ON VESSELL MANAGEMENT OF LIVE SOUTHERN ROCK LOBSTER

SRL Industry Best Practice Guide

Fisheries Research and Development Corporation Report

FRDC project NO 2019-028: Improving Southern Rock Lobster on-vessel handling practices, data collection and industry tools for lobster quality assessment

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GENERAL BACKGROUND

The Southern Rock Lobster (SRL) industry endeavours to deliver lobsters to market in robust condition, thereby ensuring a high-quality product. Several co-occurring factors during capture and onboard holding place stress upon lobsters, affecting their short- and long-term vitality. The most significant of these factors in live holding conditions on vessels are, air exposure, light exposure, poor handling, bodily damage, and poor water quality. While exposure of lobsters to these factors is often unavoidable, following recommended practices can limit exposure and vastly improve lobster condition. Practices of collection, handling, sorting, and holding of live lobsters on vessels can be enhanced to reduce the severity of stress factors and limit the physiological effects of stress. These recommendations are to improve the efficiency of processes in a way that accounts for the health of captured stock, improving resilience and therefore survival going onto further post-harvest stages.

PHYSIOLOGY

As crustaceans, Southern Rock Lobsters have a rigid exoskeleton encasing their soft bodies which are described by two major body segments 1) a combined head and thorax (cephalothorax) protected by a hard-shelled carapace, 2) and a flexible, muscular tail. The carapace covering the cephalothorax, is a vital protective structure, as almost all internal organs are positioned within the soft tissue of the cephalothorax. The gills sit within gill chambers on either side of the cephalothorax and are protected by the carapace. Water passes through the gill chamber and the flow of water over the filamentous gills allows for respiration via this vital structure. Legs are attached to the underside of the cephalothorax via joints, which are considerably softer than the surrounding exoskeleton. The head of the lobsters features many vulnerable external structures, such as the eyes, mouth, and antennae. The base of the antennae (the horns) is thick and heavily spiked, and significantly tougher than the remaining length of the antennule, which are prone to breaking with poor handling. The tail is comprised of a strong muscle, which facilitates the important rapid escape behaviour known as tail flipping, which allows a lobster to dart backwards from a threat. The dorsal side of the tail is covered in a segmented exoskeleton, while the ventral side is soft, allowing for flexibility. The soft ventral side of the tail is where females carry fertilised eggs.

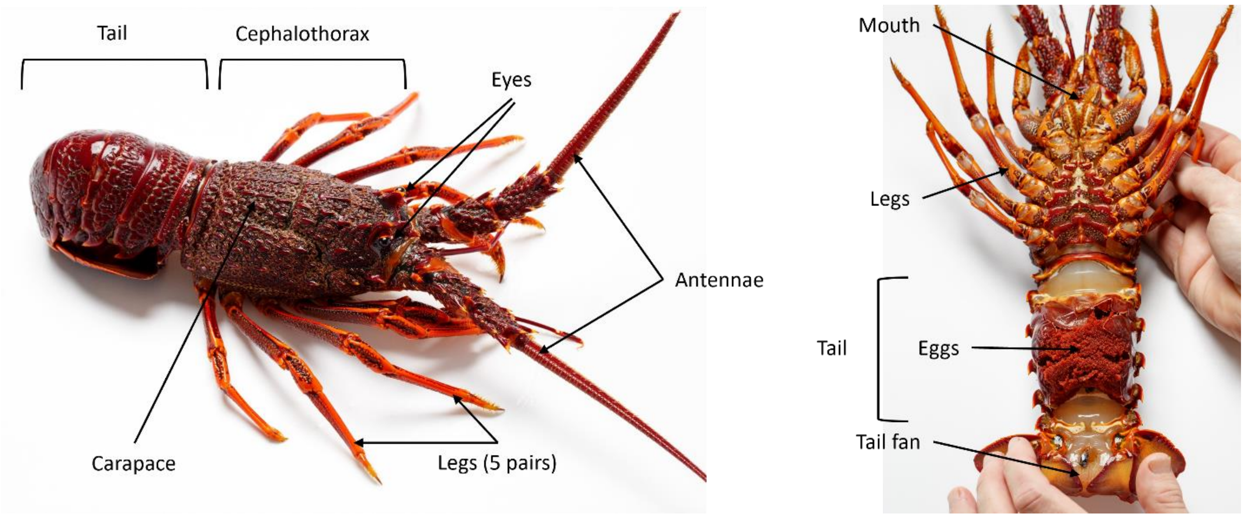

Figure 1. Basic external anatomy of the Southern Rock Lobster. The head and thorax are combined as the cephalothorax which contains almost all internal organs (Left). The legs and antennules attach to the cephalothorax. Females carry eggs on the underside of the tail (Right).

RESPIRATION

Aerobic respiration produces energy through the uptake of oxygen from the external environment into the tissues and cells of an animal, and results in the release of carbon dioxide. To optimise oxygen uptake from seawater, lobsters must be kept in water with dissolved oxygen (DO) concentration greater than 70% (Crear and Forteath, 2000). Energy can also be produced via anaerobic metabolism. This form of energy production is commonly utilised for short periods of time to facilitate activities with high energy demands, such as tail flipping. Anaerobic metabolism is also engaged during emersion, as lobster oxygen uptake is significantly impaired when out of the water. Anaerobic metabolism cannot be sustained during long periods and causes metabolic stress through the build-up of lactate and waste products (carbon dioxide and ammonia) within the tissues which will become lethal at high concentrations.

Oxygen consumption is influenced by multiple extrinsic and intrinsic factors. Salinity, temperature, and water flow rate affect the availability of oxygen in seawater. The solubility of oxygen decreases as water temperature and salinity increases. The temperature of coastal waters is seasonal and subject to influences from currents and eddies. Water temperature in holding tanks can also vary due to exposure to atmospheric heat and sunlight. Water pumps may also introduce added heat, particularly when recirculating water, opposed to delivering new water from the environment. The salinity of coastal waters can be influenced by freshwater input from rivers or evaporation in enclosed bays. Salinity in holding tanks can also be influenced by the external environment, as rain dilutes the salt concentration of water, while heat evaporates water and increases salt concentration. Therefore, temperature and salinity parameters must be assessed under various holding conditions to maintain adequate DO. Water can become deoxygenated if oxygen is used by lobsters at a greater rate than it is replenished through water exchange, causing lobsters to suffocate and die quickly.

Lobster body mass, activity and stress all impact oxygen requirements, consumption, and respiration. Lobster oxygen demands are enhanced after periods of stress such as handling a capture and air exposure. Lobsters are also naturally nocturnal, therefore oxygen consumption increases when lobsters are active throughout the night (Crear and Forteath, 2000). External influences such as stress during holding on vessels may also result in increased oxygen consumption. Body size also influences metabolic rate, with smaller lobsters requiring more oxygen and producing more ammonia per kilogram body mass compared to larger lobsters, making smaller lobsters more vulnerable to metabolic stress when DO is too low.

