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ROCK LOBSTER POST-HARVEST SUBPROGRAM
FRDC

OPTIMISING WATER QUALITY

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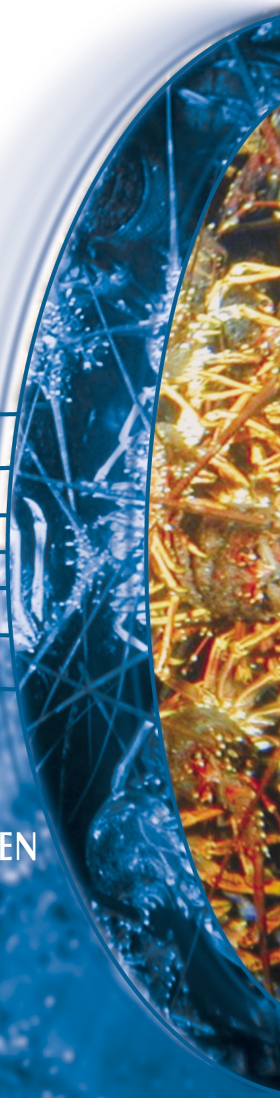
BRADLEY CREAR AND GRANT ALLEN



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Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, PO Box 252-49, TAS 7000.

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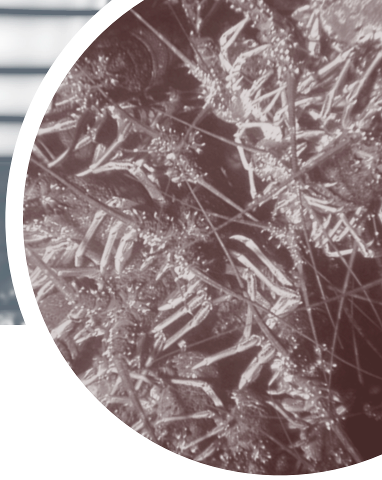

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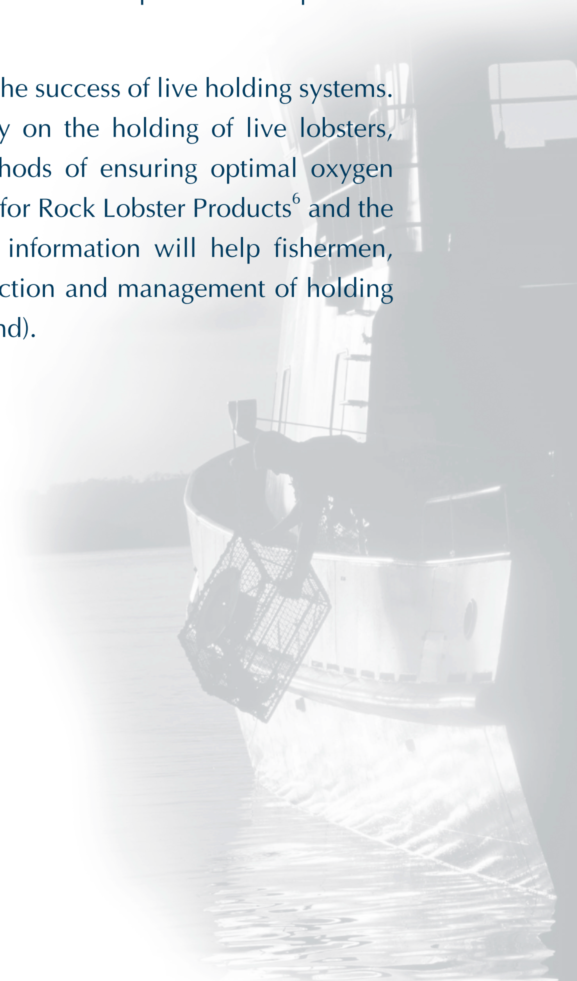
INTRODUCTION 1

The primary aim of capturing, holding and transporting live lobsters is to deliver them to markets in the best possible condition. Lobsters will be exposed to some level of stress during all or part of the process. Stress can be defined as any factor (either external or internal) causing a physiological disturbance to the lobsters. In the live lobster industry these factors include capture and handling, poor water quality, strong sunlight, air exposure, and physical damage. Lobsters are generally able to recover from such stresses, however if any or a combination of those stresses are sufficiently intense, then poor quality or dead lobsters will result. Thus, transport and holding systems need to ensure lobsters are held in conditions that keep stress to a minimum.

The design of transport and holding systems is governed by a number of factors, with economics being a major driving factor. Systems also need to be practical to use and manage, and designed to suit the biological requirements of the animal. For a number of lobster species there is now a range of biological information that can be practically used in the design of systems. How the information is adopted will depend on the type of system being designed i.e. on boat, on shore, flow through or recirculating. For example, on a fishing vessel, ratios of kilograms of lobster to litres of water can exceed 1:1; space, weight and time are at a premium; the lobsters are in an extremely active state and the ambient seawater can be very warm and very low in oxygen. Some operators must store lobsters under these conditions for extended periods (days to weeks) before they are delivered to a processing facility. Given these factors, a range of innovative design features are required to ensure lobsters are kept in the best possible condition[7].

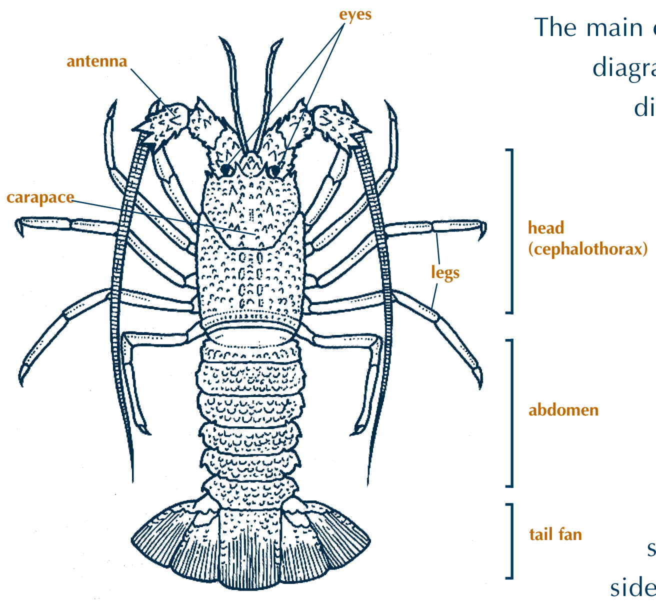
Oxygen is generally the major water quality variable limiting the success of live holding systems. This guide provides information to the rock lobster industry on the holding of live lobsters, focussing on the oxygen requirements of lobsters and methods of ensuring optimal oxygen supply. It has drawn from the New Zealand Code of Practice for Rock Lobster Products[6] and the Australian Code of Practice for Live Rock Lobster[11]. This information will help fishermen, processors and boat builders in the practical design, construction and management of holding systems for live rock lobsters (both on board boats and on land).



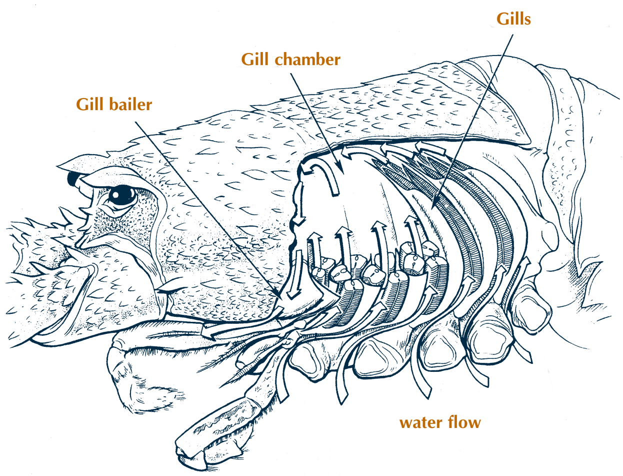
LOBSTER RESPIRATION BIOLOGY AND THE ENVIRONMENT 2

2.1 RESPIRATION BIOLOGY

Rock or spiny lobsters belong to a large class of invertebrate animals called Crustacea. In Australia, four species of lobsters support significant commercial and recreational fisheries[10]. The western rock lobster (*Panulirus cygnus*) is found off the lower western Australian coast, the tropical rock lobster (*Panulirus ornatus*) in northern Australia, particularly the Torres Strait and far north Queensland, the eastern rock lobster (*Jasus verreauxi*) off the central eastern Australian coast and the southern rock lobster (*Jasus edwardsii*) off the southern Australian coast.



