2004 11:49	7	26.9	2	1	0	0	0	12	cc	123	70	F	25.6	25.2
10/02/2004 8:26	6	27.3	1	?	0	0	0	2	cc	110	65	?	27.8	28
10/02/2004 9:00	6	27.3	2	2	0	0	0	7	cc	134	81	M	27.1	26.3
10/02/2004 9:09	6	27.3	2	1	0	0	0	>20	cc	176	a	M	26.5	26
10/02/2004 9:56	6	27.3	1	?	0	0	0	10	cc	134	83	F	27.9	27.4

Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Girth diameter	Sex	Anterior Temperature	Tail Temperature
10/02/2004 10:36	6	27.3	2	2	0	0	0	3	cc	124	?	M	26	25.8
10/02/2004 13:29	6	27.3	2	2	0	0	0	8	cc	138	?	M	28.1	27.4
11/02/2004 9:20	5	27.3	2	2	0	0	0	15	cc	120	?	F	25.7	25.8
11/02/2004 9:42	5	27.3	2	2	0	0	0	8	cc	121	?	F	26.9	26.5
11/02/2004 13:12	5	27.3	2	2	0	0	0	7	cc	125	?	F	27.6	26.7
11/02/2004 15:14	5	27.3	2	2	0	0	0	>50	cc	181	?	F	27.7	26
12/02/2004 9:43	4	27.3	2	2	0	0	0	2	cc	128	?	M	26.7	24.9
12/02/2004 11:40	4	27.3	2	2	1	1	0	5	cc	146	?	F	26.4	25.5
13/02/2004 8:58	3	27.7	1	?	1	1	0	7	cc	125	?	F	27	?
13/02/2004 10:29	3	27.7	1	?	0	0	0	>20	cc	150	?	F	28.5	27.9
13/02/2004 11:19	3	27.7	2	2	1	1	0	>20	cc	135	?	M	28	27.1
13/02/2004 11:56	3	27.7	2	2	0	0	0	8	cc	144	?	F	26.9	26.8
13/02/2004 M	3	27.7	2	2	1	1	shark bitten bill	>20	cc	185 (+ OR - 5)	?	F	28.2	27.5
13/02/2004 13:36	3	27.7	2	2	0	0	0	>20	cc	138	?	F	27.6	27
14/02/2004 8:08	2	27.5	1	?	0	0	0	6	cc	112	?	F	27.8	27.3
14/02/2004 9:29	2	27.5	2	2	0	0	0	9	cc	123	?	F	26.9	26.2
14/02/2004 11:22	2	27.5	2	2	1	4	0	>50	cc	204	?	F	27.4	26.6
14/02/2004 12:30	2	27.5	2	1	0	0	0	5	cc	133	?	M	27.8	27.3
15/02/2004 12:10	1	27.6	2	2	1	3	0	5	cc	141	?	F	26.4	26.2
16/02/2004 15:00	14	25.2	2	2	1	5	0	>50	cc	186	108	M	22.8	22

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some M=missing data, Fork Length and Girth diameter in cm

Figure 43. Temperature of swordfish A during storage and unloading for Trip 6.

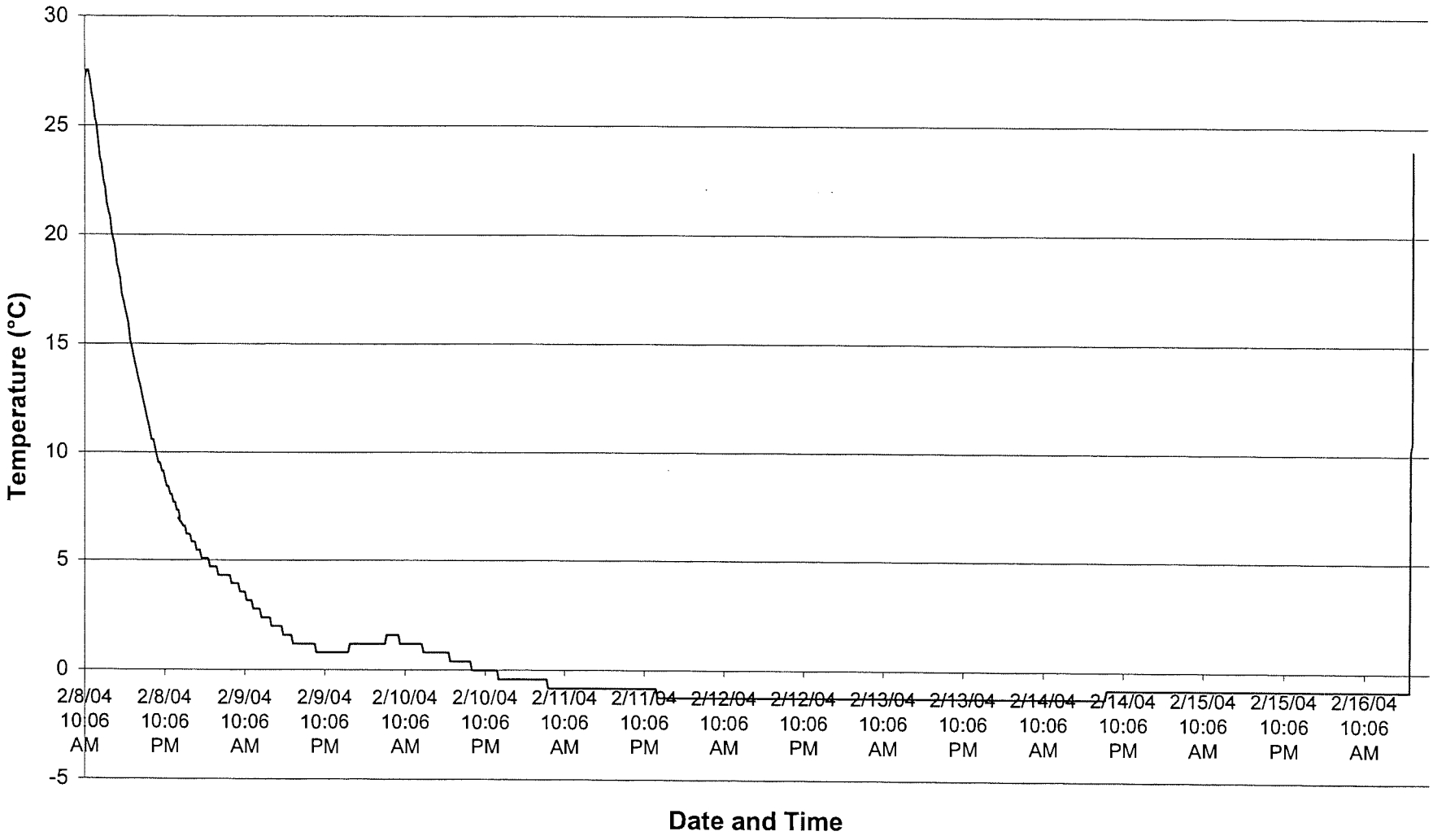


Figure 44. Temperature of swordfish B during storage and unloading for trip 6.

