



Freezer dehydration
of Pāua (*Haliotis iris*)

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1. Executive summary

The ability of applying freezer dehydration to age pāua, is a useful tool for compliance. Specifically the capability of being able to assess the deterioration and dehydration of external pāua surface over time, enables corroboration of documentation associated to the product.

Freezer burn is surface dehydration caused by a difference in temperature between the product surface and the coldest part of the freezer. For pāua, freezer burn gives it a leathery appearance. The translucent white coloured adductor muscle on a fresh pāua slowly starts to deteriorate over time becoming cloudy/opaque. Because of dehydration, oxidation will then occur which gives rise to yellow and brown colours.

The use of domestic freezers by dealers in fish (fish shops, restaurants, takeaways) is the most dominant practise for storing seafood products including pāua. Therefore, domestic freezers were the focus for testing and monitoring freezer burn. Results from this study showed that freezer burn occurred in pāua when moisture loss was greater than 3 or 4% of the original body mass.

Pāua stored in open bags were observed with freezer burn from as early as 2 months, and 3 months for pāua in loose but closed bags. In some batches the rate of moisture loss was 2 to 4 times greater in open bags compared to the rate of loss in closed bags, due to the greater variation in temperature and consequent vapour pressure.

At 6 months freezer burn was visible on the adductor muscle of all pāua, irrespective of packaging, as the adductor muscle had changed from a clear colour to an opaque cream colour.

Frozen pāua stored in a domestic freezer in plastic shopping bags that has no signs of freezer burn must relate to a purchase invoice that is less than 3 months.

Observed freezer burn on frozen pāua stored in plastic shopping bags, in a domestic freezers, must relate to a purchase invoice of in all probability greater than 3 months but without doubt more than 6 months.

2. Background

The concept of using freezer burn to age pāua and to compare against records, commenced during the prosecution of a Christchurch based restaurateur (*Ministry for Primary Industries v LI, 2015*). To strengthen this as a compliance tool, a project was undertaken to examine in more detail the correlation between storage time and the effects of freezer burn on pāua.

In *Ministry for Primary Industries v LI, 2015*, a restaurateur produced an eighteen month old docket in an attempt to legitimise pāua located for sale by fishery officers. The logical conclusion was the pāua had to be eighteen months old to be validated by the dockets coverage.

On inspection no freezer burn was observed on the pāua, and paperwork for tour group bookings showed substantial amount of pāua meals being consumed in the intervening 18 month period.

One of the restaurants domestic freezers was seized and temperature recorders were attached to the freezer (Figure 6 – Freezer A). A further two freezers were also used during this experiment to determine the duration of time before freezer burn could be observed on pāua.

3. Introduction

New Zealand's pāua fishery is managed by strict quotas, which allow a set amount of pāua to be taken commercially each year. The Total Allowable Commercial Catch (TACC) for each Quota Management Area (QMA) is monitored by the Ministry for Primary Industries and periodically stock assessments are carried out to determine the sustainability of the pāua resource.

Pāua is commonly found in shallow coastal waters along rocky shorelines in the subtidal zone (Hahn, 1989). Due to its easy accessibility, low set up cost and high demand by black-market receivers it is the sought-after species targeted by poachers since the 1980s.

The illegal catch of pāua has been assessed by Ministry for Primary Industries (MPI) in the Fisheries Assessment Plenary May 2014: Stock Assessments and Stock Status. For the South Island the illegal catch is assessed at 42.5 tonnes. This equates to 17 tonnes of meat weight, with a relative commercial value of NZD\$1.7 million per year, every year. With approximately 7 pāua meats to a kg, this is equivalent to 119,000 individual pāua taken illegally (Fisheries Science Group, 2014).

The stock assessment for the North Island does not offer an illegal catch estimate. Instead it reports that it is “widely believed that the level of illegal harvesting is high around Wellington and on the Wairarapa coast” (Fisheries Science Group, 2014).

Abalone is a delicacy in China. It is traditionally reserved for special occasions but has become more commonly consumed due to available commercial overseas farmed stocks. (Taggart, 2002). China is New Zealand’s second largest tourist market (Australia is the first), with 405,504 Chinese visitors arriving in New Zealand for the year to September 2016. This is a 23.7% increase on the previous year. The 405,504 international visitors stayed on average for 8.4 days, with 80% travelling by tour coach. (Tourism New Zealand's China Marketing Development Unit, 2016). Food and entertainment are a primary source of expenditure and because abalone is a delicacy it has put pressure on local restaurants to provide abalone in meals.

4. Legislative framework

The Fisheries Act 1996 is the legislative mechanism for protecting fish stocks. Its purpose is ensuring sustainable utilisation. Under the Act, Fishery Officers are warranted and have the powers and duties to carry out inspections, searches and examination of premises, records and fish products.

Dealers in fish are described in the Act as persons who are engaged in acquiring fish for the purposes of sale. There are three exclusions to this general rule, which hold no relevance to this study.