MOULT CYCLE

Moulting is an energy-demanding process necessary for the growth of lobsters. The moult cycle features several stages, characterised by substantial physical and molecular changes that may not be visually obvious. However, simple visual and tactile assessments enable consolidation of these fine-scale events into three key stages. These identifiable stages are post-moult, inter-moult, and pre-moult. The inter-moult stage is the longest, during which lobsters are the most physically robust and resilient. Post-moult lobsters have recently moulted their exoskeleton, leaving them physically soft, with depleted energy reserves and a high metabolic rate. Pre-moult lobsters preparing for moulting and compromised exoskeletons which are brittle and prone to cracking from external pressure. During the physical act of moulting, lobsters are extremely vulnerable to environmental changes and predation or cannibalism, especially in communal holding facilities. Stress tolerance changes throughout the moult cycle, with pre- and post-moult lobster being highly susceptible to physical damage and metabolic stress, therefore effective identification of moult stages is important for determining quality or resilience of captured stock.

Utilising a clear method for identifying stages of the moult cycle ensures suitable inter-moult lobsters are selected and pre- and post-moult lobsters are returned to sea in good condition, improving overall vitality and survival of catch. The hardness and fragility of the exoskeleton changes throughout the moult cycle, therefore gentle handling techniques must be employed during moult staging as brittle pre-moult and soft post-moult lobsters are likely to experience more serious consequences from metabolic stress, limb loss, or impacts against hard surfaces. Furthermore, vulnerable pre- and post-moult lobsters need to be handled with extra care when returning them to the sea.

COLLECTING STOCK

Many factors contributing to stress simply cannot be avoided during the capture and sorting of lobster stock. However, co-occurring stressors impact the resilience and vitality of lobsters, ultimately reducing survival to market. To diminish the long-term impact of stress, it is best to avoid compounding stressors by limiting those which can be reasonably controlled. Education and practice surrounding gentle handling and above deck holding conditions can improve efficiency and the wellbeing of retained lobsters, as well as those returned to sea which are not fit to survive to market.

HANDLING

Repeated handling is necessary for live capture and processing, nevertheless careful practice can reduce potential damage and long-term impacts of handling stress. Poor handling often results in limb loss or impact injuries due to dropping or tossing lobsters. Lobster limb loss occurs via two mechanisms, autotomy and autospasy. Autotomy, commonly known as self-amputation, is the ability to release or drop a limb as a survival reflex. Autospasy is the loss of a limb due to brakeage at a weak point, such as a joint, and subsequent pulling of the limb from an external force. Loss of legs and antennae due to autospasy can occur due to rough handling, inappropriate holding of the legs or antennae, and when lobster limbs protrude from pots or creates during capture and snap off. Limb loss diminishes the value of lobsters and leaves them susceptible to pathogen infection via the open wound (Fotedar et al., 2001). Furthermore, lobsters can take hours to days to recover from the stress of emersion handling and tail flipping (Whiteley and Taylor, 1992) resulting in relatively poorer meat quality (Taylor et al., 1997). Damage from the impact of dropping or tossing a lobster is likely to occur when processing speed and efficiency is prioritised without consideration for animal welfare, however these are not mutually exclusive goals. Education and practice of careful handling can optimise workflow and ensure high-quality lobsters survive to market.

Lobster pots and landing gear should be designed and handled to limit damage during the capture process. All pots should have rails on the base to reduce the occurrence of limb damage as pots are hauled aboard. Alternatively, rails can be incorporated in the pot landing platforms. Lobster limbs often protrude through the base of the pot and rails create a clear space under pots preventing limbs from catching when pots are moved across the vessel. Pots should also be handled carefully and securely to avoid dropping and sudden jolts. While lobster exoskeletons are relatively robust, the internal organs have little support and are subject to trauma through dropping and sudden jolts. Gentle handling techniques allow for a secure grip to reduce tail flipping and dropping of lobsters, whilst also protecting the limbs. Ideally lobsters should be picked up and moved with two hands. One hand with a secure grip on the carapace (firm but not squeezing) or base of the antennules (horns, Figure 1), and another hand supporting the tail. These grips reduce limb loss, tail flipping and accidental drops. Taking care to place down, and not toss, lobsters is especially important. Tossing lobsters is a major cause of poor condition on vessels in *Homarus americanus* fisheries (Lavallee et al., 2000). Lifting a lobster by the legs or antennae is inadvisable as these limbs are not strong enough to support a lobster's weight and will result in autospasy. When holding, the tail needs to be supported by a second hand, tucking the tail towards the underside of the lobster. This limits tail flipping, an escape tactic which uses a significant amount of energy to flip the strong tail muscle quickly and repeatedly. This movement rapidly depletes energy and causes lactate build-up in the muscle from a shift to anaerobic metabolism (England and Baldwin 1983; Gade, 1984). Gentle handling which supports the tail and prevents tail flipping, also reduces accidental drops.

RECOMMENDATIONS

- **All pots or landing platforms should have rails on the base to reduce occurrence of limb damage as pots are hauled aboard.**
- **Pots should be handled carefully to avoid dropping and sudden jolts.**
- **Lobsters should be handled gently, preferably by using two hands: one hand with a secure grip on the carapace (firm but bot squeezing) or base of the antennules (horns), and another hand supporting the tail.**
- **Lobsters should not be dropped or thrown at any stage.**

EMERSION AND AIR EXPOSURE

Once a lobster is removed from the water it begins experiencing physiological change to compensate its limited ability to absorb oxygen from the air. Compensating for low oxygen results in increased metabolic function and reduced energy reserve, as the animal becomes deficient in the oxygen required for aerobic respiration. In the absence of adequate oxygen, energy is produced via anaerobic respiration which is not sustainable and results in death if persistent.

Although air contains a significant concentration of oxygen, lobster gills are not designed to breathe air. During emersion the gills clump together reducing the surface area available for oxygen exchange (Taylor and Waldron, 1997). Additionally, extended periods of air exposure risks gills dehydration damage, which ultimately impairs oxygen uptake once returned to water. During emersion, waste products such as carbon dioxide and ammonia cannot be discharged into the air, leaving them to build-up and cause physiological damage. This build-up of waste products decreases haemolymph pH resulting in respiratory acidosis. Lobsters have a limited capacity to buffer against acidosis, allowing for pH stabilisation for up to 4 hours of emersion, followed by a rapid drop in haemolymph pH (Morris and Oliver, 1999). Furthermore, the build-up of lactate due to prolonged air exposure is associated with increased mortality (Simon et al., 2016). After return to water, it can take up to 4 hours for pH to return to normal, however it takes up to 24 hours for lactate levels to normalise and the affects are much more serious (Taylor and Waldron, 1997).