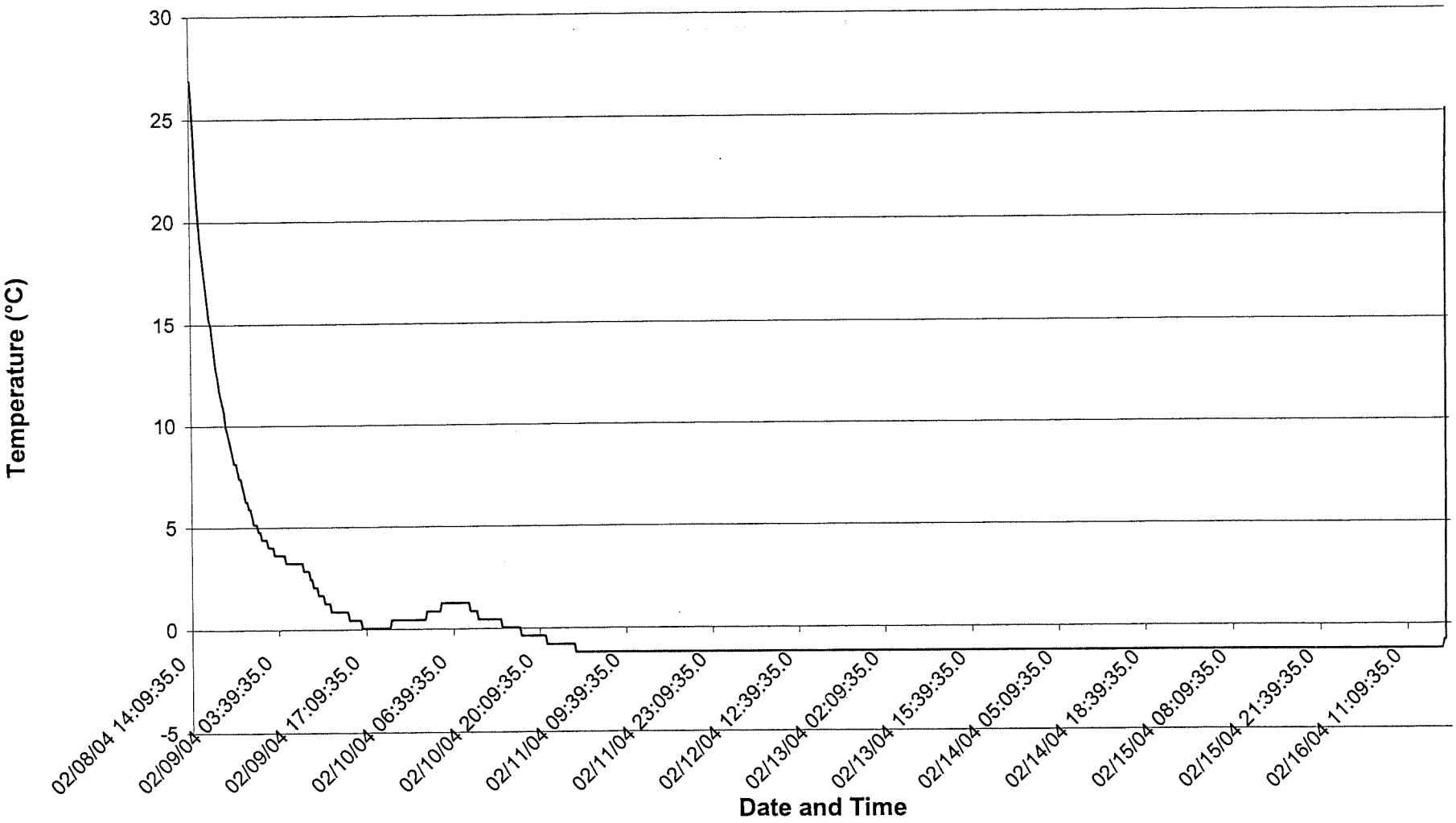
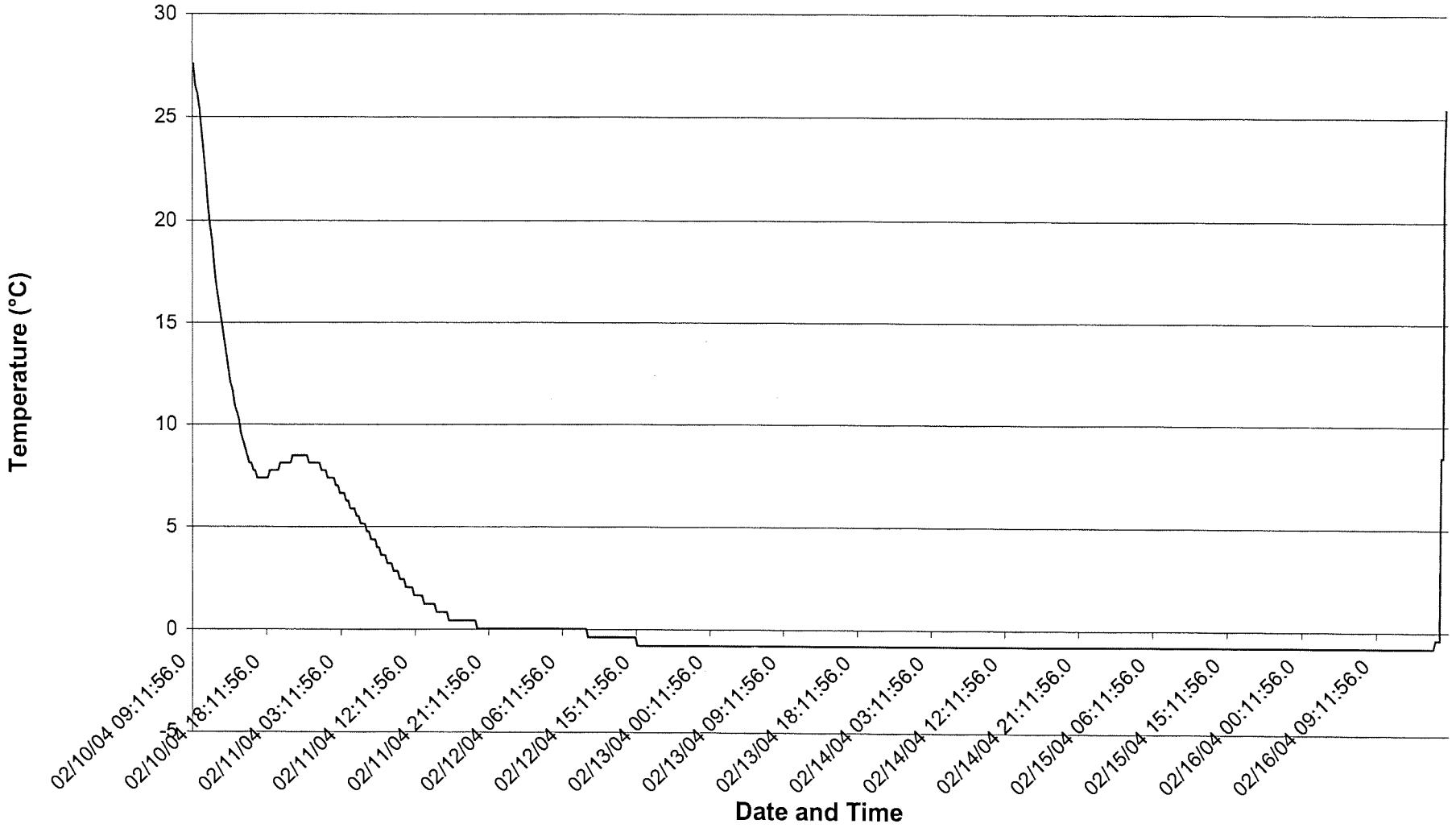


Figure 45. Temperature of swordfish C during storage and unloading for trip 6.



APPENDIX 8 Raw data, internal temperatures and colour measurements of fish caught for trip 7.

Table 32. Physical data collected for swordfish caught during trip 7.

Departed on Ocean Odyssey owned by Tasman Bluefin from Mooloolaba and returned to Mooloolaba.

Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Weight	Sex	Anterior Temperature	Tail Temperature
2/04/2004 8:05	14	24.1	1	1	1	7	0	>20	Shark +CC	206	76.3	F	25.2	24.7
2/04/2004 9:27	14	24.1	2	2	1	1	0	6	s	191	?	F	24.8	23.7
2/04/2004 10:04	14	24.1	2	2	1	3	0	10	s	165	?	F	24.8	24.4
2/04/2004 11:04	14	24.1	1	1	1	5	0	>12	s	190	70.6	F	24.4	24.7
3/04/2004 7:17	13	24.2	2	2	1	0	0	>12	s	169	64.3	?	24.1	23.8
3/04/2004 7:55	13	24.2	2	2	0	0	0	>30	s	159	?	?	24.4	24.1
3/04/2004 8:29	13	24.2	1	1	1	1	0	>30	s	189	?	M	25.9	25.2
3/04/2004 9:26	13	24.2	2	2	0	0	0	>30	s	177	?	F	24.4	24.4
3/04/2004 10:44	13	24.2	2	2	1	3	0	>30	s	172	74.2	F	24.9	24
3/04/2004 11:12	13	24.2	2	2	0	0	0	>12	s	166	?	M	24.9	24
4/04/2004 9:19	12	24.2	1	1	1	0	0	>12	s	149	47.7	M	25.2	24.5
4/04/2004 11:52	12	24.2	2	2	1	2	0	>100	s	199	?	F	21.8	22.8
4/04/2004 12:00	12	24.2	1	1	1	2	0	>30	s	224	143.5	F	23.2	22
4/04/2004 12:24	12	24.2	2	2	1	1	0	>20	s	185	95.9	F	21.5	20.4
4/04/2004 14:15	12	24.2	1	1	1	1	0	>10	s	174	?	F	23.7	22.3
4/04/2004 14:27	12	24.2	1	1	0	0	0	>12	s	189	?	F	23.9	23.4
5/04/2004 6:33	11	23.9	2	2	1	2	0	>30	s	198	?	M	23.3	21.8
5/04/2004 6:56	11	23.9	1	1	0	0	0	>12	s	184	66.4	F	23.3	22.7
5/04/2004 7:33	11	23.9	1	1	0	0	0	>6	s	169	?	F	25.3	24.2
5/04/2004 8:10	11	23.9	1	1	0	0	0	>12	s	192	?	F	24.6	24.1
5/04/2004 9:27	11	23.9	1	1	1	1	0	>10	s	155	?	F	25.5	24.5
5/04/2004 9:58	11	23.9	1	1	0	0	0	>30	s	204	52.3	F	25.1	24.2
6/04/2004 14:00	10	23.9	2	2	1	2	0	>20	s	187	?	F	23.8	23.8
8/04/2004 7:15	8	23.7	1	1	0	0	0	>10	s	130	?	F	25	24.6
8/04/2004 8:40	8	23.7	2	1	0	0	0	7	s	141	?	M	24.3	24.1
8/04/2004 10:08	8	23.7	2	2	0	0	0	>200	s	246	169.4	F	23.4	21
8/04/2004 11:23	8	23.7	2	1	0	0	0	>12	s	174	?	F	23.5	23.8
8/04/2004 11:58	8	23.7	1	1	0	0	0	0	s	127	?	M	25.6	25.3

Date & Time caught	Days Stored	Sea Temperature	Live or Dead	Rigor Stage	Presence of damage	Cookie bites	Fresh wounds	Healing wounds	Deep/Shallow old wounds	Orbital Fork Length	Weight	Sex	Anterior Temperature	Tail Temperature
8/04/2004 14:02	8	23.7	2	2	0	0	0	>30	s	180	?	M	23.7	22.7
9/04/2004 7:02	7	25.2	1	1	0	0	0	>50	s	230	?	F	25.2	24.8
9/04/2004 7:31	7	25.2	1	1	0	0	0	>20	s	188	81.8	M	25.6	24.8
9/04/2004 8:15	7	25.2	2	2	1	2	0	>20	s	191	?	F	25.2	25.3
10/04/2004 9:25	6	25.3	1	1	0	0	0	>10	s	178	61.2	F	26.2	25.7
10/04/2004 10:17	6	25.3	1	1	1	0	1	>10	s	169	?	F	26.2	25.9
10/04/2004 10:30	6	25.3	2	1	1	1	1	>10	s	122	?	?	25.5	25.3
10/04/2004 12:55	6	25.3	1	1	0	0	0	>20	s	179	103.2	F	26.1	25.4
10/04/2004 13:31	6	25.3	2	1	1	1	1	>10	s	131	?	F	25.3	25.2
11/04/2004 9:22	5	25.4	?	?	0	0	0	7	s	133	?	M	27.3	26.6
11/04/2004 12:11	5	25.4	2	2	0	0	0	>10	s	137	?	F	25.2	25.2
11/04/2004 M	5	25.4	2	1	0	0	0	6	s	126	?	M	25.2	24.9
12/04/2004 11:33	4	24.8	2	1	1	1	0	>12	s	151	73.2	F	25.8	24.9
12/04/2004 15:46	4	24.8	1	1	0	0	0	5	s	119	?	?	26.5	25.5
13/04/2004 12:51	3	25.1	2	2	0	0	0	>10	s	142	?	F	25.2	25.6
13/04/2004 13:36	3	25.1	1	1	0	0	0	>15	s	131	?	F	26.2	24.8
13/04/2004 15:05	3	25.1	2	1	1	1	0	>50	s	171	?	M	20.6	21.6
14/04/2004 6:47	2	25.9	1	1	1	1	0	<10	s	151	?	F	26.6	26.2
14/04/2004 7:11	2	25.9	2	?	1	3	0	>10	s	151	?	F	26.3	26.1
14/04/2004 7:37	2	25.9	1	1	0	0	0	>10	s	159	?	F	26.7	26.4

s= shallow d=deep cc=cookie cutter shark bite Presence of damage 0=none 1=some ?=missing data, Fork Length in cm, Weight in kg, Girth measurements not available.

Figure 46. Temperature of swordfish A during storage and unloading for trip 7.