Illegal pāua is difficult to detect. Fishery Officers have three significant legislative components to use in inspections: -

1. *Size. Fisheries (Amateur Fishing) Regulations 2013, r19, there is a minimum size for blackfoot pāua of 125mm shell length. A limiting factor of this legislation is once a pāua is shucked (removed from the shell) the ability for a Fishery Officer to ascertain its legal size is limited.*
2. *Quantity. Under the Fisheries (Amateur Fishing) Regulations 2013, r16 an amateur fisher is limited to an accumulation limit of 20 pāua or a shucked weight of 2.5kgs. Dealers in fish are able to accumulate commercial quantities of pāua as long as the person holds records and the pāua does not exceed recorded weights on records.*
3. *Records. The Fisheries (Recordkeeping) Regulations 1990, state that all persons dealing in fish are required to keep a record of all fish held or stored in the possession or under the control of the dealer. And the records shall include the date of deposit and removal of the fish; and the species, processed state, and weight in kilograms of the fish.*

Illegal pāua is often drip feed into dealers of fish, restaurants and tourist operations under the guise of legitimate product. Drip feed is where the dealer stores and holds pāua off-premises and only brings it in on an as required basis. Once intermixed it is not easily identifiable since there is no tagging or identifiable markings to differentiate it from legitimate product. This obviously undermines the sustainability and integrity of the Quota Management System and New Zealand food safety standards which are put in place to ensure the safety of consumers.

Casola, (2007) states that typically government agencies try to reduce any black market activity, by targeting the supplier rather than the consumer. MPI is no different, where Fishery Officer core duties involve conducting random inspections on the beachfront or at dealers in fish commercial premises which sell or hold pāua. Dealers in fish are commonly inspected, aware of the rules and often store pāua destined for the restaurant at home. The powers under the Act excludes inspecting residential addresses (an authority to enter is required).

A significant limitation of the record keeping legislation is that a dealer in fish is not required to keep records of outgoings. For example, a dealer in fish buys legitimate pāua with a receipt. The dealer then sells the pāua to customers but because the sales are consumer sales they are exempt from recordkeeping. Fishery Officers can audit purchases and stock on hand. But vitally they cannot audit sales of stock. The dealer has the advantage of significantly downplaying consumer demand, subsequent sales and even the amount of pāua in a meal.

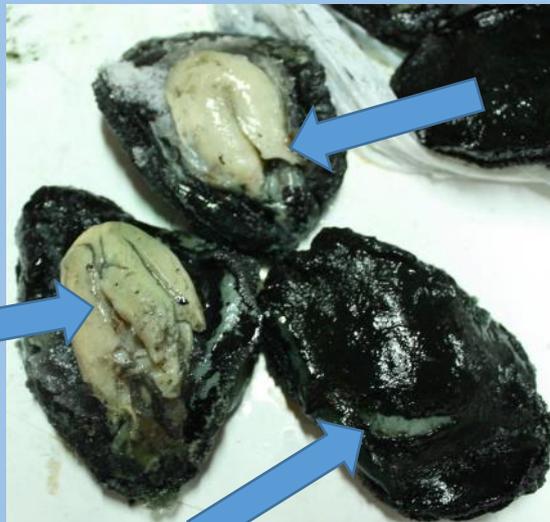
In any market whether it is food or drugs, as long as demand for a cheaper product exists, there will be a legal and illegal supply (Casola, 2007). It is clear that legislative frameworks do offer protection to pāua stocks but whilst pāua can be taken by poachers for little to no cost and sold at a price of approximately \$100 per pāua in a restaurant, then a black-market will exist.

Photograph 3 - Pāua shucking tools seized from unlawful pāua gathers



Photograph 4 reveals the damage caused to pāua when shucked by sharp tools. Two pāua have cuts on the adductor muscles, caused by shucked with sharp tools. The third pāua is sliced in the foot, caused by using a sharp tool to take the pāua from the rocks.

Photograph 4 - damage caused to pāua when shucked by sharp tools



This is in comparison to photograph 5 and 6 which is of commercial product. The pāua is high quality, individually frozen and layered within plastic sheets. Notice it is glossy and with no cuts. Commercial pāua will often have the tooth (radula) still attached. It is also preferable to maintain the natural salt water covering on the pāua, therefore it is not cleaned prior to freezing and grit may be present.

Photograph 5 and 6 – commercial quality pāua. Individually frozen, glossy and with no cuts



6. What is Freezer Burn

Surface dehydration caused by a difference in temperature between the product surface (pāua in this case) and the coldest part in the freezer (i.e. the refrigeration coils in the side of the freezer which we call condenser in this report). Since vapour pressure (or humidity) is dependent on the temperature, the temperature difference between the product surface and the condenser sets up a humidity difference which drives the dehydration of the surface by sublimation of the ice from the product to condense on the cold freezer surface.

Photograph 7 shows a fresh sample pāua at day 1. Photographs 8 and 9 show the development of freezer burn on the same sample pāua after 39 and 120 days. Red circles indicate areas of freezer burn on the adductor muscle of pāua. The surface colour changes from translucent to opaque with a papery texture as the surface tissue dehydrates. There is often an increase in brown colouration of the dehydrated tissue.

Photograph 7– Sample paua fresh



Photograph 8 – Sample paua frozen 39 days



Photograph 9 – Sample paua frozen 120 days



Photograph 10 – severe freezer burn



Photograph 10 demonstrates the leathery texture change to freezer burnt pāua, as dehydration and oxidation takes its toll.

Photograph 11 – seized domestic freezer used to store pāua



Photograph 11 shows the build-up of ice on the inside of a domestic freezer. This ice would have come from water vapour from sublimated product ice, and also from condensed water vapour from warm, moist air that entered the freezer when the lid was opened.