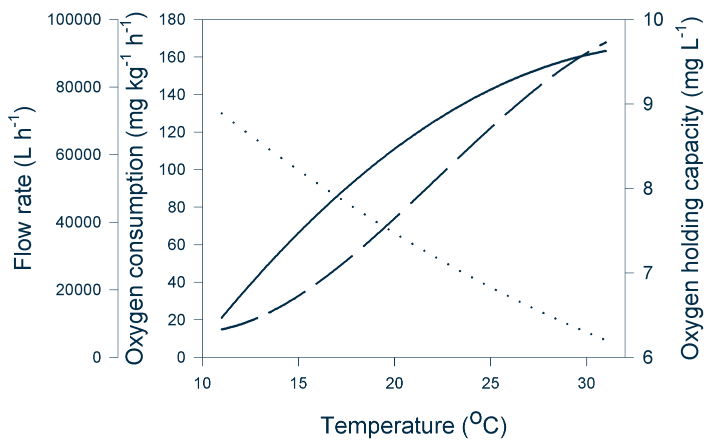
The main external features of lobsters are shown in the diagram left. The body of crustaceans is typically divided into three sections: head, thorax and abdomen (or tail). In lobsters, a carapace covers the head and thorax effectively forming a single section termed the cephalothorax (commonly called the head). Within the head are the major organs, including the heart, stomach, digestive gland and gills. The gills, situated in the gill chambers on either side of the head under the carapace, are used to extract oxygen from seawater. There are generally 21 gills on each side. Each gill is composed of numerous threadlike gill filaments containing capillaries enclosed in a thin membrane; oxygen is absorbed from the passing water and carbon dioxide is discharged. Water is drawn through the gill chambers, from back to front, and over the gills, by the beating of a special organ called the gill bailer, which is situated at the front of the chamber. See diagram below[12].



2.2 OXYGEN CONSUMPTION

Lobsters require oxygen in order to survive and they obtain this from the seawater. Recent studies have shown that lobsters must be stored in water with dissolved oxygen concentrations greater than 70% saturation to ensure they are in the best possible condition[5]. Although maintaining dissolved oxygen levels > 70% at all times seems a relatively simple task, it can be anything but this in practice. There are many factors that affect the rate of oxygen consumption by lobsters, with water temperature, lobster weight and level of activity and/or stress being the major ones. There is a maximum level of oxygen consumption that lobsters can achieve; this is the level that needs to be used in the practical design of holding systems. Lobsters need to be provided with sufficient oxygen to ensure maximum consumption rates are possible at all times.

Factors that affect the oxygen requirements of lobsters can also alter the availability of oxygen. For example, as temperature increases, the lobster's demand for oxygen increases but the solubility of oxygen in water, and therefore it's availability to the lobsters, decreases. As a result the water flow required at higher temperatures increases markedly. The relationship is illustrated in the figure below. Salinity also affects the availability of oxygen to lobsters (Appendix A).



Oxygen consumption (solid line – mg kg^{-1} h^{-1}) of active western rock lobsters at various temperatures compared with the oxygen holding capacity (dashed line – mg L^{-1}) of water at those temperatures. The resultant water flow requirements (dotted line – L h^{-1}) for western rock lobsters at the temperatures are also shown[5].

The maximum solubility of oxygen in water at normal atmospheric pressure is termed 100% saturation. As the amount of oxygen in water varies with temperature it is much more convenient to express oxygen in terms of % saturation rather than as mg per litre (mg L^{-1}). The following example illustrates why. A generally recommended minimum oxygen level is 6 mg L^{-1}. In seawater at 27°C, 6 mg L^{-1} of oxygen equates to 92% saturation, whereas at 10°C it is 66% saturation. Thus, at certain temperatures, using 6mg L^{-1} as the minimum oxygen level can result in lower oxygen levels than the recommended minimum level of 70% saturation. At higher temperatures obtaining an oxygen level of 6 mg L^{-1} would be difficult to achieve using standard aeration equipment.

2.2.1 EFFECT OF EXPOSURE TO AIR

Lobsters are aquatic animals that are not naturally exposed to air (emersed). However, they do have a limited ability to extract oxygen from air and can survive for extended periods when exposed to air. It is this capacity that makes transport of live lobsters to markets around the world possible. Lobsters held in deoxygenated water suffocate quickly due to rapid loss of their available oxygen. For this reason, most lobster holding facilities are designed to be self-draining in the event of a systems failure that would prevent the circulation of oxygenated water.

Indicators of stress are evident when lobsters are exposed to air. Generally these changes are quickly corrected when lobsters are submerged. Thus, as long as lobsters are held under suitable conditions (appropriate temperature and humidity, with minimal disturbance) there appears to be no long-term effects due to short-term (<36 h) air exposure. The transport of lobsters to markets, which are further afield (eg. Europe) is likely to require longer exposure times. Exposure periods of up to 48 hours appear feasible, but require strict control of environmental parameters, which can be difficult.

NOTE: THE USE OF PURE OXYGEN TO AID THE OXYGEN UPTAKE OF LOBSTERS EXPOSED TO AIR IS NOT RECOMMENDED. MOST CRUSTACEANS DIE QUICKER WHEN EXPOSED TO A HIGH LEVEL OF OXYGEN IN AIR, AS IT RESULTS IN HARMFUL PHYSIOLOGICAL CHANGES.

2.3 WATER QUALITY

To maintain lobsters in prime condition they need to be provided with an environment that satisfies their physiological and behavioural requirements. Water quality has to be maintained at optimum condition for the lobsters, the most important being oxygen, temperature and salinity. Movement of any of those parameters outside the range tolerated by lobsters will result in mortalities within a short period of time (minutes to hours). There are other parameters that need to be monitored and controlled (e.g. ammonia, pH) although variations in these parameters will generally only result in mortalities over longer periods of time (hours to days). The table below outlines the water quality parameters regarded as being within the tolerance limits of rock lobsters.

Tolerance limits for various water quality parameters for the southern rock lobster (SRL) and the western rock lobster (WRL)

PARAMETER	TOLERANCE LIMITS
Temperature	SRL: 8 to 23˚C (OHT[A] 9-13˚C)
	WRL: 12 to 31˚C (OHT 17-23˚C)
Dissolved Oxygen (% saturation)	Min. 70%, preferably >80%
Salinity (g kg^{-1} or ppt)	30 to 38
Ammonia (mg L^{-1})	<2
Nitrate (mg L^{-1})	<5
Nitrate (mg L^{-1})	<100
pH	7.8 to 8.4
Hardness (ppm)	100-200

[A]OHT - Optimum Holding Temperature.

HOLDING SYSTEMS 3

3.1 DESIGN AND OPERATION OF THE OXYGEN SUPPLY IN HOLDING SYSTEMS

Oxygen is supplied to lobsters via the water pumped through a holding system and/or via supplementary aeration. Flow through systems need to be designed so that under normal circumstances sufficient oxygen is supplied via the incoming water. However, aeration also should be incorporated into the system to provide for those times when there is insufficient oxygen being provided via the incoming water e.g. pump breakdown, restricted flow (seaweed at the intake), or low levels of oxygen in the incoming water. Aeration can also increase the carrying capacity of a system, provided all other water quality parameters are acceptable[8]. Aeration is currently the most effective means of increasing dissolved oxygen availability[3].

The design and operation of systems which provide oxygen to lobsters is based on:

- the amount of oxygen needed per unit of time.
- the minimum tolerable dissolved oxygen concentration required by the lobsters.

3.2 BOAT HOLDING FACILITIES

The only reliable method of maintaining lobsters in prime condition on board boats is to place them into live storage tanks where they are fully submerged in good quality water. Three types of holding systems are generally found on board boats – wells, below deck tanks and above deck tanks. Any of these methods are equally acceptable as long they are set up correctly.