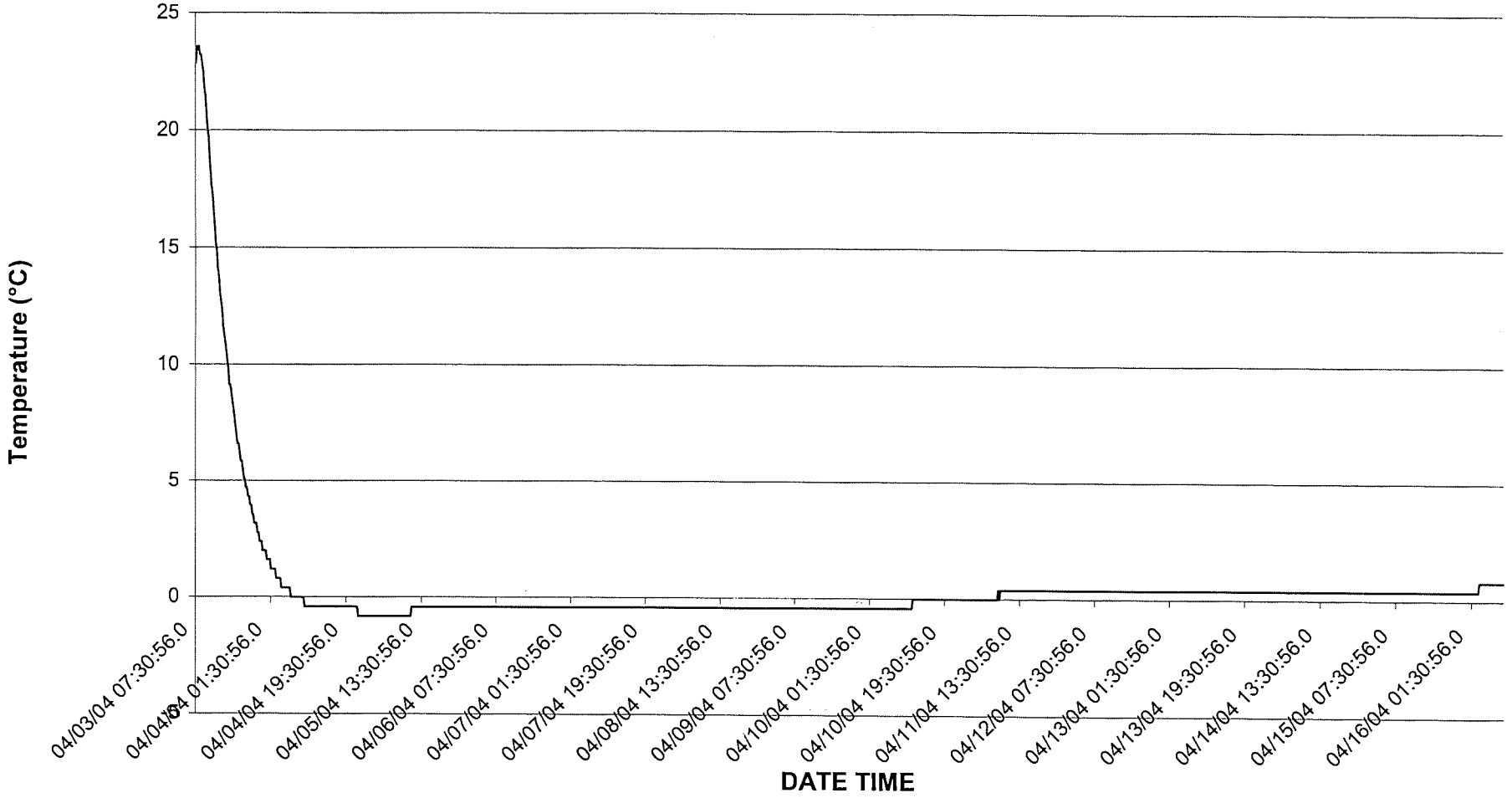


Figure 47. Temperature of swordfish B during storage and unloading for trip 7.

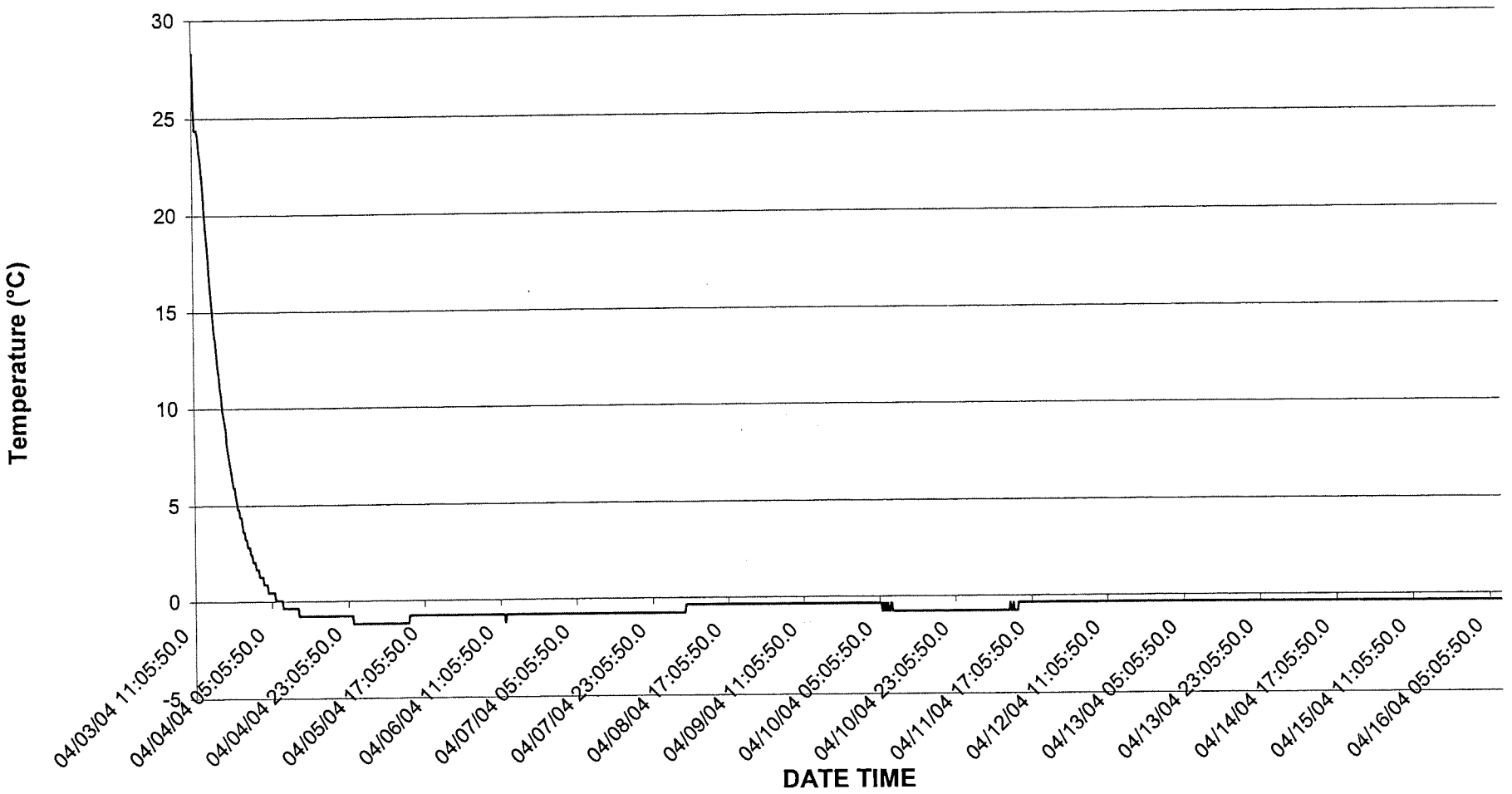


Figure 48. Temperature of swordfish C during storage and unloading for trip 7.