Packaging does affect the rate of freezer burn. Vacuum packed product may not show freezer burn because the packaging film in close contact with the product surface stops sublimation of ice from the surface of the product. Photograph 12 shows pāua that has been packed in a loose, moisture impermeable bag and the ice has sublimated from the product and condensed on the inside of the packaging. For product that is exposed to the atmosphere in a freezer the sublimated water vapour will condense on the sides of the freezer and the product will lose weight on storage. Consequently, weight loss can be used as an indirect measure to show propensity to exhibit freezer burn.

Photograph 12 – Vacuum packed Blackfoot pāua

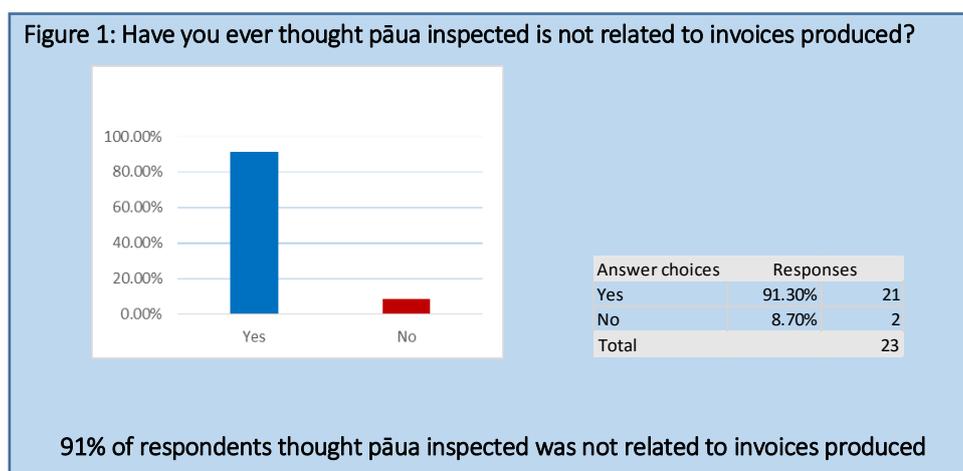


Loose ice in a moisture impermeable bag containing pāua that had been stored at $-18\pm 1^{\circ}\text{C}$ for more than 3 years.

7. Quantifying unlawful pāua located in dealers in fish

Fishery Officers stationed around New Zealand were approached to answer a questionnaire relating to unlawful pāua located in dealers in fish. The purpose of the questionnaire was to quantify the issue and examine variables from a participant observer approach.

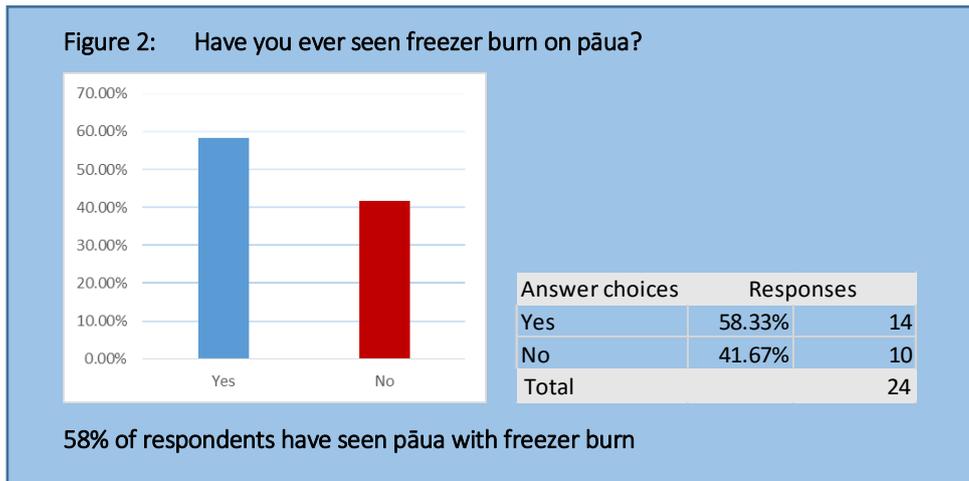
Twenty-four Fishery Officers responded, with a length of service varying from 2 years to 38 years. The average length of service was 10 years. Significant questions, responses and comments are detailed below: -



Responses for opinions in *figure 1* are:

- lack of commercial packaging;
- lack of recent invoices;
- amount of pāua purchased versus throughput of tour groups;
- legal sized smaller pāua are not typically caught by commercial fisherman;
- amount of frost on the pāua compared to recent invoices;
- employees of the business noted gathering recreational pāua;
- pāua meat not shucked properly;
- bulk meat stuck together not free flowed like a commercial entity would sell it;