One of the problems of holding lobsters on board boats, especially for extended periods, is the need to drive either water pumps and/or aeration equipment (either directly or via batteries). There is a range of aeration equipment now available, which should minimise any inconveniences, such as power usage and/or noise. The benefits to the fisherman should serve to counteract those inconveniences. For example, with aeration in a well tank it would be possible to move into a sheltered bay where water movement is minimal. Thus, the fishermen can be physically comfortable whilst knowing that the lobsters will still be maintained in good condition.

3.2.1 WELL TANKS

In well tanks it is difficult to control the flow of water, both in volume and in direction, through the tanks. Water flow through the well tank relies solely on the movement of the vessel or a reasonable current flow to force water into the well. Where there is a lack of boat movement or current flow, the transfer of water to the wells and hence the supply of oxygen to the lobsters can be restricted. Operators must be aware of this and move position if such conditions occur. Additionally, when lobsters are stored in large quantities and at high densities in wells, lobsters in the centre can suffer from lack of water flow. Airation should be an essential component of well tanks. The addition of aeration into the wells would largely prevent problems associated with this method of holding lobsters. It would increase the level of oxygen in the water and the movement of water (and thus distribution of oxygen and removal of waste).

When coming into estuaries or areas of poor quality water well tank inlets/outlets are usually blocked, and a pump is used to circulate water within the well. This prevents the lobsters coming into contact with external sources of poor quality water, but can result in the oxygen becoming depleted within the well. The addition of aeration would ensure that the lobsters in the static well tank remain in reasonably good quality water. Over a 2-3 h period it is unlikely that other water quality parameters would decrease to a harmful state.

3.2.2 BELOW DECK TANKS

Below deck tanks are perceived to be the best method of holding lobsters on board boats. Even so, they need to be designed properly to ensure they are effective. A dedicated pumping system is required to produce a constant flow of water to the tanks. This needs to pump sufficient water to supply the oxygen requirements of the lobsters. It is also necessary to check the water flow rate regularly or have a flow alarm. Below deck tanks face similar problems to the well tanks when coming into estuaries or areas of poor water quality. Similar strategies should be used to overcome those problems.

3.2.3 ABOVE DECK TANKS

Above deck tanks can be a very effective means of holding lobsters. However, when using above deck tanks it is important to consider the possible additional stresses which the lobsters can be subjected to: sunlight; increased temperature; and movement of people and objects across the deck of the vessel. Lobsters should be protected from these factors as much a possible by keeping tank lids in place. A shaded area for the tanks would also be good, however, it is not feasible on board many boats. One of the major problems in the use of above deck tanks can be the lack of a dedicated water source, with water flow being provided by the deck hose. The pump for the deck hose is often run directly off the main engine. Thus, if the deck hose is used for other purposes or the engine is not going fast (e.g. whilst idling at pot lifts) the water flow is stopped or reduced. As for below deck tanks, a dedicated pump that provides a constant flow of water via dedicated piping should be used.

3.3 ON SHORE HOLDING FACILITIES

3.3.1 FLOW THROUGH VERSUS RECIRCULATING

In both the flow through and recirculating systems oxygen is being stripped from the water and waste materials added. This is acceptable in a flow through system when oxygen levels are sufficient to maintain the lobsters' requirements and the used water goes to waste. In a recirculating system the water is re-used. Oxygen needs to be replaced and the waste material removed before the water is returned to the lobsters. The easiest way to achieve this is to aerate the water and have a physical and biological filter to remove the waste.

Recirculation systems are best used in areas where: external seawater quality is not guaranteed (e.g. estuaries); where pumping costs from the sea are excessive (inshore holding facilities); where specific control over temperature or other environmental parameters is required; or where environmental controls are in place to reduce nutrients in effluent water. One major down side to recirculation systems is that water quality parameters must be regularly monitored to ensure optimal water quality for the lobsters. These include temperature, pH, salinity, ammonia, nitrite and nitrate.

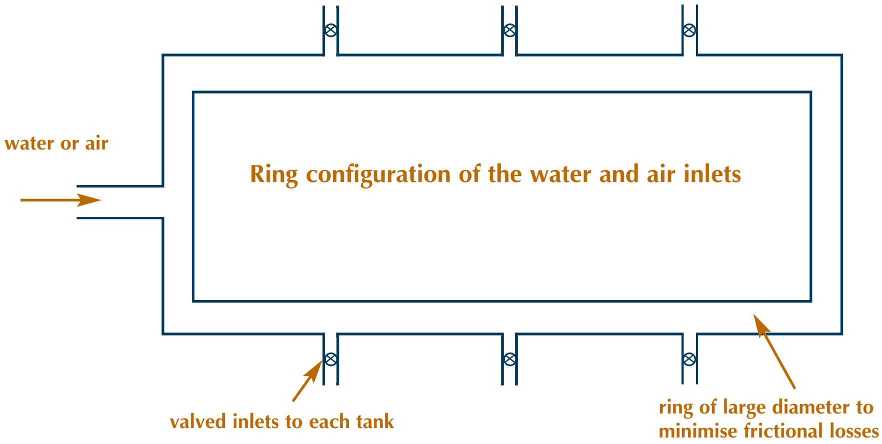
3.4 FACTORS THAT AFFECT HOLDING SYSTEM PERFORMANCE

Outlined below are some general factors that should be considered when designing and/or using a live holding system. Water quality is the major factor that affects the performance of a holding system.

3.4.1 WATER FLOW

- When designing a holding system, water inlets and outlets should be situated at the greatest distance from each other i.e, inlets at the bottom and outlets at the top, or vice versa. Flow from the bottom to the top is preferable. This increases the distribution of water within the holding tank, minimises the formation of 'dead spots', and maximises the removal of waste water.
- Although the overall size of a holding system is likely to vary markedly on each boat (dependent on expected maximum catch), the size and shape of an individual tank in a below deck storage system should be virtually standard. Each tank should be self-contained (own inlet and outlet) and of a size that matches the baskets being used.
- Baskets containing lobsters should fit tightly within tanks, with no holes in baffles between tanks. Air and water must freely pass through the baskets (and hence the lobsters) and not short circuit around them.
- Plumbing of water should be in a ring configuration to ensure equal pressure and therefore equal delivery to all tank sections (see diagram on following page).

- The main outlet lines from the pump (ie. the ring configuration) should be of as large a size as practical to minimise frictional losses of the flow rate (see diagram below). The flow to each tank should be able to be controlled (each tank should have a valved pipe branching off the main ring configuration) so that water flow can be regulated according to tank size and stocking biomass.



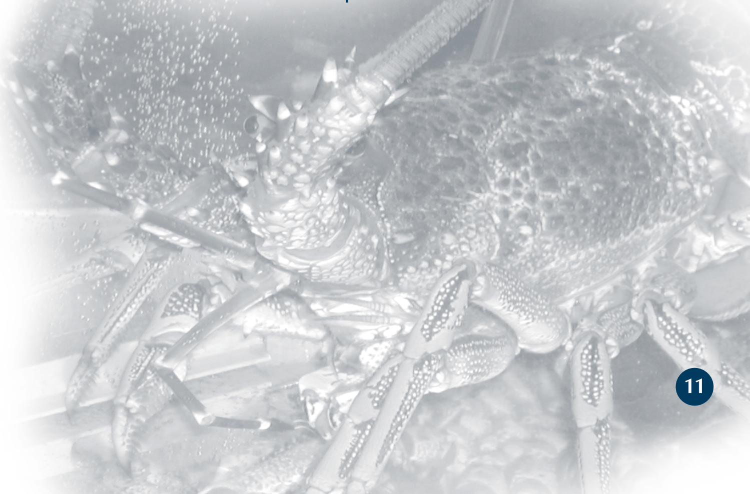
- Similarly, each tank should have its own water outlet to ensure tanks drain at the same rate as filling.
- How to measure water flow rate? Calculate the volume of the top 10 cm of tank. Then calculate the flow based on the time to refill this portion of the tank. This method accounts for effects of increasing head pressure with water depth. Another method is to simply fill a bucket of known volume with the outflow from a tank, and time how long it takes to fill. If the bucket is 20 L and it takes 10 seconds to fill, then there is a flow of 120L min^{-1} (= 60sec ÷ 10sec) x 20 L).
- If a flow alarm is fitted set it to 75% of water flow (for partial blockages of intake/strainers) and/or have a flow gauge.
- Ensure there are no suction side leaks and that the water intake is always below the water line, as air intake to the water pump can result in gas supersaturated water. Signs of suction leak: milky coloured water due to microbubbles.
- If the water quality parameters in a particular area (eg. estuary) are thought to be sufficiently different from the oceanic water from which the lobsters were caught, then it is best to shut off the flow through system and recirculate the water, ensuring appropriate aeration. Alternatively, the holding tanks should be completely drained and the lobsters kept emersed. Lobsters can survive much longer out of water than in de-oxygenated water.