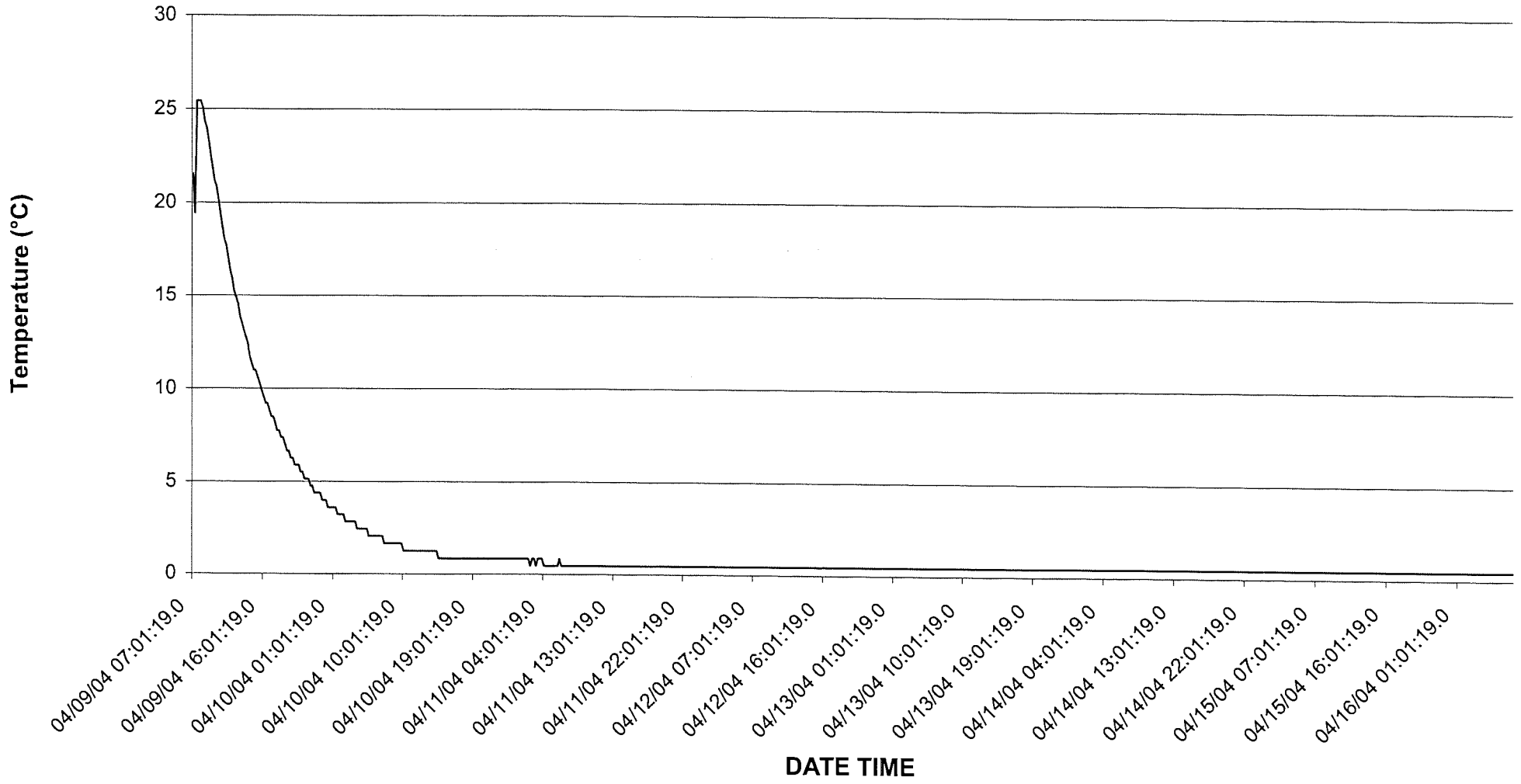
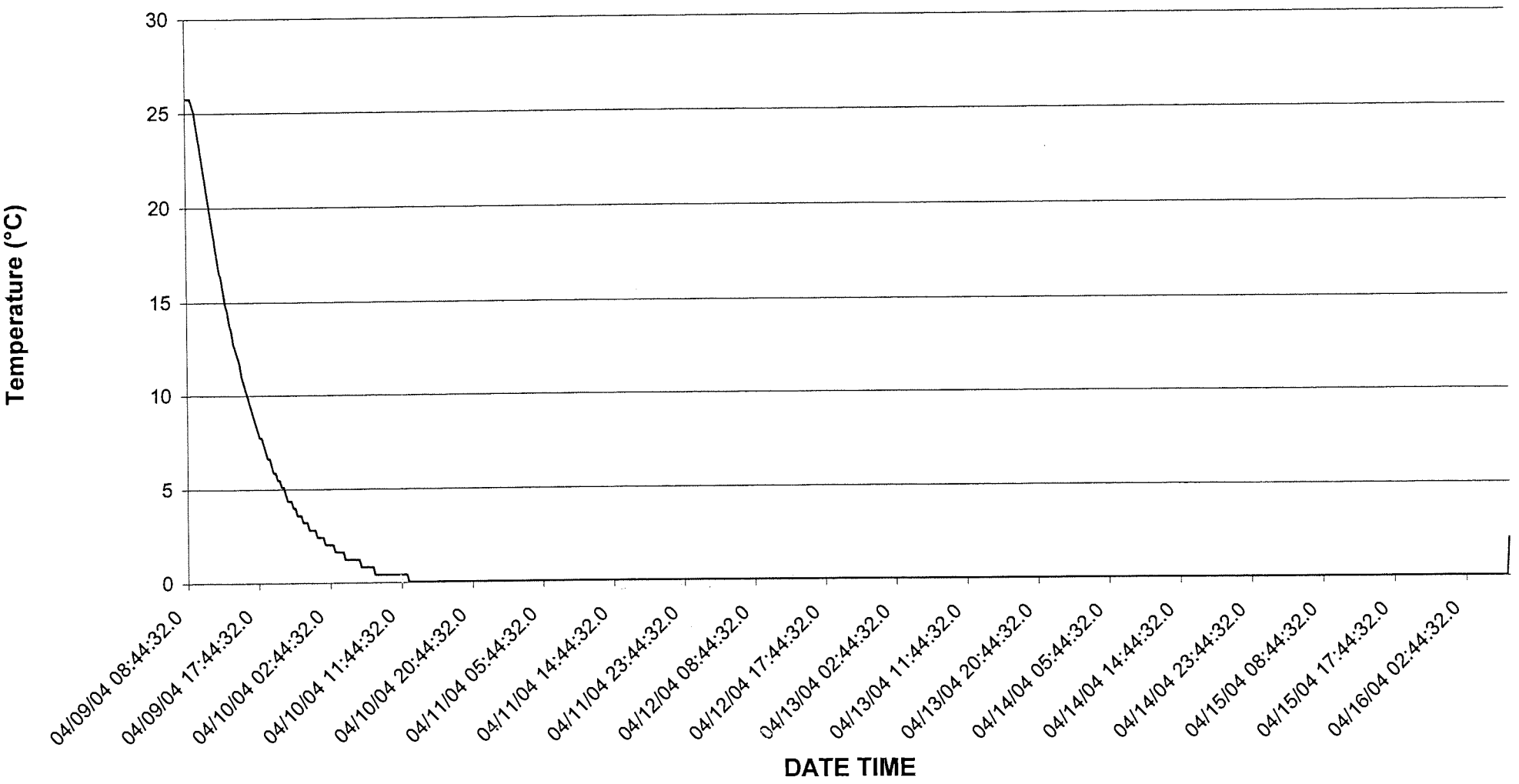


Figure 49. Temperature of swordfish D during storage and unloading for trip 7.



APPENDIX 9 Microbiological counts of swordfish muscle.

Table 33. Microbiological counts of damaged swordfish flesh.

Wound description	Sampling site	Standard plate count (cfu/g)	Psychrotroph count (cfu/g)
Large shark bite A	edge	>1,000,000	>1,000,000
	10mm in from edge	150,000	920,000
	20mm in from edge	120,000	170,000
Large shark bite B	edge	>1,000,000	>1,000,000
	10mm in from edge	140,000	840,000
	20mm in from edge	120,000	140,000
Large shark bite C (remnant of a trunk sold locally)	edge	>250,000	>250,000
	10mm in from edge	>250,000	>250,000
	20mm in from edge	120,000	180,000
Large shark bite D	edge	>1,000,000	>1,000,000
	10mm in from edge	500,000	560,000
	20mm in from edge	64,000	63,000
Large shark bite E	edge	140,000	140,000
	10mm in from edge	55,000	57,000
	20mm in from edge	23,000	28,000
Recently healed cookie cutter bite	edge	95,000	90,000
	10mm in from edge	85,000	81,000
	20mm in from edge	20,000	20,000
Recently healed cookie cutter bite	edge	80,000	150,000
	10mm in from edge	2,200	10,000
	20mm in from edge	500	200
Fresh cookie cutter bite A	edge	92,000	110,000
	10mm in from edge	11,000	10,000
	20mm in from edge	2,200	2,600
Fresh cookie cutter bite B	edge	720,000	590,000
	10mm in from edge	280,000	290,000
	20mm in from edge	40,000	40,000
Fresh cookie cutter bite C	edge	5,000,000	4,900,000
	10mm in from edge	190,000	172,000
	20mm in from edge	110,000	160,000
Fresh cookie cutter bite D	edge	970,000	980,000
	10mm in from edge	21,000	49,000
	20mm in from edge	31,000	41,000
Fresh cookie cutter bite E	edge	>1,000,000	>1,000,000
	10mm in from edge	>1,000,000	>1,000,000
	20mm in from edge	>1,000,000	>1,000,000
Fresh cookie cutter bite F	edge	400,000	530,000
	10mm in from edge	13,000	21,000
	20mm in from edge	3,600	4,800
Fresh cookie cutter bite G	edge	>1,000,000	>1,000,000
	10mm in from edge	>1,000,000	>1,000,000
	20mm in from edge	98,000	130,000
Belly Slit Knife Cut	edge	>1,000,000	>1,000,000
	10mm in from edge	270,000	370,000
	20mm in from edge	63,000	63,000

APPENDIX 10 Industry manual for handing swordfish.