Processes must be in place to ensure that lobsters are not left exposed to air on vessels during and the capture and sorting of lobsters must be done quickly to reduce air exposure time The consequences of emersion, such as depleted energy, waste build-up, and gill damage, have serious impacts on lobster health.

RECOMMENDATIONS

- **During capture and sorting all effort should be made to process the lobsters quickly and gently, and to reduce the time of air exposure.**

LIGHT EXPOSURE

Light plays a significant role in several biological processes for lobsters. Day length (photoperiod) determines seasonal process, such as moulting and reproduction. Lobsters are naturally nocturnal and adapted to low light, therefore abnormal or harsh light exposure can induce stress, affecting activity and feeding behaviour. The damage caused by bright light exposure essentially induces blindness and reduces survival success (Brown and Caputi, 1983; Meyer-Rochow, 1984). For lobsters returned to sea, reduced survival following eye damage is due to an impaired ability to locate shelter and an increased vulnerability to predators. These lobsters are also more likely to be recaptured and experience additional stress and long-term health impacts. For retained lobsters, vitality and survival may be reduced by the physiological damage and associated behavioural changes that light exposure can induce. Response to subsequent handling and exposure may be more pronounced, with increased escape behaviour (tail flipping) depleting energy reserves and causing metabolic stress, ultimately reducing condition and long-term resilience.

As with emersion, light exposure should be kept to a minimum and lobsters should be kept from direct sunlight, wind, and rain. Above deck holding tanks require an opaque or light proof cover to shield them from the external environment. Providing additional shade to above-deck tanks can also assist with temperature control, preventing metabolic stress due to increased water temperature. Unsuitable lobsters must be treated with the same care before returning them to the sea, to reduce eye damage and improve their survivability.

RECOMMENDATIONS

- **Exposure of lobsters to direct sunlight should be kept to a minimum.**
- **Above deck holding tanks require an opaque or lightproof cover to shield from the external environment.**

SORTING AND GRADING

Stress factors are often unavoidable during capture and processing, however reducing the severity and frequency of these stressors is highly recommended. Sorting lobsters directly following capture reduces repeated exposure to inevitable stressors, such as handling, emersion, light exposure and variable temperature. Prompt sorting also benefits rejected lobsters, as it prevents unnecessary repeated stress for these lobsters. Lobsters should be assessed for legality, health and vitality, physical damage, and moult stage at capture. Rejected lobster should be returned to the sea in a gentle manner as quickly as possible. Lobsters should never be thrown back into the sea, instead reject slips that gently return the lobster to the sea are highly recommended.

RECOMMENDATIONS

- **Lobsters should be assessed for legality, health and vitality, and moult stage at capture to prevent repeat handling.**
- **Rejected lobsters should be gently returned to the sea as quickly as possible, preferably using a reject slip.**

HEALTH AND VITALITY ASSESSMENT

Assessing the physical condition and vitality of lobsters at collection is necessary to identify those with existing damage or stress, causing low vitality and poor quality. Vitality grading identifies lobsters unlikely to endure the subsequent stress of holding and transport. Vitality is assessed by lifting a lobster by the carapace, holding it horizontal to the floor, and grading reflex impairment as either no impairment, medium impairment or high impairment (Figure 2). A strong reflex response with no impairment is characterised by a flexed and lifted tail, legs lifted above the carapace base, and antennae pointed up and back. Medium impairment is characterised by a flexed and lifted tail, front legs lifted above the carapace base, fourth leg below carapace base, and antennae not lifted. A high reflex impairment is observed by relaxed limbs, legs below the carapace base, tail not flexed, and antennae not lifted. Compromised lobsters may also be identified by lethargy being lobsters do not display escape responses such as tail flipping.

Lobsters that are assessed to have a high reflex impairment, or poor vitality at capture should be returned to the sea in a gentle manor. These lobsters are unlikely to be able to withstand the rigors of the post-harvest supply chain, likely leading to mortality. The natural environment provides the best possible opportunity for poor-condition lobsters to recover.

RECOMMENDATIONS

- **Lobsters that are assessed to have a poor vitality due to lethargy or high reflex impairment at capture should be returned to the sea in a gentle manner.**

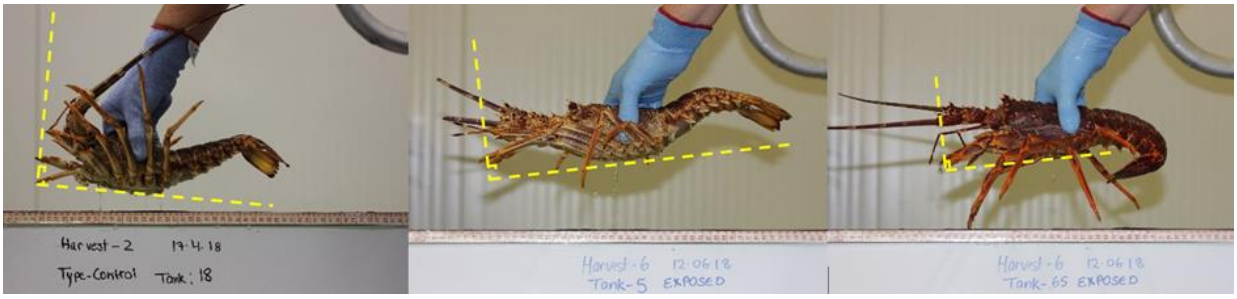

Figure 2. Examples of reflex response in southern rock lobsters. A strong reflex response (left) compared to a weak response (right) derived from Turnbull et al. (2021). Weak lobsters (those with a high reflex impairment) are characterised by relaxed limbs, including legs that fall below the carapace base, tail not flexed, and antennae not lifted. Compromised lobsters are also characterised by lethargy and do not typically display escape responses such as tail flipping.

PHYSICAL DAMAGE

Possible damage visible on captured lobsters is limb loss, puncture wounds, and cracked exoskeletons. Legs are most often lost at the joint closest to the cephalothorax, leaving a short stump. Antennae may be missing due to a break at the base, or they may be partially broken. When fresh these wounds are clear in colour and might be weeping. Older wounds have melanised, making them dark in colour. Old wounds will have limited impact on the vitality of lobsters, which may be of suitable harvest quality depending on market acceptance. Puncture wounds can be seen on the underside of the tail which is covered in a soft membrane (Figure 1) and are commonly caused by lobsters grasping each other when inappropriately stored at high density with limited alternative substrate to grasp. Cracks in the exoskeleton are most common on the sides of the cephalothorax. This type of damage can occur when lobsters are squeezed too tightly whilst being held or moult staged, or if dropped.