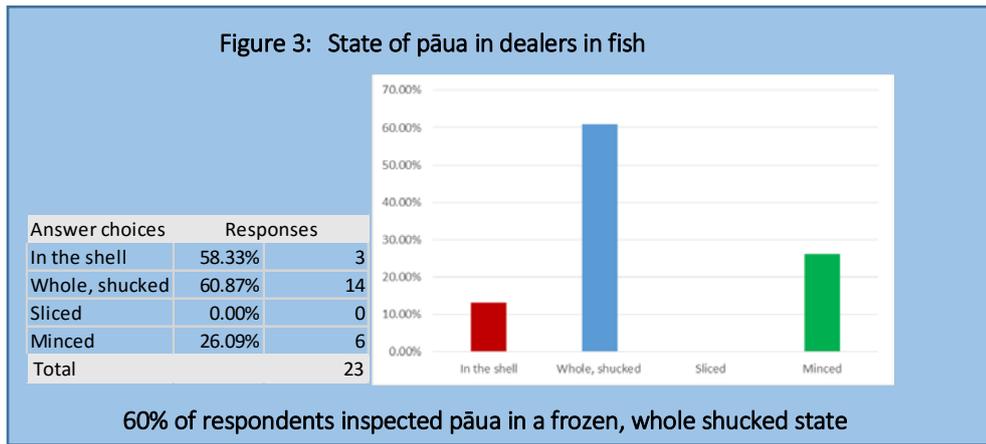
A common theme for *figure 1* was that the condition of the Pāua did not “look right” when compared to the date of invoices produced for that pāua.



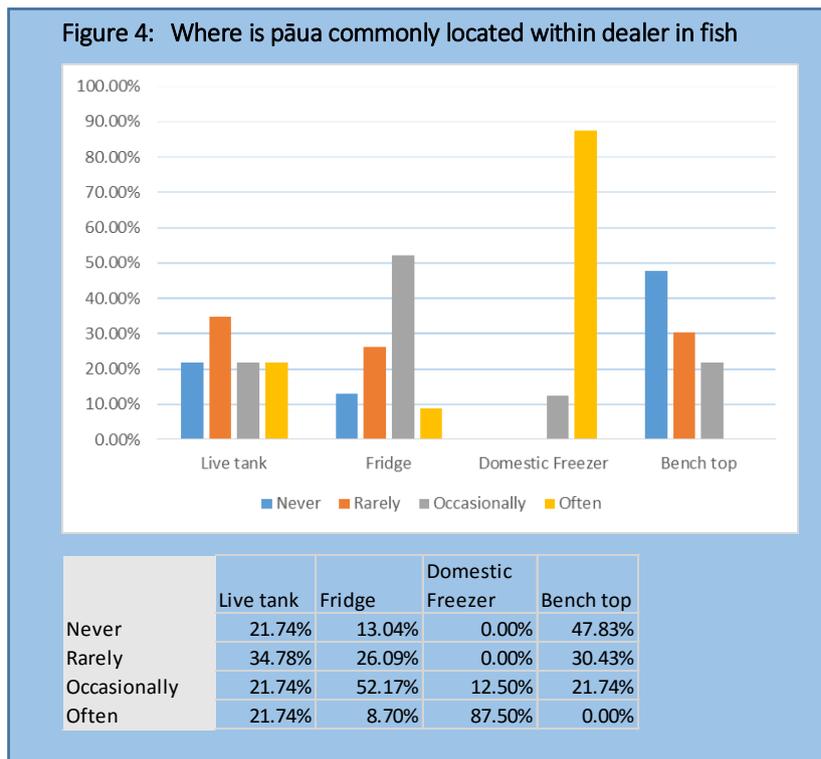
For *figure 2*, there is a connection between length of service and examining pāua meats for freezer burn. The more time spent on the job, the more factors are taken into account by the Fishery Officer when looking for freezer burn.

Stated comments relating to indicators were: -

- ice thickness on top of pāua;
- dryness of pāua;
- discoloration of pāua;
- smell;
- whiteness on the adductor muscle;
- build-up of ice within the packaging
- packaging compared to other seafood stored in the same freezer (with supposedly similar purchase dates)
- shrinkage of the
- ‘yellowing’ of pāua
- crystallization on the edges



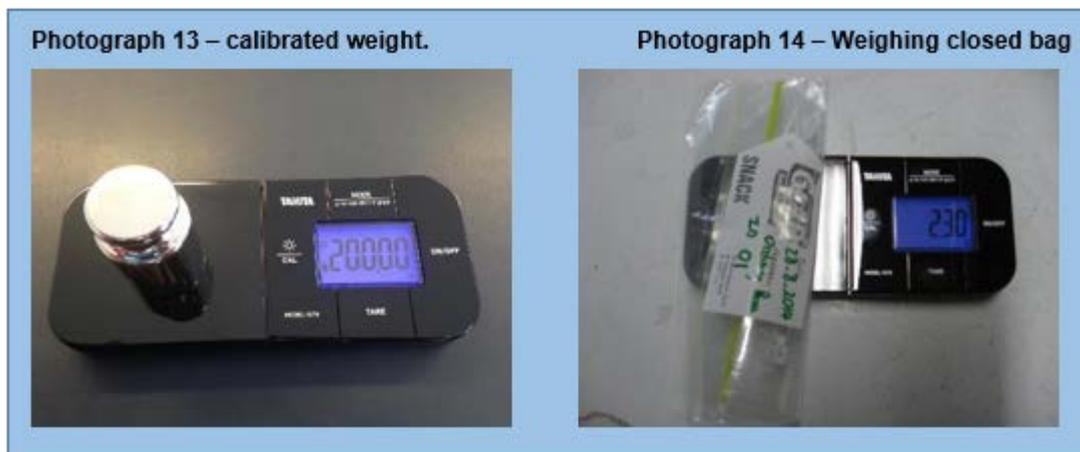
In *figure 3*, the majority of pāua inspected is in a frozen, whole shucked state. This may in fact be higher, as minced pāua is primarily pāua guts, trimmings, or pāua skirts, being a by-product of the pāua industry.