SWORDFISH HANDLING MANUAL

INTRODUCTION

Broadbill Swordfish (*Xiphius gladius)* represents a major component of the income derived from commercial longline fishing. In calendar year 2000 the total catch of swordfish in Australia (3519 t) represented $A34.9M or 44.3% of earnings from longline fishing in the Eastern Tuna and Billfish Fishery (BRS, 2000). The same report found that swordfish were fully fished in the Western Tuna Billfish Fishery and status uncertain in the ETBF. The total catch of swordfish fell from 1929 t in 2000 to 1396 t in 2001.

Such pressure on stock places even greater demands on quality of product to maximise returns and maintain a viable industry. This manual is an attempt to provide fishers with a greater understanding of swordfish as food and ensure maximum returns for effort in a fishery under pressure.

SWORDFISH BIOLOGY

Swordfish are a highly migratory species inhabiting almost all the oceans of the world from latitude 50^{0}N to 50^{0}S. Spawning takes place in waters above 24^{0}C, being tropical and sub-tropical waters. As swordfish grow they move towards more temperate waters.

Swordfish are equipped with excellent vision. They appear to prefer low levels of light, spending their days between 100m and 300m, rising to near the surface at night. They even have a 'heater' muscle at the back of their eye that supplies warmth to the brain and the eye. This allows the swordfish to maintain optimum eye and brain function in the cold waters of deepwater dives.

Although they do not heat their bodies as tuna do, they are designed to conserve body temperature. This is especially important during these deep dives. This conservation of body heat means that live swordfish are generally landed at or up to 2°C above sea surface temperature.

This means that chilling swordfish quickly is just as important as it is with tuna, to preserve maximum available fish quality.

Swordfish use their hefty bill to stun their prey as well as for self-defense. Diet consists primarily of squid (approximately 70% by weight) with the remainder consisting mostly of fish.

Growth rates of swordfish are extremely high for their first year. Some fish can grow up to 15kg during this time. Males and females, however, display different growth patterns. Male swordfish are believed to reach their maximum size of ~130kg by 9 years, while females reach ~350kg after 15 years. It is nutrition that ultimately determines the growth rate of a swordfish. Fish smaller than these weights may be older due to poor nutrition, or due to the presence of parasites.

The majority of swordfish landed are female. Young and Drake (2002) found that, between July 1999 and April 2000, 70.7% of the catch was female. They concluded that 77% of these were not sexually mature. This means that just under half the catch is being removed from the stock prior to reaching sexual maturity. Their research found no difference in overall quality due to sex.

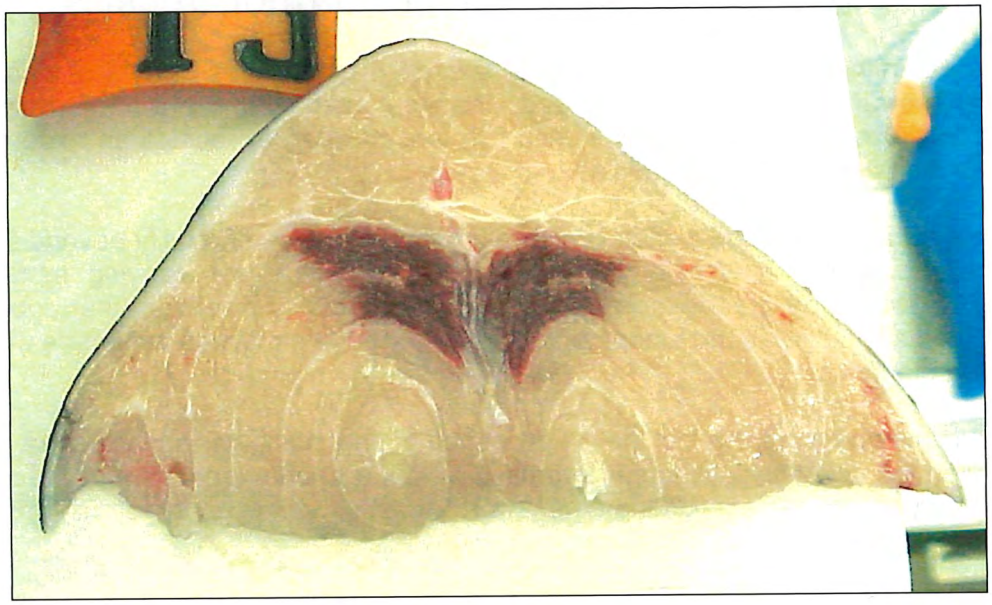
GRADING SWORDFISH

Swordfish are graded, like tuna, from a tail cut. The tail cut is made just in front of the caudal keel. Grading is dependant upon several factors.

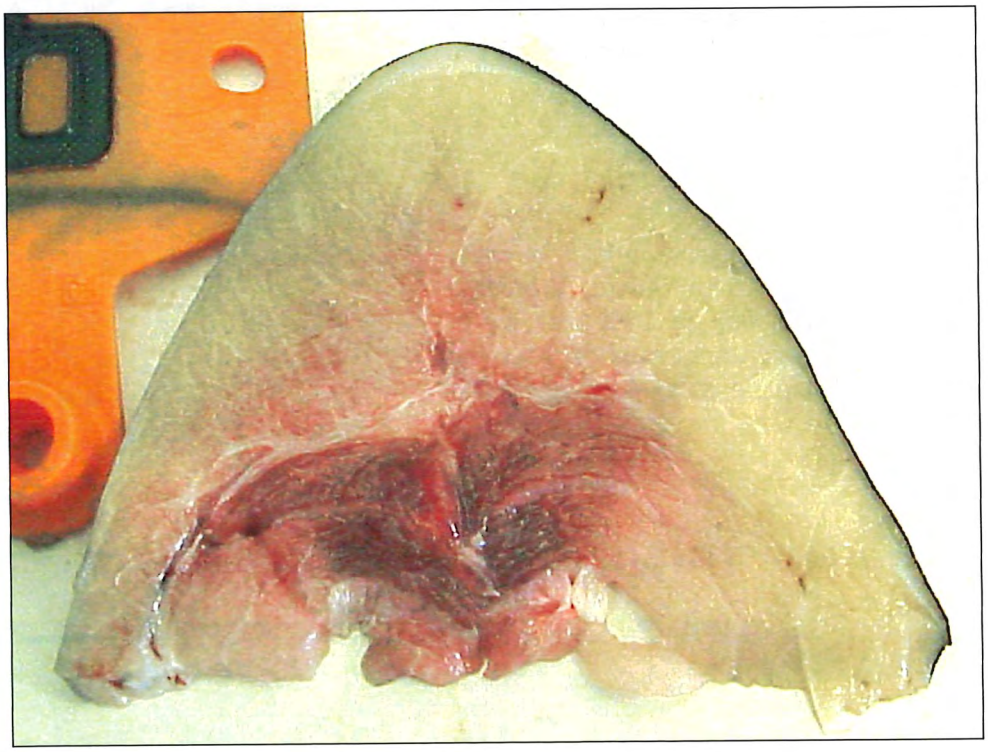
- The 'bloodline' (red muscle tissue) is examined for tightness and colour. Tightness refers to the extent of, or lack of diffusion of the blood into the surrounding white muscle tissue.
- The degree of redness of the bloodline is also evaluated. Bloodlines with browning are considered as poorer quality and receive lower scores.
- The white muscle tissue is also examined for colour. Good quality white muscle retains a pink or peach colour. Poor quality fish have white muscle that appears brown.
- The fat content of the white muscle is also considered important. Fat appears as marbling of the white muscle, in a similar way to that of beef.

EXAMPLES

Below is a tail cut of an export grade swordfish. Good colour and tightness of the bloodline displays the aspects desired for export swordfish. The white muscle also shows nice consistency of colour and some marbling of fat.



Below is the tail cut of a swordfish that is not export quality. Although the bloodline retains reasonable colour, blood has diffused into the surrounding tissue. The white muscle tissue also displays some browning, especially close to the skin.