3.4.2 AERATION

- Aeration should be fitted as a standard accessory to any vessel catching lobsters.
- Plumbing of airlines should be in a ring configuration to ensure equal pressure and therefore equal delivery to all tank sections.
- Each tank should have its own adjustable air valve so that air flow can be regulated. If a tank is empty and air flow is on, air will short circuit to the atmosphere, effectively cutting air flow to full tanks.
- Air diffusers (airstones, leaky pipe etc.) need to be replaced frequently as they become clogged and lose their efficiency. Also lobsters have a tendency to chew them. Therefore, they should be simple to replace (eg. at the end of season service). Some air diffusers are able to be cleaned and thus should be on a regular basis. Air diffusers should not be left submerged in water when not in use; tanks should drain to below the level of the air lines.
- The air pump should be located above the tank water line to prevent back siphoning if the power fails (or use stainless check valves).

3.4.3 ENVIRONMENT

- Estuarine and harbour water can vary greatly from oceanic water, with particular regard to temperature, salinity, sediment load and pollution. Therefore, care must be taken when entering estuaries and harbours.
- **Temperature** – lobsters can handle a wide range of temperatures; the recommended Optimum Holding Temperature (OHT) ranges are well within the tolerable temperature limits (see Section 2). Cooler temperatures tend to reduce activity, oxygen consumption, waste excretion and aggressive behaviour of lobsters.
  Therefore, the maintenance of the health of lobsters is easier when held at temperatures towards the lower end of the OHT. Although lobsters can generally tolerate large and/or rapid changes in temperature without any adverse effects (e.g. chilling is commonly used to prepare lobsters for aerial transport), it is best to avoid exposing them to such changes where possible. Due to the presence of shallow sand / mud flats, estuaries and harbours can have different water temperatures



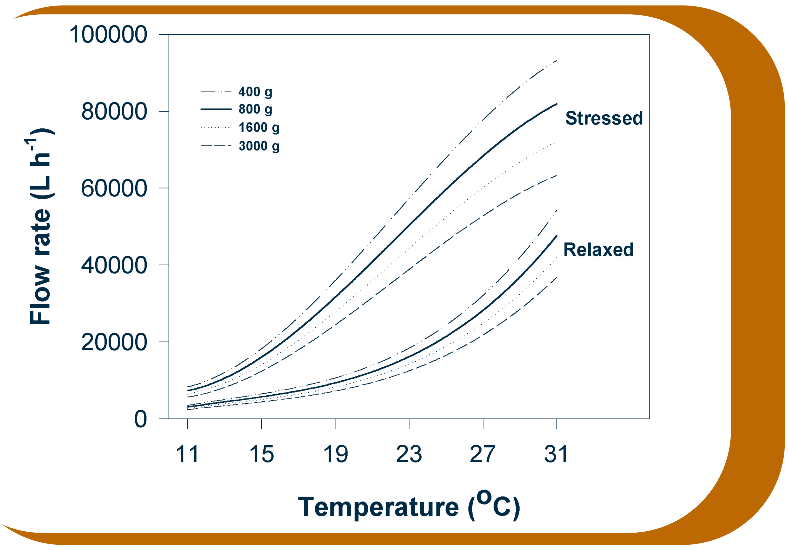
(usually warmer) from the ocean. Increased water temperature should be avoided as it leads to increased activity thereby increasing oxygen consumption and waste production.

- **Salinity** – fresh water is not as heavy as salt water and therefore floats on the surface. In an estuary, harbour or river after heavy rain the salinity of the surface water can be very low. Continued operation of a flow through system in this instance will begin to stress the lobsters.
- **Sediment** – storms and heavy rain can stir up sediment, which can result in clogging of lobster gills and make extraction of oxygen from the water more difficult.
- **Pollution** – estuaries and harbours can have heavy vessel traffic, industrial discharge and storm water run off. Any resulting pollution may have a detrimental effect on the lobsters.
- **Sunlight, wind** – in most situations the exposure of lobsters to direct sunlight and wind should be avoided. Both are stressful as they can quickly dry the lobsters out. Strong sunlight is also likely to damage the eyes of lobsters.

WATER FLOW AND AERATION 4

4.1 WATER FLOW REQUIREMENTS

Water flow requirements for lobsters vary in relation to animal size, temperature and stress. This is illustrated for the western rock lobster in the figure below. Thus, 1 tonne of relaxed 400g lobsters being held at 19˚C will require 10,811 L of fully saturated seawater per hour. However, if that same 1 tonne of lobsters is moved into 23˚C water and during the process are stressed, they will require 61,951 L of fully saturated seawater per hour, or almost 6 times as much.



The water flow (L h^{-1}) requirements of 1 tonne of western rock lobsters at various combinations of temperature, body weight and stress. Calculations are based on the incoming water being fully oxygen saturated and the maintenance of 70% oxygen saturation in the outgoing water[5].

4.1.1 CALCULATING FLOW RATES

From the above figure and Appendix B we can calculate the required water flow to maintain through a holding tank. Let us assume that western rock lobsters are stressed, the water temperature is 27˚C and the incoming water is oxygen saturated. The flow rate required to provide the oxygen requirements of 1 tonne of 400g lobsters, whilst maintaining 70% saturation at the outlet would be 74539 L h^{-1}. This works out to be approximately 1.2 L kg^{-1} $minute^{-1}$ (= 74539 ÷ (60 sec x 1000 kg). However, if the incoming seawater was not fully oxygen saturated, then a flow of 1.2 L kg^{-1} min^{-1} water would not provide the necessary minimum of 70% saturation at the outlet. Thus, aeration of the water becomes necessary. The required water flow rate of lobsters under various conditions is outlined in the table on the following page.

The water flow (L h^{-1}) requirements of southern and western rock lobsters at various temperatures. Calculations are based on the incoming water being fully oxygen saturated and the maintenance of 70% oxygen saturation in the outgoing water.

Southern rock lobster *J. edwardsii*			Western rock lobster *P. cygnus*		
Temp.(°C)	**Flow rate**		**Temp.(°C)**	**Flow rate**	
	L $tonne^{-1}$ h^{-1}	L kg^{-1} min^{-1}		L $tonne^{-1}$ h^{-1}	L kg^{-1} min^{-1}
5	4607	0.08	11	8384	0.14
9	16251	0.27	15	18755	0.31
13	29909	0.50	19	33081	0.55
17	33717	0.56	23	61951	1.03
21	40000	0.67	27	74539	1.24
			31	94053	1.57

Tropical Lobsters – there is little information available for tropical lobsters, although some is available for the Caribbean lobster, *P. argus*[1]. From that data it would appear that the recommendations for the sub-tropical species *P. cygnus* would be applicable. At higher temperatures the data would need to be extrapolated. That is at 35°C a flow rate of 1.96 L kg^{-1} min^{-1} (117,000 L $tonne^{-1}$ h^{-1}) would be required.

4.2 AERATION REQUIREMENTS

Aeration is required where the incoming water is low in dissolved oxygen or where the water is being recirculated. It can also be used to increase the carrying capacity within a particular body of water. There are many different methods of aerating water. Unfortunately, in general there is a poor understanding of aeration fundamentals and as a result aeration performance is often less than optimal.

In the case of a water pump breakdown all of the oxygen requirements of the lobsters will need to be supplied by aeration. Lobsters will survive for an extended period in a static tank as long as the oxygen is maintained at an appropriate level. For example, in a 10,000 L tank of water at a temperature of 23°C, stocked with 1 tonne of western rock lobsters (stocking density 100 kg m^{-3}), with no water flow or aeration, declining oxygen levels will cause significant mortalities after 1-2 hours (dependent on activity levels of the lobsters). However, if adequate aeration is available, the ammonia (the next critical water quality parameter) level will reach approximately 5 mg L^{-1} after 24 hours. This concentration would result in few, if any, mortalities. Aeration systems therefore provide a large buffer time in the event of a problem with water flow.