As shown in *figure 4*, domestic freezers were the most common location where pāua had been observed by Fishery Officers. 80.95% of Fishery Officers responded that plastic packaging – specifically shopping bags, was often associated with the packaging of pāua located in dealer in fish inspections.

8. Methodology

91 freshly shucked pāua were individually weighed on calibrated scales and placed in snap-lock bags. Given the small scale changes in weight, the scales were calibrated before each weighing and measured incrementally at 0.01 grams (photograph 13). The snap lock bag weights were also weighed and recorded (photograph 14).

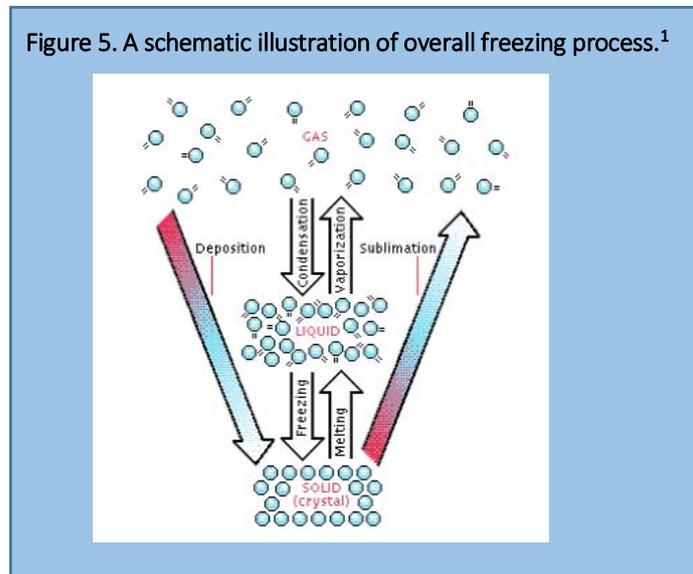


Each pāua was then assigned a number, dated and photographed (photograph 15). The pāua meat was then weighed and recorded.



Half of the samples were in closed bags and the other half were in bags left open. A further 70 pāua (total sample of 8.857kgs) was frozen in 6 plastic shopping bags, bowed at the top to simulate storage of samples found in some commercial restaurants.

Figure 5 is an illustration of the overall freezing process. During the initial freezing process for pāua meats, a small amount of sublimation can occur. Closed bags can give some protection from the freezer burn process by slowing down the rate of sublimation.



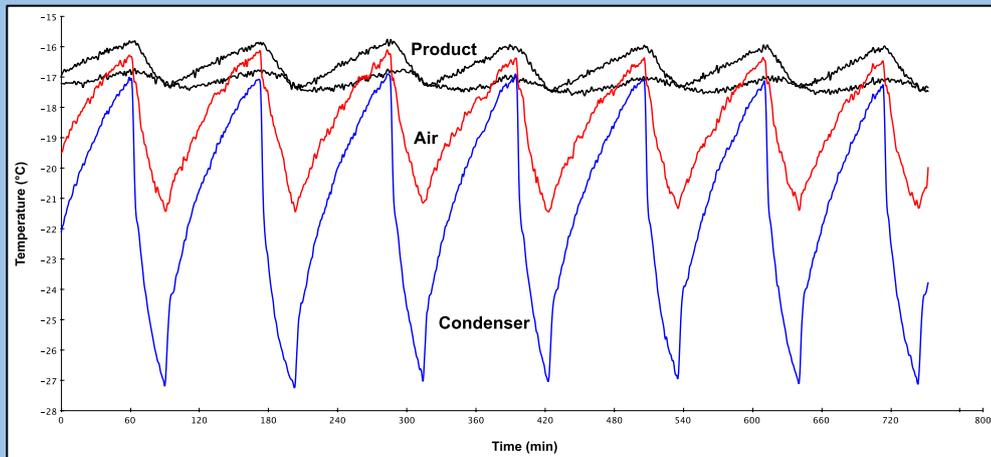
Packaging materials should be moisture-vapour-proof to reduce sublimation in frozen products, thus helping retain the high quality in frozen foods (Gustavo V. Barbosa-Cánovas, 2005). The opened snap lock bags allow for an increased state of sublimation and a faster occurrence of freezer burn.

Pāua from three separate batches were stored in three different models of domestic chest freezer (Freezers A, B and C). The domestic chest freezers were typical of freezers found in dealer in fish inspections (refer to figure 4 where 87% of Fishery Officers ‘often’ located frozen pāua in domestic freezers). Strengthening the representativeness of the freezers, one domestic freezer had been seized from a restaurateur due to storage of unlawful pāua.