ISSUES AFFECTING SWORDFISH QUALITY

The overall quality of swordfish is a result of many direct and indirect influences, which may be controlled or not.

QUALITY ASPECTS BEYOND THE CONTROL OF CREW

The greatest influence on overall quality of swordfish beyond the control of deck crew is whether a swordfish is landed alive or dead. The great majority of live landed fish receive an export grade. The chances for a swordfish fish landed dead to receive an export grade is much less than that of a live landed fish.

The condition or health of swordfish is also a primary influence of quality beyond the crew's control. Large swordfish with large girth and rotund shape are carrying more fat and generally obtain export grades more consistently than smaller swordfish that appear much thinner. Food availability is the fundamental factor for condition. Males tend to be thinner and smaller than females.

Other influences on condition include the presence of parasites, which place extra metabolic demands on the swordfish. Although swordfish exhibit a phenomenal ability to recover from physical injury, damage from fighting other swordfish, sharks or even larger mammal species can also affect quality.

DECK PRACTICES

Deck practices are the first real opportunity for fishing crew to influence the ultimate quality of fish landed. While these practices may be secondary to those already outlined as being beyond control of the crew, they still have the ability to reduce export grade fish to a domestic grade, and thus impact on the financial return to boat owners, skippers and crew.

LANDING SWORDFISH

Landing swordfish is arguably one the most dangerous aspects of longline fishing. Handling an angry and powerful fish of 100kg or more, armed with an extremely dangerous bill requires good teamwork, discipline and respect for the fish.

Remember – There are no ambulances where you go fishing!!!

ALWAYS RESPECT THE SWORDFISH!

- Multi-gaff devices are often employed by crew to assist in landing larger fish. Great care should be taken when using these devices as they also have the ability to dislodge the hook and free the fish, which can be very upsetting to all concerned.

- Skippers will sometimes use firearms to quieten larger 'green' fish prior to landing. High levels of crew discipline are required when firearms are employed.

- Gaffing of swordfish should be through the eye socket, as this provides a good hold of the skull needed to lift large fish into the vessel and does not damage the edible portion. With live fish, at least two crewmembers should have a firm gaff hold though the eye socket, and at least one other needs to hold the bill as the fish is brought onboard.

- The swordfish should then be dragged across the deck matting to the killing and cleaning area. Here the head is sawn off while the gaffers and bill holder maintain a tight hold on the fish. This is usually achieved by several crew holding the head of the fish hard to the deck.

The photograph on the right shows a crew member standing on the bill of a medium sized swordfish while another saws the head.

DO NOT ATTEMPT TO HOLD THE TAIL OF A LIVE SWORDFISH AT ANY TIME!!!

- The tail can easily break your arms or any other bone structure on your body. As long as a firm hold is maintained upon the head, forcing it into the floor, the head can be sawn off quickly, resolving a dangerous situation.

- The fish also needs to be killed quickly and safely to prevent bruising and other damage that can reduce the quality of the flesh.

- Removal of the head allows for the blood to flow out under pressure from the still pumping heart. Draining of excess blood will ensure it does not pool in the tail to later impair the bloodline grade.

- Once the fish is dead, core the spinal tissue as would be done to a tuna. With the head removed, the spinal canal is exposed and easily penetrated by the coring tool. This is done for the same reason as tuna: to destroy the neural tissue so rigor is reduced, maintaining a higher level of freshness.

- Removal of fins and gill plates is then completed using the hacksaw. The tail fins should be cut approximately 20cm away from where the fins separate from the body as the tail is used to lift the fish by rope and winch.

- A cut is made around the anus, which is then pushed in and a small cut made along the belly. This allows the intestines to be cut or pulled away easily from the belly lining, taking care not to nick them and let their contents contaminate the intestinal cavity.

- The belly can then be cut open right up to the pectoral bone, where the gut, gills and other organs are to be removed by pulling them from the front.

- Once all the organs have been removed from the belly cavity, the dorsal aorta and surrounding blood vessels can be cut and scraped out. This group of blood vessels lie between the belly cavity and the backbone. A cut either side of the dorsal aorta, to the backbone, and along the length of the cavity allows these blood vessels to be removed by the aid of a scraper. Scrub the backbone to reveal the white bone colour underneath.

- The belly cavity then needs to be scraped of the lining that covers it. This is quite difficult and can take some effort, but must be done to limit bacterial growth.

- Once the belly cavity has been cleaned thoroughly, trim up any rough edges around the head cut and any other untidy areas. The fish is now ready to be placed into the chilling tanks.

- Transfer into the chilling tanks will usually require assistance for large fish. Take care not to bruise fish on the side of the tanks during transfer.

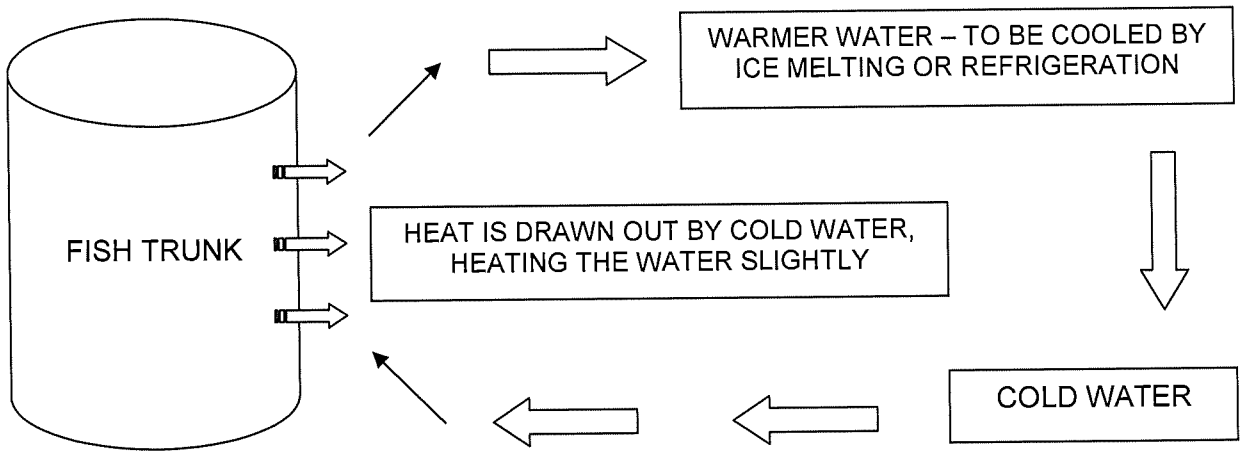
It is especially important not to mistreat the tail in any way, as this is the area the grader uses to make their evaluation. We have seen many swordfish trunks given domestic grades, only to reveal prime swordfish quality in the rest of the fish when cut up for market.

CHILLING PRACTICES

Chilling of fish onboard is usually achieved by one of three methods, refrigerated seawater (RSW) refrigerated brine (RB) or ice slurry (freshwater or a mix of ice and seawater). Each system has its strengths and weaknesses. Deck crew will invariably work on different vessels and chilling media, so an understanding of all three methods is essential.

From the diagram below of the heat transfer process, the critical role of circulation can be understood. The rate of heat removal from the fish is dependant upon good circulation within the tank.

HEAT TRANSFER PROCESS WITHIN A CHILLING TANK



This is the process of chilling seen in all styles of tanks. However, each method outlined so far has special needs and considerations that all crew, not just skippers, should be aware of.

These methods can be described as active (in the case of RSW and RB) or passive (ice slurry). This is basically due to the presence of circulation within the tank. Circulation is the most critical aspect of the chilling process.

The fundamental principle of chilling is to draw heat from the object. This is achieved by bringing the object into contact with a medium, in this case being cold water. Heat is then transferred from the fish surface, to the medium where it can then be taken away. The process continues until the temperature of this fish approaches that of the medium.