Lobsters which have significant damage to the exoskeleton such as cracks, multiple fresh puncture wounds, or newly missing limbs should be returned to the sea. The natural environment will provide the best opportunity for the lobster to recover.

RECOMMENDATIONS

- **Identify lobsters with physical damage making them unlikely to survive post-harvest processes; cracks in the exoskeleton, fresh puncture wounds under the tail, or newly missing limbs.**
- **Lobsters with significant physical damage should be gently returned to the sea.**

MOULT STAGING

Identifying the moult stage of lobsters is an essential assessment to differentiate between physically vulnerable pre- and post-moult lobsters and more robust inter-moult lobsters. Adult SRL typically moult once a year, with females moulting in autumn and males moulting in spring. There can be considerable variation in the timing of moulting lobster populations within their distribution range and fishers should avoid targeting moulting populations. Some lobster populations (or subsets of populations) may moult more than once in a year which typically presents as an out-of-season moult at an unexpected time of year. There is some evidence that climate change is triggering more regular out-of-season moulting, particularly for populations in the northern range of the distribution where water temperatures are higher and possibly subject to greater seasonal variation (such as marine heat wave events) (Fitzgibbon et al., 2019). This out-of-season moults presents a significant challenge for the SRL industry as it increases the likelihood that pre- or post-moult lobsters will be landed during the fishing season and these lobsters will perform poorly during the post-harvest supply chain. Again, if out-of-season moulting is identified in a population, fishers should avoid targeting these populations until the moulting has ceased.

Post-moult lobsters are physically soft for several days/weeks after they moult and this softness can be easily felt on the sides of their cephalothorax, at the ridge connecting the gill chamber cover and the top of the carapace. Softness can be assessed by lifting the lobster by the carapace using a gentle handling technique and applying slight pressure with a single finger to one side of the cephalothorax. If this area gives way or feels spongy, the lobster is still in the post-moult stage. Note that this assessment does not require hard squeezing of the cephalothorax. Cracked carapaces due to hard squeezing may lead to false identification of post-moult lobsters, as well as damaging their physical condition. Identifying pre-moult lobsters is more difficult and requires a visual and tactile assessment. During the pre-moult stage, the previously solid carapace develops sutures, or cracks, along the sides of the carapace (gill chamber covers) where it will split open to allow the lobster to exit when it moults (Figure 3). When the gill cover is lightly pressed, as described above, it will move independently of the dorsal carapace along these suture lines for pre-moult lobsters. Also, pre-moult lobsters have brittle shells which is another valid reason to not forcefully squeeze lobsters while holding the carapace. These suture lines often become more apparent (whiter) in pre-moult lobsters, providing an additional indicator. Pre-moult lobsters can also be identified when an antenna is accidentally broken, and the new “soft” antenna is intact beneath. However, breaking antenna is not recommended as a method to assess moult stage. Inter-moult lobsters have an intact, rigid exoskeleton with no distinct suture lines and no softness.

All lobsters should be gently handled to determine the rigidity of the cephalothorax exoskeleton and lobsters with soft shells should be returned to the sea. This assessment should be done at the same time as health and vitality assessments, limiting the number of times a lobster must be handled while experiencing light and air exposure.

Figure 3. The sutures, or cracks, along the sides of the carapace (gill chamber covers) where the shell will split open to allow the lobster to exit when it moults. These lines become more visible and brittle during the pre-moult stage. When the gill cover is lightly pressed, it will move independently of the dorsal carapace along these suture lines for pre-moult lobsters.

RECOMMENDATIONS

- **Fishers should avoid targeting moulting lobster populations.**
- **All lobsters should be gently handled to determine the rigidity of the cephalothorax exoskeleton and identify suture lines using gentle pressure applied by a single finger.**
- **Pre- and post-moult lobsters should be gently returned to the sea.**

TEMPORARY ABOVE DECK TANKS (STRIPPING BOX)

When lobsters are brought onboard, they are sometimes placed in an above deck tank (stripping box) before being transferred to vessel wells. Maintaining water quality and stocking density in stripping boxes may be problematic and short-term stress due to poor conditions in stripping boxes may have long-term effects on vitality and survival.

In general, the use of temporary above deck tanks is not recommended as they are often small in volume and have limited or variable water supply, often delivered by a deck hose dependant on engine load for flow rate. Above deck tanks may also subject the lobsters to sunlight or rain. If used, these tanks need to be covered to limit light and rain input. Temporary above deck holding also requires double handling of the lobsters which induces additional stress. Care needs to be taken to limit the number of lobsters stocked and time they are held in these tanks before transfer to the vessel well. High densities of lobsters will result in a rapid depletion of oxygen from the water and can lead to incidence of physical damage as lobsters grasp each other. Care needs to be taken to ensure the water flow rate to on-deck tanks is sufficient and consistent to maintain appropriate dissolved oxygen and water temperatures.

RECOMMENDATIONS

- **The use of temporary above deck tanks is generally not recommended as they are likely to introduce additional stress factors: high stocking, variable water supply, exposure to sunlight and rain, and repeated handling.**
- **If temporary above deck tanks are used, they need to be covered and stocked at reasonable densities.**
- **Procedures must be in place to ensure water flow rate is sufficient to maintain appropriate dissolved oxygen and water temperatures.**

HOLDING CONDITIONS

Following the unavoidable stress of the capture and sorting stages, lobsters require a suitable holding environment to aid recovery. This allows for the purge of built-up waste products and normalisation of physiological parameters, such as haemolymph pH. If lobsters are held out of water for more than 1 hour during collection and sorting, they require 24 hours in good quality water to recover before additional handling or emersion. Lobsters may be held onboard fishing vessels for several days to weeks, therefore holding tanks need to be configured to limit stress and maintain high water quality conditions. Common vessel holding facilities are divided into two types, 1) well tanks where water passively enters the well through holes in the vessel hull and 2) pump tanks where water is delivered by pump to the holding tanks (below or above deck). Each holding system has its own advantages and disadvantages for fishers and lobsters, however tanks with pumping capacity provides greater control and independence from factors that influence passive water exchange.