If the pump breakdown is caused by a problem with the power supply, then it may also be affecting the aeration system. In such a case it is important that the tanks are self-draining as lobsters will survive significantly longer in humid air than in stagnant deoxygenated water. In a recirculating system, aerating the water is the only means of replenishing oxygen levels.

Aeration is also useful where water flow is purposely turned off to ensure that no problems are caused by poor water quality (pollution / low salinity), such as when a boat enters a harbour / estuary.

NOTE: WHEN THE FLOW IS TURNED OFF IT IS IMPORTANT TO REMEMBER THE WATER TEMPERATURE MAY QUICKLY RISE. THE RATE OF RISE WOULD DEPEND ON THE PROXIMITY TO HEAT SOURCES (ENGINES/SUNLIGHT) AND THE OUTSIDE AIR TEMPERATURE. IF THE CONDITIONS ARE UNFAVOURABLE AND THE TANKS NEED TO BE STATIC FOR A CONSIDERABLE TIME THEN THE TEMPERATURE MAY INCREASE TO UNACCEPTABLE LEVELS

4.2.1 DETERMINING THE AERATION REQUIREMENTS

As stated earlier, the design of aeration equipment is based on the amount of oxygen needed and the minimum tolerable dissolved oxygen concentration. As this information is available (Appendix B provides information on the oxygen consumption of lobsters under different conditions), it should just be a matter of using it to determine the appropriate aeration equipment. Unfortunately, it is not that simple. As a first step you need to be guided by what you wish to achieve. Ideally you should have an aeration system that provides all of the oxygen required by the lobsters at the maximum rate of oxygen consumption (Example 1a). However, that may not be practical due to cost or power restrictions (eg. on board a boat). Therefore, you may wish to install an aerator that provides supplemental aeration to that provided by the flow through water supply. This would be sized so that it provides the oxygen requirements of relaxed lobsters (Example 1b). Thus, even if the water flow is stopped the lobsters will still be provided with sufficient oxygen as long as they remain unstressed. Lobsters will generally return to relaxed levels of oxygen consumption within a few hours of being stressed (eg. due to capture or sorting).

Example 1. Aerator calculations

(a) Calculate the size of the aerator required to provide sufficient oxygen to 1 tonne of active and stressed 400 g western rock lobsters at 23˚C.

The lobsters require 130g of oxygen h^{-1} (Appendix B). Under ideal (standard) conditions a 250 W (1/3HP) aerator with medium sized (3mm) bubble diffusers will transfer between 250 and 400g of oxygen to water per hour[4]. For this example we will assume 300g h^{-1} is being transferred; thus there would appear to be sufficient oxygen to meet the lobsters' requirements. However, that rate of transfer is only achievable under optimum conditions (i.e. if the oxygen level of the water is low then the transfer efficiency is high). Since there is a need to keep the oxygen level relatively high (above 70% saturation at all times), the efficiency of transfer of oxygen to the water is decreased to approximately 20% of the maximum rate. Thus, there are only 60g (20% of 300g) of oxygen available to the lobsters per hour: a bigger aerator would be required. A 560 W (3/4HP) pump would deliver sufficient oxygen (135g per hour) under those conditions.

(b) Calculate the size of the aerator required to provide sufficient oxygen to 1 tonne of relaxed 400 g western rock lobsters at 23˚C

The oxygen requirements of relaxed lobsters is much less (~40 g h^{-1})(Appendix B). Thus, the 250 W aerator would more than adequately provide their oxygen requirements.

Another complicating factor is that the efficiency of transfer of oxygen from aeration systems to the water (transfer efficiency) is dependent on a number of factors, which include: depth of water, temperature, concentration of oxygen in the water, size of air piping, type of diffuser, bubble size, air flow rate and type of aerator. The ability of aeration equipment to transfer oxygen to water (standard oxygen transfer rates) is developed under standard conditions (including low oxygen saturation levels). Manufacturers of aeration equipment should be able to supply this data. Under field conditions the oxygen transfer rate can be much less. Typically in aquaculture or holding systems, where there is already quite a high oxygen saturation level in the water, the oxygen transfer rate is generally less than 25% of that under standard conditions.

As there are so many factors to consider, the design of an aeration system can be difficult and should be discussed with an experienced person. Appendix B outlines the airflow required to provide sufficient oxygen to lobsters under various conditions. However, due to differences between systems resulting in very different rates of aeration efficiency, these should be used as a guide only.

4.2.2 COST OF AERATION

Aeration is an insurance against water quality problems and can lead to increased survival and vigour of the lobsters. It also gives increased flexibility in how lobsters can be stored. Even though the cost of installing and running an aeration system is easy to justify, it is still worthwhile ensuring the costs are minimised. For example, aerator prices and running costs increase with size therefore obtaining one of the appropriate minimum size will result in lower overall costs.

Using Appendix B we can calculate the approximate cost of supplying aeration to 1 tonne of lobsters. First you must determine the size (wattage) of motor required to deliver the amount of air necessary for your given aeration demand. This will need to be discussed with an air pump supplier. When a unit cost of electricity is applied to the required wattage ratings for your motor, a cost per hour can be generated (see Example 2). Your local electricity supply company will be able to provide you with this unit cost.

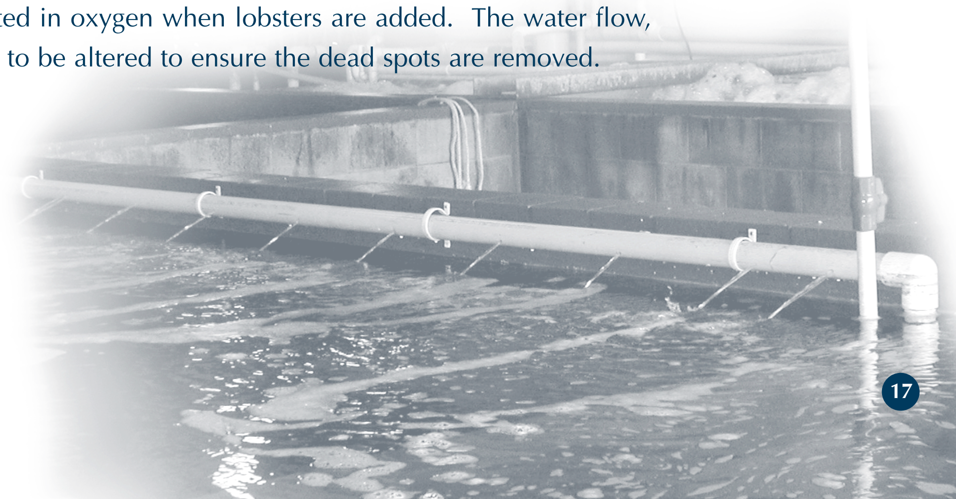
Example 2. Aeration running costs

If you are holding 1 tonne of stressed western rock lobsters at 23˚C, the approximate wattage requirement of a motor to run an appropriate air pump is 600 W. If a unit cost of $0.20 per kW h^{-1} is charged, then the cost to aerate your tank for an hour will be $0.12 (0.6 kW x $0.20).

4.3 WATER CIRCULATION

Although oxygenation is the most important function of aeration, water circulation caused by aeration is also beneficial. Good circulation ensures there are no dead spots in tanks, moves oxygenated water to the lobsters and helps maintain high oxygen transfer efficiencies.

The circulation of water (and oxygen) within a tank can be easily tested using a dye (e.g. food colouring). Before stocking, add the dye to the inlet water and observe its' dispersal through the tank. Any dead spots will not receive coloured water; these represent areas of the tank that may become depleted in oxygen when lobsters are added. The water flow, aeration or tank design will need to be altered to ensure the dead spots are removed.



4.4 AERATION EQUIPMENT

4.4.1 DEVICES FOR AIR TRANSFER

Aeration relies on the movement of air through water or water through air. This movement creates an air-water interface via which gases, including oxygen, can be transferred. Although there are many methods of aerating water there are only a few which are generally used in lobster live holding systems.

- **Diffusers:** These introduce bubbles from depth to achieve oxygen transfer and circulation. Diffusers can be made of porous bonded silica, carbon, ceramic polyethylene, or other porous material and can be found in a range of shapes and sizes. The most common ones in use in lobster holding facilities are air stones and leaky pipe tubing. It doesn't matter what types of diffusers are used, at some stage they will clog. Therefore, they need to be fitted in such a way that they are quick and simple to clean or replace.