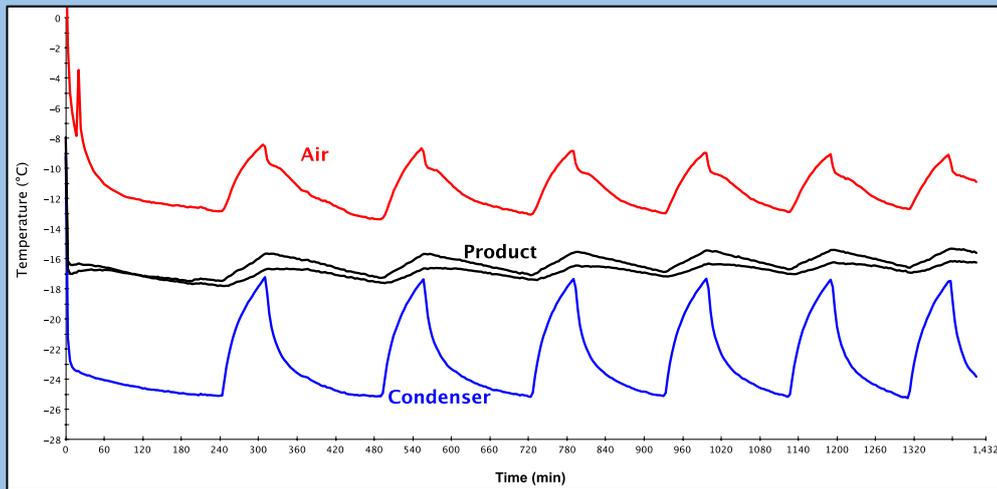
Prior to commencement of the study the temperatures of these freezers were recorded (product, air and condensers) and are shown in **Figure 6**.

¹ Retrieved www.fao.org/docrep/008/y5979e/y5979e03.htm

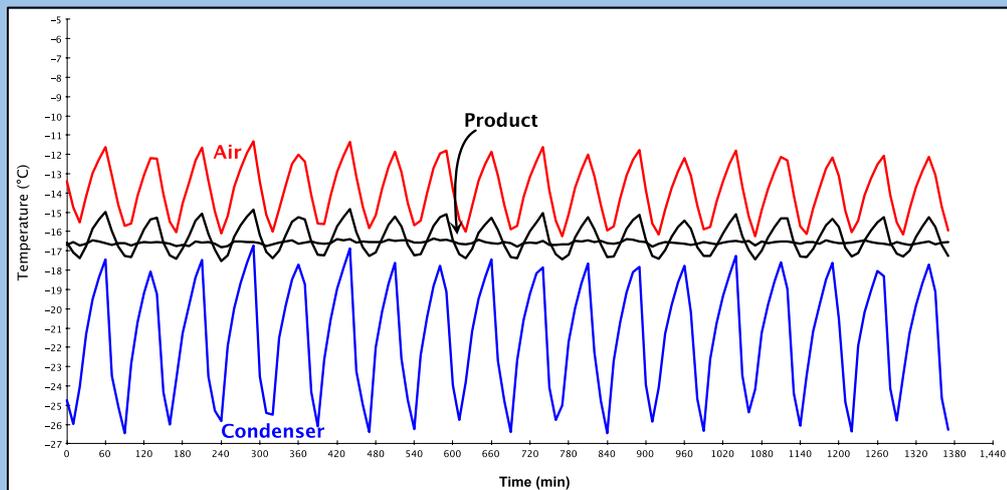
Figure 6 Plots of product surfaces (black), air (red) and condenser (blue) temperatures in chest freezers containing pāua used in this study.



Freezer A



Freezer B



Freezer C

Freezer and Product Temperature Profiles

High rates of moisture loss and rapid freezer burn are typical of poor frozen storage conditions found in many home freezers (MacDonald, 2015). Figure 6 shows representative plots of the temperature fluctuations occurring in the three different models of domestic chest freezers. For freezer A there were large fluctuations in condenser temperature with a freezing cycle approximately every 2 hours, showing there was a continual influx of heat into the freezer over this period, even though the ambient temperature was reasonably cool and between about 5 and 15°C during the test period.

For freezer A during this logging period, the mean temperature for the condenser was -21.3°C with a variation of more than $\pm 5^\circ\text{C}$ about the mean. These conditions are poor storage conditions that would promote freezer burn (MacDonald, 2014). Similarly the freezer cycles for the other freezers varied greatly depending on the length of the cycle and heat influx through the lid and walls.

The relationship between freezer and product temperatures and the humidity difference at these temperatures has been discussed in greater detail by MacDonald (2015). For example, the conditions in Freezer A (Fig. 6A) give vapor pressure differences of between 15 and 85 Pa. Over time, vapor pressure differences of this magnitude would quickly accumulate and provide a substantial driving force to sublimate sufficient ice to dehydrate exposed surfaces.

Each individual pāua and snap lock bag was re-weighed on a calibrated scale circa every month. The weight loss of individual pāua was followed with storage time. At the same time observations of the amount of freezer burn were made and photographs were taken as a visual record. Similarly, observations of surface freezer burn were made on the bulk packed pāua.

Observations of freezer burn were made immediately on removal from the freezer. This is best practice as pāua will thaw. It does not take long in the thawing process for the ice/moisture on the surface of the pāua meat to some extent be reabsorbed, however remnants of the opaque scarring is still visually seen on the pāua abductor muscle when defrosted. As a reference point, pāua with freezer burn (not subject to the trial) were completely thawed and examined. Freezer burn scarring was still evident as the pāua had been damaged by dehydration and oxidation. This is easily relatable to the common household situation of freezer burn in thawed red meat.

9. Results

The sublimation of moisture from the pāua meat is evidenced by the weight loss of the meat. During the study there was a correlation between the amount of weight loss and increased observations of freezer burn on the pāua meat. Consequently, observational results are significant to this study. A number of factors that can influence time of appearance and severity of freezer burn, therefore the age of the pāua in the freezer cannot be aged daily, but rather monthly.