HOLDING TANK REQUIREMENTS

One of the most significant parameters is dissolved oxygen (DO), which can be effectively maintained in each holding tank with some additional design consideration. Firstly, holding tanks need a supply of quality seawater passing into wells or pumped into tanks with adequate available oxygen. Secondly, supplemental aeration should be incorporated into the system to increase DO availability quickly and under circumstances where incoming water from the environment is limited or of poor quality. Poor quality water should never be allowed into holding tanks, therefore water intake may need to be halted when in an area with subpar water quality. During this situation, aeration provides a critical lifeline, as it increases the availability and distribution of oxygen. Well tanks are the most difficult system in which to maintain water flow, and therefore maintain oxygen supply. This is particularly pertinent when vessel movement is limited (such as when in port or at anchor in calm conditions). Supplementary aeration is essential in well tanks under these conditions.

Pump tanks allow for greater control over holding conditions, however, to be most effective the system should use a pump dedicated to exclusively provide water supply and the flow rate must be monitored regularly or affixed with a flow alarm. Deck hoses which are powered by the main engine should not be used to supply water to tanks as this flow rate is variable depending on the engine load. Plumbing of tanks should be permanently fixed in place and designed to deliver an even distribution of water flow across the tank or tanks if multiple tanks are used. Supplementary aeration is also recommended for pump tanks for the event of pump failure or if intake must be ceased due to poor external seawater quality (such as low salinity).

RECOMMENDATIONS

- **All holding wells or tanks should have supplemental aeration to quickly increase dissolved oxygen under circumstances where incoming water from the environment is limited or of poor quality.**
- **In particular, well-boats (those without active water pumping) need to provide aeration, particularly during periods of limited passive water exchange (such as when the vessel is at anchor during calm conditions.**
- **Pump tanks require a dedicated pump supply to exclusively supply an appropriate water flow rate. Flow rate should be regularly monitored regularly or affixed with a flow alarm. Spare pumps should be carried onboard.**
- **Deck hoses should not be used to supply water to tanks as the flow rate can be variable depending on the engine load.**
- **Plumbing of tanks should be permanently fixed and designed to deliver an even distribution of water flow within and between tanks.**
- **Poor quality water should never be allowed into holding tanks and water intake needs to be halted when in an area of subpar water quality, during which time supplemental aeration is essential.**

WATER QUALITY

Maintaining water quality parameters within the tolerance limits of lobsters (Table 1) is vital for successful, long- and short-term, holding on vessels. Changes in temperature, salinity and DO outside the tolerance range can result in sudden mortality, or long-term physiological damage (Crear and Forteath, 2000; 2001). Parameters, such as DO, temperature, flow rate and lobster stocking density are interconnected and must be balanced to sustain good water quality. As water temperature in lobster fisheries changes seasonally, calculations are required to adapt holding tank flow and aeration rates according to water temperature. Additionally, the rate of oxygen consumption differs between unstressed lobsters and those which are stressed or active. Due to these multiple and confounding factors, appropriate water quality monitoring and infrastructure is required to compensate and control conditions when unforeseen changes occur.

Table 1: Water quality tolerance (minimum or maximum) limits for southern rock lobster from Crear and Allen (2002)

Water quality parameter	Tolerance limit
Temperature (°C)	8 - 23
Dissolved oxygen saturation	70%
Salinity (g.kg^{-1} or ppt)	30 - 38
Ammonia (mg.L^{-1})	< 2
Nitrate (mg.L^{-1})	<100
pH	7.8 – 8.4
Hardness (ppm)	100 - 200

Southern rock lobsters require a minimum of 70% dissolved oxygen saturation; however, it is recommended %DO be greater than 80% with sufficient flow to evenly distribute oxygenated water at all times (Crear and Forteath, 2000; 2001). All vessels should carry a working dissolved oxygen sensor to measure holding water oxygen levels regularly or during periods of uncertainty (such as during periods of water flow or aeration failure or when poor water quality is present). The next section provides recommendations on suitable dissolved oxygen sensors.

Care must be taken during warm temperature conditions as warm water holds less oxygen and the metabolic (and oxygen demands) of lobsters are enhanced thus they are more likely to experience metabolic stress. Although SRL can tolerate water temperatures between 8 and 23°C, research has shown a decline in physiological performance at temperatures above 22 °C. Growth, feed intake, oxygen consumption and aerobic scope all decrease at temperature above 22 °C (Thomas et al., 2000; Twiname et al., 2020), demonstrating a likely reduced tolerance to stress. In warm conditions (water temperatures >20 °C), care must be taken to ensure that appropriate vessel carrying capacities of lobsters are not exceeded and water quality is monitored regularly (see below stocking density and water quality monitoring sections). At water temperatures at or above 22 °C, it is recommended that effort is made to seek cooler water and the maximum vessel carrying capacity of lobsters is reduced by 25%. At water temperatures of 23 °C or higher, fishing effort should cease, and cooler conditions found, or the lobster returned to port or released. We acknowledge that cooling water may be cost prohibitive on-board vessels, however all vessels should be fitted with a temperature monitoring and alarm system and prolonged periods in bodies of high-water temperature (> 22°C) should be avoided.

Exposure of lobsters to low- or high-salinity conditions can induce osmoregulatory stress, potentially resulting in mortality (Spencer et al., 2023). Osmoregulatory disfunction can present as abdomen swelling which is often a symptom of detrimental salinity exposure (Figure 4). Low salinity condition in coastal waters can occur after periods rainfall particularly in inshore or estuary environments. Fresh or low salinity water sits on the surface layers of seawater and is likely to be drawn into vessel holding tanks as they draw from close to the surface. Conversely, the salinity level in enclosed bays can increase due to evaporation particularly during hot and dry conditions. All vessels need to carry a working salinity probe or refractometer to measure holding water salinity levels on a regular basis or during periods of uncertainty (such as when entering estuary systems or during the presence of discoloured surface water layers). Seawater typically has a salinity of approximately 34 parts per thousand (ppt or $^{0}/_{00}$). The salinity tolerance of SRL is not well understood, however it is considered that salinities below 30 ppt and above 38 ppt will induce stress. Under severe high or low salinity conditions, water intakes should be shut off. Aeration is essential to ensure water quality in the holding tanks during this time. See next section for recommendations on suitable salinity sensors.

Figure 4. Swelling of the abdomen which is commonly considered a symptom of detrimental salinity exposure (note, other conditions may also cause this symptom).

Ammonia is the dominant nitrogenous excretory waste product from protein metabolism (protein turnover and synthesis). It is largely excreted from the circulatory system across the gills while the lobster is immersed (in water). Ammonia build-up in water is toxic for lobsters and the maximum recommended tolerance level for SRL is 2 mg L^{-1} (Table 1). Ammonia excretion increases after feeding due the physiological processes associated with food digestion and assimilation. For this (and other reasons such as increased oxygen consumption rates), lobsters should not be fed during holding. Southern rock lobsters can withstand several weeks without feeding and results in a downregulation of metabolism, benefiting lobster holding capacity (Simon et al., 2015). Ammonia is unlikely to build up to toxic levels in vessel holding tanks with adequate water exchange and is more often a problem in recirculation aquaculture systems. However, it may become a problem when water delivery is stopped due to equipment failure of poor external water supplies. In these cases, tank-water supplies should be monitored for ammonia and in extreme cases (>5 mg L^{-1}) the holding tanks may need to be drained.