- **Drilled air pipes:** These generally consist of PVC pipes running along the bottom of tanks with small holes drilled into them through which air is introduced. These are an inefficient method of transferring oxygen to water compared to a correctly designed and sized diffuser. This is mainly because the bubble size formed from the pipe is relatively large, even when very small holes are drilled in the pipe (see Section 4.4.2).

- **Spray bars:** These are one of the most commonly used methods. Water entering the tank is sprayed onto the surface of the tank water via a pipe with holes drilled into it. This forces air into the water, facilitating the transfer of oxygen. It is simple and appears to work reasonably well. However, in densely packed tanks there can be a lack of penetration of aerated water to lobsters at the bottom of the tank. Another problem is that they generally result in a very noisy working environment. Additionally, this method depends on the pump running and if the pump malfunctions then both water flow and aeration to the tanks are stopped.

- **Venturis:** A venturi aeration system on the outlet side of a pump can be an effective means of getting oxygen into water, especially in shallow water, where it causes little loss of pump pressure. At greater depths there may be significant loss of water pressure, making the use of a venturi system inefficient. As for the spray bar system, the venturi system depends on the pump running and if the pump malfunctions then both water flow and aeration to the tanks are stopped.

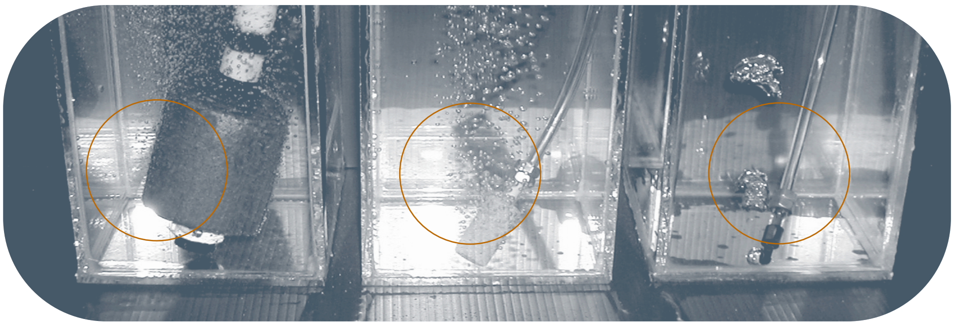
- **Gravity aerators:** These operate by allowing the water to run down over a physical substrate (eg. a column packed with plastic medium), thereby increasing the available air-water surface area[8]. This method of aeration is generally not applicable to boats.

4.4.2 BUBBLE SIZE

The bubble size created by diffusers and drilled pipes are a very important design consideration. Most deliver either coarse (approx. 6mm diameter), medium (approx. 3mm), or fine (approx. 1 mm) air bubbles. Bubble size directly relates to the ratio of volume to surface area of the bubble and the ability of the air contained within the bubble to come into contact with the water. The larger the bubble, the less likely the air in the middle of the bubble will come into contact with the water and be dissolved into the water.

Medium sized air bubbles are the best size bubbles to aim for. They require only slightly higher air pressure to generate than coarse bubbles, yet have a much higher oxygen transfer efficiency. In practice, more air can be released through coarse bubble diffusers. This aids water circulation, however this positive does not offset the negative of decreased oxygen transfer efficiency.

Fine-bubble diffusers have superior transfer efficiency, but have a much higher pressure requirement and tend to clog much more frequently. Fine bubble diffusers are typically used for pure oxygen or ozone systems where transfer efficiency is of greater importance.



4.4.3 TYPES OF AIR PUMPS

For application on board boats, low cost diaphragm air pumps are suitable. These have low maintenance requirements and are suitable where the water depth is not great (most tanks on board boats are around 1-2 metres in depth).

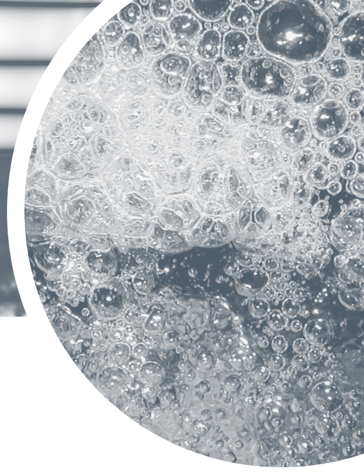
Depending on the size of a holding system there may be a need to use a regenerative blower to supply the aeration requirements. A blower provides large volumes of air at low pressure. The heat input from blowers into the water can be substantial and needs to be considered in systems where low water temperatures are to be maintained. It may be necessary to cool the air before it enters the holding tanks.

4.5 PURE OXYGEN AERATION

For applications that have very high oxygen demands or requirements for oxygen concentrations greater than 95% saturation, pure oxygen aeration systems should be considered[8]. The design and installation of pure oxygen aeration systems should to be discussed with an experienced person. The cost of pure oxygen aeration needs to be considered when examining the benefits. Although there may be some advantages in maintaining oxygen saturation levels close to or above 100% under certain conditions when holding live lobsters (e.g. during recovery of stressed lobsters[5]), the benefits are probably not sufficient to warrant the use of pure oxygen aeration. Correctly designed aeration systems using air should more than adequately meet most systems requirements.

Pure oxygen (in oxygen bottles) can be used as emergency aeration when the water and air pumps fail (e.g. mains power failure). The advantages of keeping a supply of oxygen on hand would depend on the type of system and the other backup equipment that is in place e.g. a generator could be used to provide power in the event of mains power failure. The ability of lobsters to survive extended periods out of water (under the right conditions) also limits the advantages of a pure oxygen backup.

RELATED ISSUES 5



5.1 TOTAL GAS SUPERSATURATION

Gas supersaturation occurs when water contains more than the "natural" amount of a particular gas or gases. The sum of all the gasses dissolved in the water is called the total dissolved gas pressure (TDGP) of the water; under normal conditions this is 100% and is equivalent to atmospheric pressure. Under some conditions however, TDGP can increase above 100%. This is calculated from the difference between atmospheric pressure and TDGP and is represented in terms of % Saturation or Δp (% Saturation = TGDP / atmospheric pressure x 100), (Δp = TDGP – atmospheric pressure). Δp is usually expressed in terms of mmHg.

Nitrogen and oxygen are the primary gasses in air. Nitrogen can cause health problems (gas bubble disease) at anything greater than 100% of its "natural" water concentration of around 79% of TDGP, whereas oxygen can be safe up to and over 200% of its "natural" water concentration of around 20% of TDGP. The main cause of supersaturation is air leakage on the intake side of water pumps. The air readily dissolves in the pressurised water. When the water leaves the pressurised pipe and enters the storage tank, it is suddenly back to normal atmospheric pressure. All the extra gas in the water is now in excess to the natural amount that the water should hold and the water becomes supersaturated. Nitrogen can only escape out of the water through the water surface and a reduction from 110% to 100% can take up to several hours.

A tank with supersaturated water can sometimes be detected by observing bubbles forming on tank surfaces and any items put in the water. Often however these signs are lacking as the saturation level is not high enough. Meters to measure excessive saturation levels (tensionometers or saturometers) are available, however, they are not common and thus may not be readily available. Although dissolved oxygen concentration is not a good measure of total gas supersaturation[8], it is useful as an indicator that supersaturation may be occurring. If an oxygen level of over 100% saturation is measured, and there is no pure oxygen being used anywhere in the system, then it is reasonable to assume that gas supersaturation is present. It is important to double-check the calibration of the oxygen meter if an oxygen level of over 100% saturation is measured.

Levels of concern for holding facilities either on shore or on board vessels for long term exposure would be over 103% nitrogen saturation (Δp = 25) or for short term exposure levels in excess of 105% (Δp = 40). These levels allow the dissolved nitrogen to exceed its "natural" level in water resulting in an imbalance with the physiology of the lobster that can eventually lead to gas bubble disease.