There are many variables that can have an impact upon the rate of chilling of fish in tanks. These include;

- Temperature of the medium
- Temperature loss to the surface of the tank
- Ambient or outside temperature
- Cooling capacity of the refrigeration unit (or the amount of ice present in slurry)
- Circulation rate within the tank
- Total mass of fish in the tank
- Thermal conductivity, or rate of heat loss from the fish.

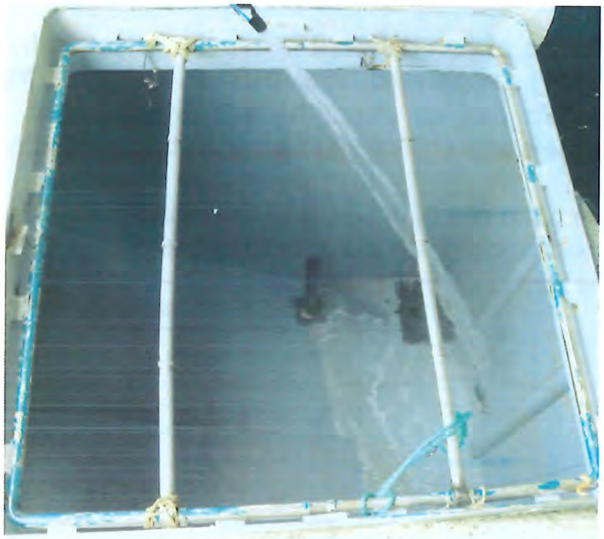
This is particularly important with swordfish, as their bodies are design to conserve heat. They do this to help them resist the cold waters of deep dives when feeding. Swordfish trunks can take much longer to reach temperatures of <1°C than tuna.

Swordfish trunks over 100KG can take up to 48hrs in chilling tanks to reach a core temperature of <1°C.

REFRIGERATED SEAWATER (RSW) AND REFRIGERATED BRINE (RB)

- Refrigeration units need to be correctly suited to the size of the tanks and working to the maximum ability. This may seem somewhat obvious, but our work has seen many tanks that cannot adequately cope with large amounts of fish. A "2 tonne shot" will place a huge strain on the system that the refrigeration unit may not meet.

- Circulation within the tank needs to be adequate to ensure maximum chilling rates. Poor circulation can also lead to warm spots within the tank.



RB TANK WITH INTERNAL REFRIGERATION

Temperature gauges within the tank should be regularly checked and calibrated. Hand held temperature probes are recommended to ensure gauges are working correctly.

- Tanks with exposed can occasionally freeze fish. This can happen if the fish comes in direct contact with the coils, or when the water temperature drops below minus 2°C. Some vessels use rubber floor matting to cover their coils.

- Exposed coils can ice up if the water is too cold or due to the lack of adequate circulation, preventing efficient chilling of all the water in the tank.

- RB tanks require extra care to maintain proper function. Because of the higher salt levels in the water (~5% compared to seawater of 3.5%) much lower tank water temperatures can be achieved without freezing the water. Again, fish will be in danger of freezing if temperatures stay below -2°C.

RSW TANK WITH EXPOSED COILS

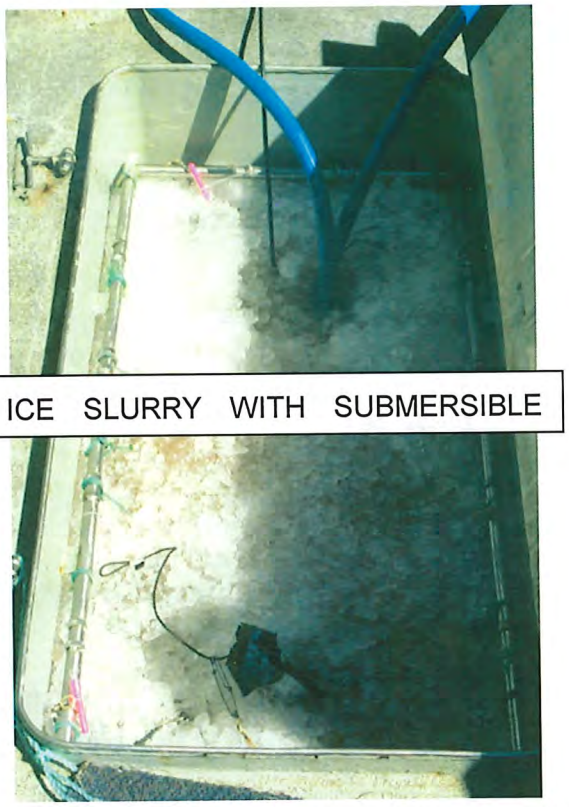
- The other concern of RB is circulation. The increased density of the water improves heat transfer from the fish, but the denser water resists circulation, and 'hot spots' at the bottom of the tank will form much easier than in RSW.

The best and worst chilling rates of all the swordfish we studied on board vessels were found in those chilled with refrigerated brine.

ICE SLURRY

- Ice Slurries are the preferred method of chilling for many skippers due their consistency and simplicity of operation. The ability of melting ice to absorb heat (described as the latent heat capacity) proves very effective in chilling all sizes of fish. From our work, chilling rates in ice slurries can match and sometimes exceed those found in poorly performing refrigerated systems.

- There is generally no mechanical circulation within ice slurry tanks while winching up the fishing gear. This means that fish go into the slurry with no circulation of the water other than thermal convection. Thermal convection is a very mild circulation caused by warm of water rising in the tank, being cooled by melting ice, and then sinking causing a mild current to develop.



ICE SLURRY WITH SUBMERSIBLE

- All the static ice slurry tanks that we have observed display a lag time of at least 30 minutes in reducing the core temperature of the trunk, due to lack of circulation. This means that the core of fish is being exposed to an extra 30 minutes of deck temperature resulting in lower quality.

- Salt is sometimes added to slurries to assist the chilling process. It is especially important to introduce circulation to brine slurries, as they are prone to forming 'hot spots' of warmer water in bottom of the tanks.

We strongly recommend that ice slurries have either internal or external pumps installed to increase circulation within the slurry for the duration of the holding time.

STORAGE PRACTICES

Swordfish and tuna are generally packed in ice within the fish hold after achieving close to 0°C core temperatures. Although some other methods are used for long-term storage (eg. ice slurry) most longline fishing vessels use this system.

- Ensure that fish core temperatures are at or below 1°C before transferring to the hold. Higher temperatures can melt the ice surrounding the fish in the hold. This forms an air pocket which may keep the temperature of the fish up to ~10°C.

- Heavy handling of the fish is the greatest opportunity to reduce quality. Do not use gaffs to move fish.

- Avoid standing directly on fish when working in the hold. Even with a layer of ice above the fish, bruising can still result from the increased pressure.

- Packing techniques will vary from vessel to vessel, depending upon the size and the shelving pattern of the hold. Every effort should be made to avoid larger fish crushing the smaller.

- Again, upon unloading the vessel, treat fish with the upmost care to avoid bruising. Even at this late stage of the trip, damage can impair fish quality.

- Unloading of vessels is carried out in almost all weather conditions. However, operating during mid-summer conditions in Australia requires extra consideration for premium seafood exporters. In these conditions, swordfish need to be transferred to cool rooms as soon as possible. Some processors pack them back into iced bins before processing, which may be up to a day or more.

ACKNOWLEDGEMENTS

Both east and west coast longline fisheries actively supported this project and we would especially like to thank Michael Boschetti Erica Starling, and all the staff of Indian Ocean Fresh Australia, Geoff Diver of Tuna West, Stuart Parkes of Tohzai King P/L, Michael Madden of Tasmania Bluefin P/L, and all the staff at De Brett Seafood of Mooloolaba.

Also, a very special thanks to all the skippers involved being Darren Kolnn on Discovery III, Graham Wilkinson on 34 South, Michael Kenny on Ocean Wanderer, Peter Grennel on Ocean Dawn, and Bernie Manston on Ocean Odyssey.