Water pH and hardness are other important water-quality parameters that impact the post-harvest survivability of lobsters. However, similar to ammonia, these are unlikely to be a problem in vessel holding tanks with adequate water exchange and are more often a problem in recirculation aquaculture systems. These parameters should only be considered in extreme situations where water supply is restricted for a prolonged period, during which the holding tanks may need to be drained.

Draining the tanks should only be employed during periods of severe water-quality concerns (such as when dissolved oxygen is not able to be maintained above 60% saturation or when salinity falls below 25 ppt or above 40 ppt. It is important to note that deoxygenated water causes lobster to quickly suffocate. Lobsters survive better out of water (given correct temperature and humidity) than in deoxygenated water, therefore it is important tanks can be effectively drained in the event severe water quality issues. When it is necessary to drain holding tanks and hold the lobster out of water, all effort should be made to resolve water quality issues and re-immerse the lobsters in appropriate quality water as quickly as possible to limit the period of emersion. In situations where adequate water supply cannot be restored for a prolonged period (> 6 hours), the lobsters should be returned to port immediately.

RECOMMENDATIONS

- **Lobsters should not be fed during holding.**
- **Maintaining water-quality parameters (particularly temperature, dissolved oxygen and salinity) within the tolerance limits of lobsters is vital for successful holding on vessels.**
- **All vessels should install a temperature monitoring and alarm system.**
- **At water temperatures at or above 22 °C, effort should be taken to seek cooler water and the maximum vessel carrying capacity of lobsters is reduced by 25%.**
- **At water temperatures of 23 °C or higher, fishing effort should cease, and cooler conditions found or the lobster returned to port.**
- **All vessels should carry a working temperature sensor, dissolved oxygen probe, salinity probe or refractometer, and measure water quality on a regular basis (3 times daily) or during periods of uncertainty.**
- **Measured water quality parameters should be recorded in the vessel log or a dedicated water parameter log.**
- **In severe cases of poor water quality, vessel tanks should be drained, and lobsters returned to port if adequate water supply cannot be restored within an appropriate period (> 6 hours).**

WATER QUALITY MONITORING SYSTEMS

Salinity	Product	Price	Pros/Cons
	BS 45-65: Eclipse hand refractometer	$464 (Imbros)	Pros • Cost effective. • Robust and easy to use. Cons • Manual sampling • Small eye piece display
	HANNA HI96822: Seawater Analysis Refractometer	$475 (Imbros)	Pros • Cost effective. • Robust and easy to use. • Large digital display Cons • Manual sampling

Dissolved oxygen	Product	Price	Pros/Cons
	YSI Pro20 Handheld DO with galvanic sensor	$1,710 (Fresh by Design)	Pros • Internal barometer for highest accuracy • Rugged, user-friendly, IP-67 & 1m drop rated • One-touch 3 second calibration • User serviceable & sensor replacement • 50 data set reviewable memory Cons • Cost • Galvanic sensor needs frequent calibration & maintenance • Wet electrolyte sensor prone to ruptures

Multi-probe	Product	Price	Pros/Cons
	YSI Pro2030 Handheld DO, Temp & Salinity with galvanic sensors	$2,640 (Fresh by Design)	Pros • Measures DO, Cond, Temp at the same time • Rugged, user-friendly, IP-67 & 1m drop rated • One-touch Quick-calibration. Remembers previous calibration values • User serviceable & sensor replacements • 50 data set reviewable memory Cons • Not as quick as optical sensors • Requires maintenance & calibration

	YSI ProSolo Handheld DO, Temp & Salinity with Optical sensors	$3,450 (Fresh by Design)	Pros • Most advanced, accurate measurements with optical sensors • Measures ODO, Cond, Temp at the same time • Site ID & Data ID tags for organisation. USB data transfer • One-touch Quick-calibration. Remembers previous calibration values • 10,000+ data set reviewable memory • Polarised sunnies compatible viewing Cons • Cost

Wireless water quality sensors	**Product**	**Price**	**Pros/Cons**

	Sedna Sensor Globe V3 equipped with dissolved oxygen, pH, acceleration and temperature monitoring	$6,995 (Sedna)	Pros • Wireless with Bluetooth connectivity. • Dissolved oxygen, pH, acceleration and temperature monitoring. • Logging and alarm capability. Cons • Cost • Wireless may not work in vessel wells.

STOCKING DENSITIES

Suitable stocking density in holding tanks is highly dependent on tank volume, configuration, water exchange, aeration potential, and water quality parameters (particularly temperature). As numerous and often interacting variables impact suitable stocking densities, it makes setting prescriptive stocking levels difficult. Therefore, water quality in all tanks should be closely monitored to ensure optimal health of the lobsters. High stocking density increases oxygen demands of the stock, disrupts water flow in a tank and limits the movement of lobsters, preventing them from leaving areas with poor water. Slow water flow and poor oxygen distribution can cause lobsters in the centre of dense stocking groups have restricted oxygen availability. Appropriate holding tank stocking densities can be calculated based on aeration, water flow, and temperature (Table 2). Remember, increased water temperature both reduces the amount of DO in seawater and increases the oxygen demands of lobsters (oxygen demand of lobsters approximately doubles for every 10°C increase). Water temperature and season needs to be considered when evaluating safe stocking densities, as fewer lobsters can be safely held during warm conditions/seasons. Holding tanks should also provide adequate flow and aeration for an assumed active rate of oxygen consumption as lobsters are likely to experience stress after capture and will be active in dark holding conditions. It is also noted that as lobsters are nocturnal their oxygen consumption increases at night (Crear and Forteath, 2000) thus it is essential that water flow and air flow are maintained throughout the day and night. As water and aeration flow are crucial to the health of the lobsters, all vessels should install water and aeration flow alarm systems. The water flow and aeration requirements for 1 tonne of active 600 g SRLs can be calculated based on water temperature using the table provided below (Table 2).

Table 2. Water flow and aeration requirements for 1 tonne of active 600 g southern rock lobsters relative to water temperature (Crear and Allen, 2002).