5.2 HEAVY METALS IN HOLDING SYSTEMS

Seawater contains a wide range of dissolved inorganic salts, in particular heavy metals, at levels that are generally not harmful to aquatic animals. However, in holding systems there is the opportunity for many of these to increase to harmful levels. This is especially so in recirculating systems through the use of inappropriate materials. Copper, iron, zinc and aluminium are metals that are most likely to reach high levels in holding systems, because of their use in chilling units, building materials (e.g. galvanised iron) and some pumps. The utmost care should be taken to remove or isolate all metals with the potential to contaminate water. High quality stainless steel and titanium are materials that can be used safely. Fibreglass, rendered concrete with an epoxy coating, plastics and PVC are usually the most suitable materials for pipe and tank construction. Even tanks made with those materials should be flushed several times prior to being used. Organometals such as tributyl tin (from antifouling paints) can also contribute to the heavy metal loads causing contamination of some waters, especially estuaries and harbours.

If mortalities occur in a system and no other obvious cause is found it may be worthwhile to have the water tested for heavy metals. However, very little is known of the concentrations of heavy metals that are harmful to lobsters. The table below shows the range of concentration of heavy metals normally found in seawater. It also shows the 95% trigger values at which remedial action must be taken. The 95% trigger value is a calculation based on available toxicity data of a number of marine species[2,9]. The value represents a probable point where 95% of species are protected. If your water contains any metals in these concentrations it is strongly recommended that an overhaul of the system be undertaken to identify possible causes of contamination.

The concentration of some metals in seawater and the concentration at which remedial action should be undertaken.

COMPOUND	NORMAL SEAWATER RANGE (μgL^{-1})	95% TRIGGER VALUES ($\mu g\ L^{-1}$)
Copper (Cu)	0.025 – 0.38	1.3
(Fe)	0.006 – 0.14	ID
Zinc (Zn)	0.022 – 0.10	15
Aluminium (Al)	0.0 – 0.7	ND
Lead (Pb)	0.006 – 0.03	4.4
Nickel (Ni)	0.13 – 0.5	70
Mercury (Hg)	0.0007 – 0.003	0.4
Chromium (Cr)	0.062 – 0.10	4.4 (CrVI)
Tributyl tin (TBT)	ND	0.006

ID = Insufficient Data, ND = No Data.

WATER SAMPLING EQUIPMENT 6

It is important that the water quality in holding systems can be measured. Therefore, the appropriate sampling equipment needs to be available. Sampling equipment can be expensive, but considering the risks they are a necessary outlay. Sampling equipment is varied but can be basically broken into two groups: a) test kits or b) meters. Each has their advantages and disadvantages.

a) Test kits are usually simple to use however, each test is usually less accurate than can be obtained with meters. Although they are generally relatively cheap compared to meters, they tend to be more expensive per sample. If a lot of testing were to be under taken it would probably be cheaper to buy a meter.

b) Meters on the other hand are generally more difficult to use, requiring some technical knowledge about their operation and maintenance. They also generally require a larger initial capital outlay. Most importantly, they require calibration on a regular basis to ensure that accurate results are obtained. Some meters allow more than one parameter to be tested at the same time e.g. oxygen, salinity, pH and temperature can all be performed using a single instrument.

6.1 OXYGEN

MONITOR WEEKLY OR IF SYSTEM CHANGES

Oxygen meters are an expensive capital outlay, varying from just under $1000 to many thousands of dollars for highly complex integrated systems. Oxygen test kits, which generally cost several hundred dollars and do around 100 tests, are also available.

The oxygen concentration in new systems should be checked regularly (every 2-3 h) for a few days to ensure that there is a good understanding of the normal oxygen concentrations (over a range of stocking densities). Provided appropriate stocking densities, flow rates and aeration are maintained the oxygen concentration should not vary greatly. Thus, it is probably only necessary to measure the oxygen concentration on a weekly basis. If there were changes to the system (e.g. temperature change, increased stocking density, pump or aeration problems) then regular checking the oxygen concentration is vital. Oxygen probes that provide a permanent display and alarm capability are available, and would be worthwhile considering in some systems.

6.2 TEMPERATURE

MONITOR CONTINUOUSLY

Temperature monitoring is relatively easy, and cheap, with many types of thermometers to choose from. It is up to individual preference as to whether to use a glass thermometer or a thermocouple with digital readout. Prices range from a few dollars to several hundred dollars. Potential contamination of lobsters from mercury and broken glass are an important consideration in the use of glass and mercury thermometers. A reasonably good quality digital thermometer should be able to be purchased for less than $50. A thermocouple thermometer placed in the tank with a permanent digital display that is clearly visible is the best option. Ideally the system should be set up so that an alarm is activated if the temperature moves outside the optimal set range.

6.3 pH

MONITOR WEEKLY OR IF SYSTEM CHANGES

pH is the measure of how acidic or alkaline a product is and is usually measured between 0 and 14. Seawater is always slightly alkaline with a pH between 7.8 and 8.4. As lobsters are marine animals, they require their holding water to be of the same pH range. To determine the level of pH in your holding system you can use a pH meter (most accurate method) or test strips (give a general estimate). pH meters range in cost from around $150 to several thousand dollars. Test kits can be purchased for around $20 to $100 and will generally do between 50 and 300 tests.

Flow through systems, either on land or on a vessel, generally do not need to monitor pH as it will remain constant with the seawater. Partial or full recirculation systems should test pH in conjunction with water hardness. If there are changes to the system (e.g. temperature change, increased stocking density, pump or aeration problems) then checking the affect on pH is vital. If you find that the pH of your holding system is below the normal parameters for seawater then you must take action to buffer the water (using calcium carbonate and/or sodium bi-carbonate) or make more regular water exchanges. CO_2 buildup causes a decrease in pH, therefore it is necessary to ensure the CO_2 is removed either by strong aeration, partial water change or via a device that creates a large air/water interface e.g. trickle filter.

6.4 SALINITY

MONITOR WEEKLY

The level of salt in seawater, salinity, can be measured with a refractometer, hydrometer or salinity meter. Seawater generally has a salinity of 33 to 35 g kg^{-1}. Levels as low as 28 g kg^{-1} or as high as 38 g kg^{-1} do occur and depend on rainfall, ocean currents, evaporation and many other factors. As seawater is heavier than fresh water, inlets for flow through systems should be located well below the water level. Salinity may need to be measured more often than weekly if flow through systems are subject to changes due to rainfall or currents.

A refractometer measures the degree to which the path of light is changed (refracted) as it passes through a thin layer of water. The amount of refraction is directly proportional to the amount of salt in the water, the more refraction the more saline the water. Refractometers can be purchased for around $200 to $300.

A hydrometer is used to determine the specific gravity (SG) of water and consists of a glass bulb with a weight at one end and a closed thin tube at the other. The greater the salinity the higher in the water the hydrometer will float. It is simply a matter of reading the salinity off the scale printed on the side of the tube (or converting the SG to g kg^{-1}). A reasonable quality hydrometer should not cost more than $50.

A salinity meter measures conductivity: the amount of electrical current that can be carried by seawater. The capacity of the water to conduct electricity is directly proportional to the level of salt in the water, the greater the current the more saline the water. Salinity or conductivity meters can be purchased for between $500 and $1000.

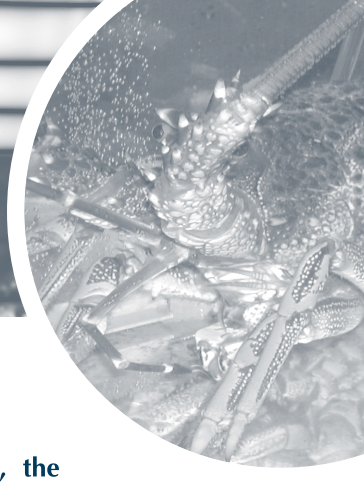
6.5 AMMONIA, NITRITE, NITRATE, ALKALINITY AND HARDNESS

MONITOR WEEKLY OR IF CONDITIONS CHANGE

There is a wide range of kits available on the market to test these parameters, the choice of which to use is up to individual preference. Most have simple to follow instructions and can be completed within a matter of minutes. Generally a water sample is treated with reagents to produce a colour, which is then compared against colour standards. They are usually available for under $50 and will perform between 25 and 200 tests.

Testing for ammonia, nitrite, nitrate, alkalinity and hardness is really only necessary for partial or full recirculation systems. However, it is good to know in a fully flow through system that the incoming water is of good quality or to check to ensure that flow is sufficient to prevent a build up of ammonia in the tanks.