Freezer burn was observed within one/two months on the surface of pāua stored in open bags (individual pāua and surface pāua in bulk bags), and within three months for pāua stored in closed bags in all three chest freezers. Freezer burn was assessed by observing oxidation which gives rise to yellow and brown colouration, surface drying of the pāua giving it a leathery appearance, and the adductor muscle becoming opaque.

Figure 7a details observations of freezer burn on individual pāua adductor muscle. Figure 7b details observations of freezer burn on any individual pāua adductor muscle within pāua stored in a clump in supermarket shopping bags, which were tied off with a bow. Significant amounts of freezer burn were seen on the surface of pāua within 6 months for all treatments, in all freezers.

Figure 7a: Observations of freezer burn on individual pāua adductor muscles

	Observed freezer burn after 3 months	Observed freezer burn after 6 months
Freezer A – open bags (15 samples)	100%	100%
Freezer A – closed bags (15 samples)	25%	100%
Freezer B – open bags (17 samples)	70.6%	100%
Freezer B – closed bags (14 samples)	21.4%	100%
Freezer C – open bags (15 samples)	82%	100%
Freezer C – closed bags (15 samples)	33%	100%

Figure 7b: Observations of freezer burn on any individual pāua adductor muscle within the clump.

	3 months	6 months
Freezer A – 1.886kgs pāua shopping bag sample	100%	100%
Freezer B – 2.975kgs pāua shopping bag sample	100%	100%
Freezer C – 3.996kgs pāua shopping bag sample	100%	100%

Moisture Loss with Different Treatments

Figure 8 shows the average weight loss for pāua stored in three different freezers for up to 270 days. Freezer burn could be observed when the moisture loss was greater than 3 or 4% for any of the treatments which was 2 months for pāua open to the freezer and 3 months for pāua in loose but closed bags. As expected, the rate of moisture loss was much greater in bags open to the freezer environment compared to pāua stored in closed bags. In some batches the rate of moisture loss was 2 to 4 times in open bags compared to the rate of loss in closed bags, due to the greater variation in temperature and consequent vapour pressure.

Storage of the individual pāua in open bags for more than 4 months resulted in 10% or more weight loss, which is excessive and a sign of the poor storage conditions in domestic freezers and the poor packaging (MacDonald, 2015). Storage in bulk showed surface freezer burn in the same time period as for the individual pāua in open bags.

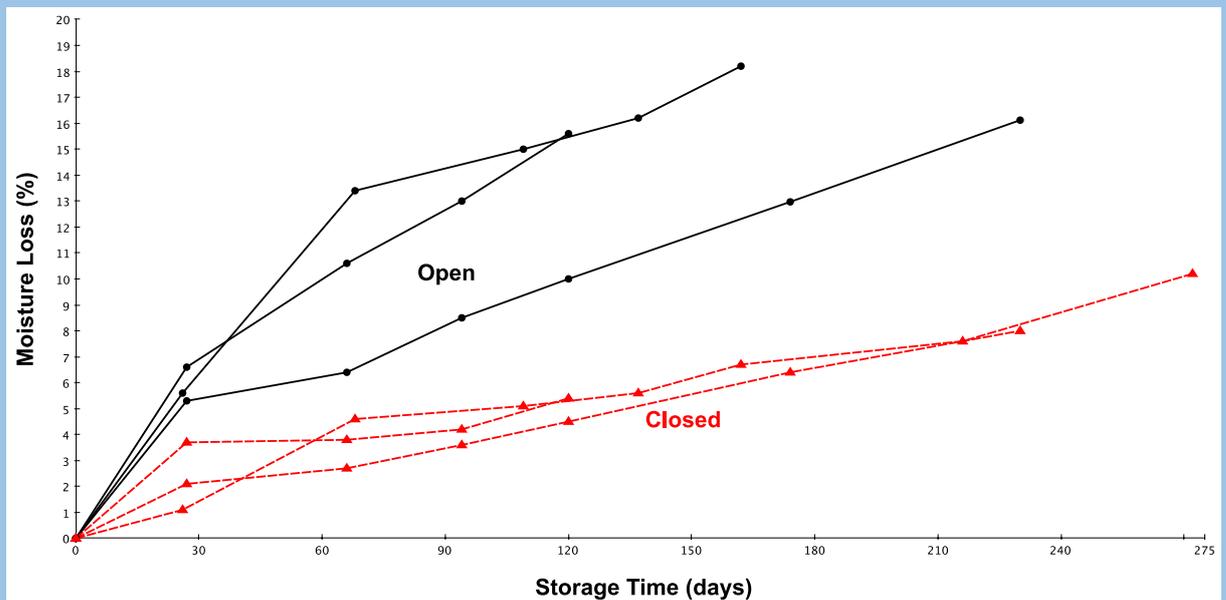


Figure 8.

Increased moisture loss for three lots pāua samples stored in freezers A, B and C for up to 270 days in bags open to the freezer and closed to the freezer environment. Each point is the average for individual pāua from each batch at each sample time.

Visually affirmation that freezer burn is present on pāua is a compliance tool for comparative analysis of pāua versus dealer in fish documentation. Identifying freezer burn does not take special skills or training. It is self-evident and readily seen.