Temperature (°C)	Oxygen consumption ($g.h^{-1}$)	Required water flow ($L.h^{-1}$)	Required air flow ($L.h^{-1}$)
5	14.0	4607	2686
9	45.0	16251	8647
13	76.0	29909	14615
17	79.1	33717	15218
21	87.1	40000	16758

RECOMMENDATIONS

- **All vessels need to measure water flow rates to all tanks and to calculate maximum stocking densities relative to water temperature.**

- **Water flow and aeration rates in holding tanks must be regularly monitored in case of blockage or restriction.**
- **All vessels should install water and aeration flow alarm systems.**
- **Tank stocking densities should not exceed the calculated safe level based on water flow and aeration rate, as well as the ambient water temperature.**
- **Temperature needs to be considered when evaluating safe stocking densities as fewer lobsters can be safely held in warm conditions.**

HOLDING TANK CONFIGURATION

Uneven or disrupted water circulation in tanks can causes areas with low or no flow, consequently these areas have poor water quality even when incoming water is suitable. Low flow areas can then be addressed by altering outlet positions, or the position of aeration lines, as aeration also promotes water movement. Water outlet positions should be evenly distributed across the base of the holding tanks. For pump boats, this is best achieved through a PVC pipe ring main system with multiple, evenly spaced outlet points to ensures even water outlet pressure across the delivery line (Figure 5). Water should then exit via the top of the holding tank to ensure that incoming water passes through the tank (and past the lobsters) before leaving the system.

Similarly, aeration should be delivered evenly across the base of the tank and is again best achieved through a ring main system to ensure even air pressure across the line (Figure 5). We recommend the use of air diffuser hose for the delivery of air, as this hose is robust and produces fine bubbles which are most efficient for oxygenation. We note that it is nearly impossible to over-aerate and recommend high levels of aeration to maximise water dissolved oxygen levels and remove potentially harmful dissolve carbon dioxide produced by the lobsters. Air diffusers must be regularly cleaned and/or replaced and the air pump should be positioned above the tank water level to preventing back siphoning if the power fails. Risk of water backflow to the air pump can also be reduce by introducing a “gooseneck” in the air piping after the pump, creating a highpoint in the line above the holding tank water level.

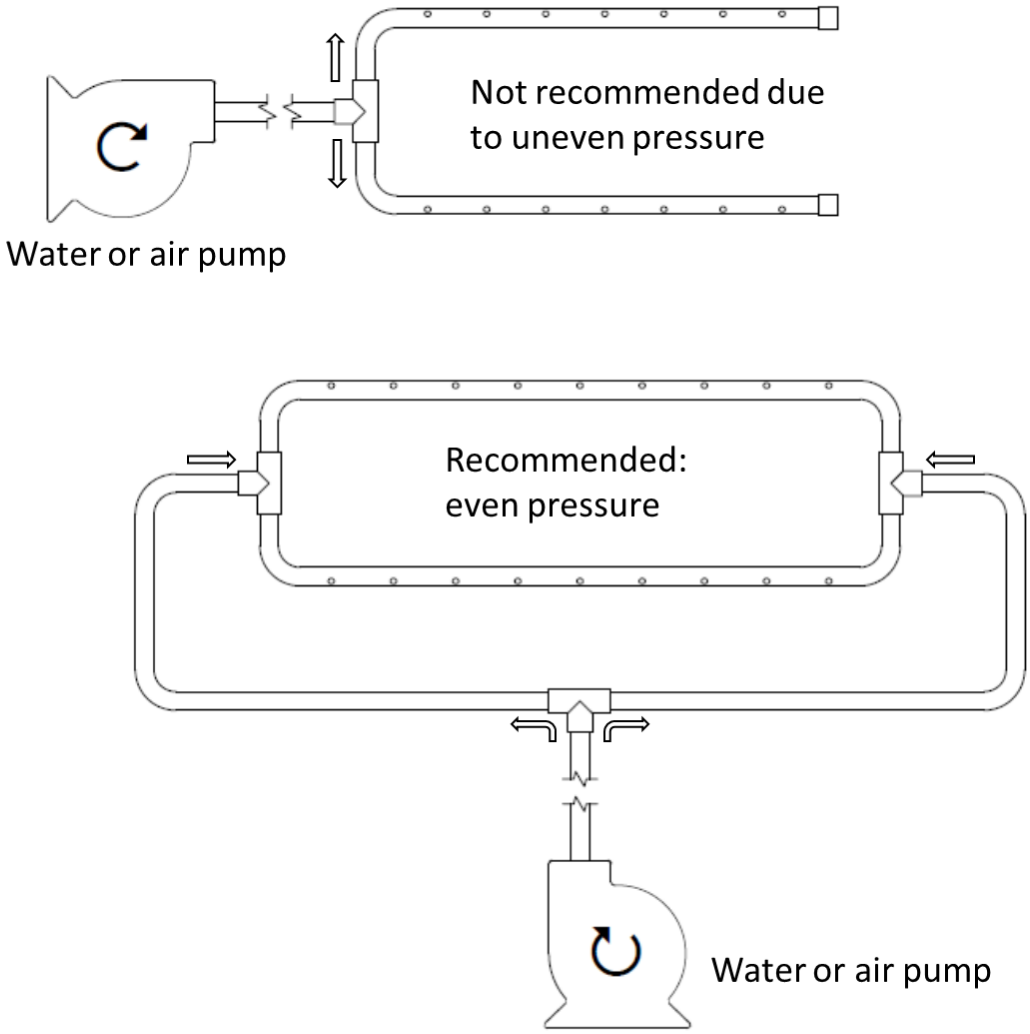

Figure 5. The recommend water or air delivery configuration using a ring main system to create even pressure and distribution throughout the holding tank. Please note that air pumps must be positioned a significant height above the tank water level to prevent back siphoning. Also note that air should not be passed through the water pump or water delivery line as this can cause dissolved gas supersaturation which can be detremental to lobsters.

Lobsters like to hide and grip surfaces and will stress in the absence of suitable substrate to hold. Lobster feet have pointed ends and cannot grip smooth surfaces. In the absence of suitable tactile substrates to grasp, lobsters' group together and grasp one another, which can lead to aggressive interactions, stress, and physical damage. Providing tactile substrate and structures will improve the distribution of lobsters throughout the tank and facilitates even water flow, allowing for higher stocking density whilst maintaining water quality and minimising stress. Providing tactile substrate for lobsters reduces co-specific interaction, limiting physical damage from gripping one another. Substrate also allows lobsters to maintain position in rough conditions. Suitable substrates include meshed or netted materials (such as oyster mesh or strong fishing net material) which should be used to line the holding tank surfaces and to eliminate sections of smooth surfaces (such a fiberglass or steel). Additionally, it is recommended that large holding tanks are divided to into smaller subsections as this will provide a greater surface of substrate for lobsters to hold and better distribute lobsters through the tank, further improving water quality and limiting stress. Baffles or dividers in large tanks also reduce water movement in the tank minimising the likelihood of lobsters being tossed around during rough conditions. Tank subsections can be progressively stocked with an appropriate number of lobsters before being closed off and a new subsection stocked. Alternatively, lobsters can be stocked into a series of net or mesh lined baskets which provide suitable tactile substrate, distribute the lobster through the water column, and allow easier sequential offload at port. However, if internal baskets are employed care must be taken to ensure all baskets receive an appropriate level of water exchange, which is best achieved with baskets which do not greatly impede water or aeration flow. It is recommended that baskets have rails on the base (and preferably the sides) to reduce the likelihood of damage to limbs which may protrude outside the basket.