SUMMARY 7



To ensure that live lobsters are maintained in prime condition after capture, the following key points summarise their requirements in terms of the provision of oxygen:

- Oxygen is generally the major water quality variable limiting the success of the live holding of lobsters.
- Oxygen levels should be maintained at or above 70% saturation (preferably >80%).
- Aeration should be a standard accessory in holding systems.
- It is important to ensure water (and thus oxygen) is distributed evenly to all parts of a holding tank (no dead spots).
- The maintenance of water temperature within an optimal range will increase the ease with which oxygen can be provided to the lobsters.

8.1 APPENDIX A – SALINITY AND OXYGEN SOLUBILITY

The effect of temperature and salinity on the solubility of oxygen in water (mg L^{-1}).

TEMPERATURE °C	SALINITY 30	SALINITY 35
10	9.32	9.03
11	9.12	8.83
12	8.92	8.65
13	8.73	8.47
14	8.55	8.29
15	8.38	8.13
16	8.21	7.97
17	8.05	7.81
18	7.90	7.66
19	7.75	7.52
20	7.60	7.38
21	7.46	7.25
22	7.33	7.12
23	7.20	6.99
24	7.07	6.87
25	6.95	6.75
26	6.83	6.64
27	6.72	6.53
28	6.61	6.42
29	6.50	6.32
30	6.39	6.22

8.2 APPENDIX B – OXYGEN CONSUMPTION AND PROVISION

The amount of oxygen consumed (g h^{-1}) (top number), and the associated water flow (L h^{-1}) (middle number) requirements and air flow (L h^{-1}) (bottom number) requirements of 1 tonne of western rock lobsters (*Panulirus cygnus*) at various combinations of temperature, body weight and activity. Calculations are based on the incoming water being fully oxygen saturated and the maintenance of 70% oxygen saturation in the outgoing water.

Note: The air flow requirements assume an absorption efficiency (percent of oxygen transferred from the air to the water) of 2%. The efficiency is variable, therefore, the air flow rates should be used as a guide only.

WESTERN ROCK LOBSTER

	TEMP. (°C)	400 g	800 g	1600 g	3200 g
UNSTRESSED LOBSTERS	11	9.5	8.4	7.4	6.5
		3598	3163	2781	2444
		1833	1611	1417	1245
	15	15.2	13.4	11.8	10.4
		6252	5495	4831	4246
		2932	2577	2266	1992
	19	24.4	21.4	18.8	16.6
		10811	9503	8354	7343
		4690	4123	3624	3186
	23	39.0	34.3	30.1	26.5
		18604	16354	14375	12637
		7502	6595	5797	5096
	27	62.4	54.9	48.2	42.4
		31854	28001	24614	21637
		12000	10549	9273	8151
	31	100.1	88.0	77.4	68.0
		54366	47790	42009	36928
		19258	16929	14881	13081
ACTIVE LOBSTERS	11	22.2	19.5	17.2	15.1
		8384	7370	6479	5695
		4271	3754	3301	2901
	15	45.7	40.2	35.3	31.1
		18755	16486	14492	12739
		8797	7733	6797	5975
	19	74.6	65.6	57.7	50.7
		33081	29080	25562	22470
		14352	12616	11090	9749
	23	129.9	114.2	100.4	88.2
		61951	54457	47870	42080
		24983	21961	19304	16970
	27	146.0	128.4	112.8	99.2
		74539	65523	57597	50630
		28081	24685	21699	19074
	31	146.0	128.4	112.8	99.2
		94053	82677	72676	63885
		33316	29287	25744	22630

The amount of oxygen consumed (g h^{-1}), and the associated water flow (L h^{-1}) and air flow (L h^{-1}) requirements of 1 tonne of 600 g southern rock lobsters (*Jasus edwardsii*) at various combinations of temperature and activity. Water flow calculations are based on the incoming water being fully oxygen saturated and the maintenance of 70% oxygen saturation in the outgoing water.

Note: The air flow requirements assume an absorption efficiency (percent of oxygen transferred from the air to the water) of 2%. The efficiency is variable, therefore, the air flow rates should be used as a guide only.

SOUTHERN ROCK LOBSTER

	TEMP. (°C)	OXYGEN CONSUMPTION (g h^{-1})	WATER FLOW REQUIRED (L h^{-1})	AIR FLOW REQUIRED (L h^{-1})
UNSTRESSED LOBSTERS	5	9.1	2985	1740
	9	16.0	5778	3075
	13	25.0	9839	4808
	17	37.1	15792	7127
	21	52.1	23908	10017
ACTIVE LOBSTERS	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

GLOSSARY

AERATION: The act of providing an air supply to water in order to increase the oxygen content of that water.

AMMONIA: Ammonia is the major end product of protein metabolism in most aquatic animals. Ammonia is toxic to lobsters and therefore must be prevented from building up in holding systems. Ammonia is present in two forms in water (ionised NH_4^+ and un-ionised NH_3), the higher the pH and temperature, the higher the percentage of the toxic fraction (un-ionised).

ALKALINITY: Alkalinity is basically a measure of the carbonate content of water. It gives a measure of the capacity of the water to accept acidity (i.e. it's buffering capacity). Alkalinity is usually measured as either mg L^{-1} (milligrams per litre) $CaCO_3$ (calcium carbonate) or meq (milli-equivalents). 1 meq = 50 mg/l $CaCO_3$.

BIOLOGICAL FILTER (BIOFILTER): A filter providing a large surface area on which denitrifying bacteria grow; used to remove waste (particularly ammonia and nitirite) from recirculating systems.

BIOMASS: Total weight (kilograms) of organisms in a system. Calculated as individual weight multiplied by total number.

EMERSION: Removal from water to a dry environment.

FLOW THROUGH: Single use water. Water enters a system, passes through the system and goes to waste.

IMMERSION: Submersing into water.

NITRATE: Formed as a result of the breakdown of ammonia to nitrite and then to nitrate by bacteria in biofilters. Generally not toxic at the levels found in recirculating systems. Chemical symbol NO_3.

NITRITE: Toxic chemical formed during the oxidation of ammonia to nitrate by bacteria in a biofilter. Most of the nitrite is converted to nitrate before the water exits the biofilter, therefore it is not generally found at toxic concentrations. Chemical symbol - NO_2.

OXYGENATION: The addition of pure or very high purity oxygen to water in order to increase the dissolved oxygen concentration of the water.

pH: A measure of acidity of a solution. It is in effect a measure of the amount of hydrogen ions. The normal pH of seawater ranges from 7.9-8.2.

RECIRCULATION: The process of taking water from a holding system which would otherwise be discarded from the system and reintroducing it to the same system. Prior to being reintroduced, the water is often treated to remove some of the wastes so that the water quality is maintained at a sufficient high level that it remains suitable for the culture animals. Recirculation systems can be operated as 100% recirculation (no new water added) or may have partial replacement water added.

SALINITY: The term used for the measurement of the total amount of dissolved salts in the water. Full strength seawater has salinity in the region of 34-36 g kg^{-1}.

SUPERSATURATION: The term given to a body of water which contains more than the normal amount of a particular gas or gases. The sum of all the gasses dissolved in the water is called the total gas pressure of the water; under normal conditions this is 100%. Supersaturated water can cause problems in aquatic animals (gas bubble disease) although nitrogen supersaturation is far more dangerous than oxygen supersaturation. Oxygen can be safe up to and over 200% saturation.

VENTURI EFFECT: The act of drawing air into a water system via a small tube or crack in a pipe. As the water passes through a restriction in a pipe, it forms a vacuum at the end of the restriction. A hole bored into the pipe at the point where this vacuum occurs will cause air to be drawn into the main flow. Although efficient at mixing chemicals and gasses into water, the operational costs of a venturi is high due to the cost of the increased pumping pressure required for the unit to operate. Venturis have their applications in some systems where there is more pressure available than is required by the rest of the system components.

WATER HARDNESS: The amount of cations (positively charged ions) of the earth metals (mainly calcium and magnesium) in the water. In most waters, the hardness is similar to that of alkalinity, as calcium and magnesium are usually bound to the main alkalinity bases (bicarbonate and carbonate). Alkalinity tends to be used more as a measurement than hardness.

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OPTIMISING WATER QUALITY

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