Photographs 17 to 33 show changes (freezer burn) observed primarily in the adductor muscle but also on the foot of pāua. The photographs show an open and closed bag sample range for each of the three freezers. Time periods between photographs and examination range from two months to seven months.

Pāua frozen in a group will stick tightly together. This is due to surface moisture freezing and causing the pāua meats to clump together. In June 2015, photograph 33 and 34 is the before and after exposé of the underneath of a frozen pāua that was broken off.

Photograph 17	Photograph 18	Photograph 19
		
Freezer B- #49: Fresh 6 January 2015 Fresh – Day 1	Freezer B- #49: 13 March 2015 Frozen – circa 2 months	Freezer B- #49: 5 May 2015 Frozen – circa 4 months
The red circles indicate the surface dehydration on the pāua abductor muscle from January to May. The colouration changes from a clear to an opaque papery colour. Closed bag sample.		

Photograph 20	Photograph 21	Photograph 22
		
Freezer A- #02: 28 August 2014 Fresh – Day 1	Freezer A- #02: 28 Nov 2014 Frozen – circa 3 months	Freezer A- #02: 22 Dec 2014 Frozen – circa 4 months
Within three months freezer burn is clearly evident on the pāua abductor muscle. Open bag sample.		

Photograph 23



Freezer A- #12: 29 October 2014
Fresh – Day 1

Photograph 24



Freezer A- #12: 28 November 2014
Frozen – circa 1 month

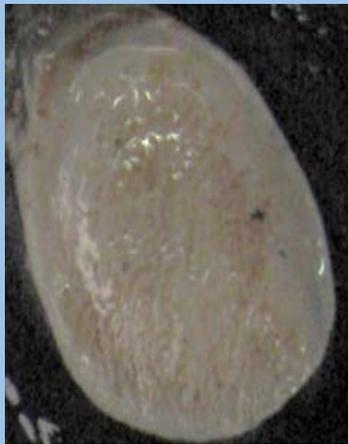
Photograph 25



Freezer A- #12: 22 December 2014
Frozen – circa 2 months

Freezer burn clearly evident on the pāua abductor muscle photographs 24 and 25. Open bag sample.

Photograph 26



Freezer C- #17: 6 January 2015
Fresh – Day 1

Photograph 27



Freezer C- #17: 10 April 2015
Frozen – circa 3 months

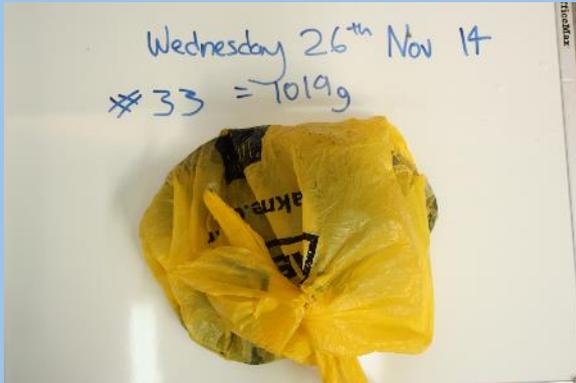
Photograph 28



Freezer C- #17: 18 June 2015
Frozen – circa 5 months

Freezer burn clearly evident on the pāua abductor muscle photographs 27 and 28. Closed bag sample.

Photograph 29



#33: 26 November 2014
Fresh – Day 1

Photograph 30



#33: 26 November 2014
Fresh – Day 1

Photograph 31



#33: 13 March 2015
Frozen – circa 3.5 months

Photograph 32



#33: 18 June 2015
Frozen – circa 6.5 months

Freezer burn clearly evident on the pāua abductor muscle within 3.5 months as shown in photograph 31. Pāua stored in a PaknSave plastic bag tied with a bow at the top. This is equivalent to a semi-closed sample.

Photograph 33



Photograph 34



Before and after exposé of the underneath of a frozen pāua that was broken off

10. Conclusion

- The extent of freezer burn on the surface of pāua gives an indication to the length of time pāua meats have been stored in domestic freezers.
- The type of freezer affects the rate of freezer burn. Highly fluctuating temperatures in domestic freezers and the consequent difference between freezer and product temperatures, leads to large amounts of moisture loss from the surface of the pāua, with 3-10% of moisture loss seen over the course of the experiment.
- The type of packaging effects the rate of freezer burn. When pāua is open to the freezer environment the weight loss was faster and freezer burn was seen sooner.
- Freezer burn could be observed when the moisture loss was greater than 3 or 4% for any of the treatments which was 2 months for pāua open to the freezer and 3 months for pāua in loose but closed bags.
- After 3 months, for pāua frozen in closed bags visual signs of freezer burn were reported in 21.4% to 33% of samples.
- After 3 months, for pāua frozen in open bags visual signs of freezer burn were reported in 70.6% to 100%.
- At 6 months freezer burn was visible on the adductor muscle of all pāua as it had changed from a clear to an opaque cream colour. This was regardless of type of freezer or packaging combinations.
- Frozen pāua stored in a domestic freezer in plastic shopping bags which has no signs of freezer burn must relate to a purchase invoice without doubt less than 3 months.
- In contrast, frozen pāua with freezer burn observed on parts of exposed adductor muscles and stored in a domestic freezer in plastic shopping bags must relate to a purchase invoice in all probability greater than 3 months but without doubt more than 6 months.

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