RECOMMENDATIONS

- **Water outlet positions should be evenly distributed across the base of the holding tanks, with multiple outlet points to ensure even delivery of water throughout the tank. Water should then exit at the top of the holding tank to ensure that water passes through the entire tank.**
- **Aeration should be delivered evenly across the base of the tank, and we recommend the use of an air diffuser hose which produces fine bubbles, most efficient for oxygenation.**
- **Vessel tanks should be tested to ensure an even distribution of water and air flow before stocking.**
- **Vessel tanks should provide sufficient tactile substrate and structures for lobsters to grasp.**
- **Large tanks should be divided to into smaller subsections, providing a greater surface of substrate for lobsters to hold and better distribution of lobsters through the tank.**
- **When baskets are used, they should be of a material that provides tactile substrate for lobster to hold, and should not greatly impede water or aeration flow.**
- **It is recommended that baskets have rails on the base (and preferably the sides) to reduce the likelihood of limb damage when baskets are handled.**

Figure 6. Good examples of two pump boat tanks. The tank on the left has a ring main water delivery loop on the base and overflow at the surface to ensure flow distribution past the lobsters before leaving the tank. The tank is subdivided into differing sections to better distribute lobsters within the tank and to provide tactile substrate for them to hold. The tank on the right uses substrate-lined baskets to distribute the lobsters through the water column and provide substrate to hold. This tank also provides water inflow which is sprayed on the surface, aiding oxygenation. However, it is noted that surface delivery of water should not be the sole source of incoming water as the new water may not reach lobsters at the base of the tank, leading to pockets of poor water quality. It is also recommended that baskets have rails on the base (and preferably the sides) to reduce the likelihood of limb damage.

LANDING AND OFFLOAD

The landing and offload of lobsters at port can present significant stress to lobsters, and if not well managed can greatly influence the quality of landed lobsters. All effort should focus on limiting the level of stress experienced by the lobsters during this process by considering several factors such as water quality, time of emersion (out of water), and the amount and quality of handling.

Entry into port may present a risk of poor water quality in coastal or estuarine environments due to freshwater incursion or high salinity in enclosed bays or estuaries. When suboptimal salinity is suspected, fishers should regularly measure holding-tank salinity levels and shut off water inflow if salinity falls below 25 ppt or above 40 ppt. During this time, it is integral to maintain aeration and regularly monitor DO. If DO cannot be maintained above a minimum 60% saturation, the tank should be drained and lobsters offloaded as quickly as possible, to prevent suffocation.

When appropriate water quality can be maintained, vessel tanks should not be drained until necessary for the removal of lobsters to minimise time that the lobsters are out of the water. The offload of lobsters needs to be conducted in a rapid and efficient manner to minimise emersion time. Lobster collection should be organised in advance and collection ready immediately at landing. Lobsters should be handled carefully; preferably using two hands with one firmly holding the carapace or base of antenna and the other supporting the tail. Lobsters should be placed directly into transport baskets to limit repeated handling. Baskets should not be excessively stocked and preferably baskets are lined with mesh or seawater wetted material (such as hessian) to provide substrate for lobsters to grasp, limiting damage to limbs which may protrude through holes in the basket. Once stocked, transport baskets should also be covered in wetted material to maintain humidity during transport and limit exposure to sunlight and rain. Transport baskets should be handled carefully to avoid dropping or sudden jolts which can damage the internal organ of the lobsters. Where possible, offloads should occur during the coolest time of the day (such as early morning) and fishers should avoid offloading during bright, hot, or rainy conditions. It is also important that lobsters are cooled as soon as possible after offload. Transport trucks should be pre-chilled, and lobsters transferred onto trucks as quickly as possible. Road transport is also significantly stressful for lobsters, largely due to the emersion time involved and cramped conditions. Where possible, lobsters should be landed at the closest port possible to the onshore holding and processing facility to limit required road transport durations.

During the return to port, it is important to ensure that contaminants (such as cleaning products) do not enter the holding tanks. Deck cleaning is not recommended until the lobsters are fully offloaded to prevent any risk of contamination in the holding tanks. Once fully offloaded, the holding tanks should be thoroughly cleaned and rinsed, and any lost limbs or body parts removed. Holding tanks are best stored dry and should be thoroughly rinsed with fresh seawater before subsequent stocking with lobsters.

RECOMMENDATIONS

- **During offload, all effort should be made minimise the time of emersion and to keep the lobsters immersed in high-quality aerated water for as long as possible.**
- **When suboptimal salinity is suspected , fishers should regularly measure holding tank salinity levels and shut off water inflows if salinities falls below 25 ppt or above 40 ppt. During these periods, it is important to maintain aeration and regularly measure dissolved oxygen levels.**
- **When suitable water quality is available, vessel tanks should not be drained until necessary for the removal of the lobsters and aeration should be maintained during draining.**
- **Lobster collection should be pre-organised and ready for collection immediately at landing.**
- **Lobsters should be carefully placed directly into the transport baskets to reduce repeated handling.**
- **Transport baskets should not be overstocked.**
- **Transport baskets should be lined and covered in wetted material to limit lobster exposure and damage, and to maintain humidity.**
- **Transport baskets should be handled carefully to avoid dropping or sudden jolts which can damage the internal organ of the lobsters.**
- **When possible, offloads should occur during the coolest time of the day (such as early morning) and fishers should avoid offloading during bright, hot, or rainy conditions.**
- **Transport trucks should be pre-chilled, and lobsters should be transferred into the truck as quickly as possible.**
- **Where possible, lobsters should be landed at the closest -possible port to the onshore holding and processing facility to limit required road transport durations.**
- **Deck cleaning is not recommended until the lobsters are fully offloaded to reduce risk of contamination in the holding tanks.**
- **Holding tanks should be thoroughly cleaned and rinsed with fresh seawater before subsequent stocking with lobsters.**

Figure 7. During offload it is recommended to process lobsters quickly into lined transport baskets and to cover with seawater wetted material (such as hessian) as soon as possible. Transport tucks should be pre-chilled and lobsters should be transferred into the truck as quickly as possible.

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