# ROAD TRANSPORT OF LIVE FISH


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## *Executive Summary*

The supply of fish live to markets is a 'value-adding' process, where the higher prices paid for live fish are dependent on fish arriving live at their destination. While this trade has been developing rapidly in Australia over the last few years, there have been technical and other difficulties in catching, holding and transporting fish for live markets. Many of these problems are associated with the inexperience of the operators concerned, and result from the fact that there is only a small experience base in Australia, particularly when compared with many overseas countries.

This report seeks to remedy the lack of information that is readily available on road transport of live fish. The information in this report was obtained from published sources and from conversations with commercial road transport operators in the US. The author visited commercial live fish transport operations in Arkansas, Texas and Louisiana. Road transport of live fish is a well established industry in the US and most of the techniques used are readily applicable to Australian conditions with minimal modifications.

The information in this report will enable operators to set up and run road transport operations for the live fish market. Some of the salient points discussed in the report are:

- matching truck size and design to specific needs
- use of insulated tanks
- transporting fish in dark or low light conditions
- design of tanks and loading systems to minimise fish handling
- provision of oxygen to compensate for oxygen consumed by respiration
- provision of water agitators to off-gas carbon dioxide
- use of liquid oxygen instead of gaseous oxygen
- provision of adequate amounts of oxygen during the loading procedure, when oxygen consumption is highest
- reduction of water temperature to reduce the metabolic rate of the fish during transport
- extensive pre-transport 'tempering' to adapt the fish to transport conditions
- effects of temperature and fish size on loading rates
- recommended loading rates for US finfish species.

Using the procedures and equipment described in this report, live fish transport operators in the US haul fish from the southern central US to markets on the east and west coasts, as far south as the Mexican border, and north into northern Canada. These trips can be up to 5 days in duration. Since the area covered by these operators exceeds the area of Australia, adoption of these procedures and equipment should enable successful road transport of live fish throughout Australia.

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## *Introduction*

As the live fish trade has developed in Australia, there have been several attempts to set up road transport operations hauling live finfish to city markets. These trucks travel as far north as Cairns in far northern Queensland, south to Tasmania, and west to South Australia to pick up fish. The fish are generally transported to wholesalers in Sydney and Melbourne.

The Fisheries Research and Development Corporation (FRDC) sponsored a Live Fish Transport Workshop which was held in Brisbane in May 1994. At this workshop, industry representatives commented that most domestic transport of live finfish would take place by road transport, rather than by air freight. Industry representatives also commented on the lack of design information which is readily available to them to construct and operate cost-efficient road transport units for live finfish.

In contrast to the Australian situation, road transport of live finfish is a well established industry in the United States of America. In early 1995, I visited the US to undertake collaborative research on production of finfish for stocking and aquaculture. The study tour was primarily funded by the Department of Industry, Science and Technology, and the Queensland Department of Primary Industries. However, the visit provided an ideal opportunity to investigate techniques used for road transport of live finfish in the US, for application in Australia. Consequently, FRDC agreed to fund a proportion of the trip costs to permit the examination of road transport techniques in use in the US, as part of the research into the development of live fish transport techniques (FRDC projects 93/184 and 93/185). This report is a synthesis of published information, unpublished data, and conversations with road transport operators from commercial and government organisations in various parts of the US. All published information used in this report is cited in the text, and a list of those persons who contributed information is included in the acknowledgments section (p. 28).

## *Stress in Fish*

Like other aspects of transporting fish live to market (Rimmer *et al.* 1994), successful road transport of fish requires the reduction of stress in the fish to the greatest possible extent. Stress in fish manifests itself as a series of complex physical and physiological changes that affect the fish's health. Failure to reduce stress in fish during transport will result in decreased survival and increased incidence of disease. Obviously, these factors will adversely affect the cost effectiveness of the road transport operation.

Stress can be reduced by:

- placing fish in dark tanks
- providing optimal conditions of water quality, particularly with regard to the provision of oxygen, removal of carbon dioxide, and control of pH
- minimising the handling of fish.

Many aspects of the design and operation of live fish transport systems listed in this report are discussed in relation to reducing stress in the transported fish as much as possible. A check list of the items discussed in the report is included as Appendix 1.



**Figure 1** Smaller live fish transport trucks used to carry fish to local markets.



**Figure 2** Large live fish transport trucks used to transport fish to interstate markets in the continental US and in Canada.

### *Trucks for Live Fish Transport*

Trucks used for live fish transport range from small 1-tonne capacity utility type trucks up to large articulated units. Smaller trucks are used to carry smaller loads over shorter distances, such as baitfish to local bait store markets that may be up to several hours away by road (Figure 1). Smaller, more manoeuvrable trucks are also used to transport harvested fish from the pond to processing plants or to holding tanks where the fish are held for several days before they are transported to market.

Larger trucks (large non-articulated and articulated units) are used to transport larger loads over longer distances (Figure 2). These trucks may undertake trips of several days duration, such as from the southern US north as far as northern Canada. Operators of articulated trucks pointed out that these units are generally not suitable for use around ponds on fish farms, and that a non-articulated truck should be used if direct access to ponds is required.

One operator expressed dissatisfaction with one truck that had an aluminium tray, noting that the stress of driving the truck over irregular surfaces around the fish farm had caused bending of the tray and fracturing of the tray supports. He suggested that steel/wood trays are more suitable, being more resistant to bending, although more maintenance is needed because of the use of salt or brackish water in transporting live fish.

Care should be taken in locating the tanks on the tray of non-articulated trucks. Most operators have used trial and error to find the best tank location. Tanks located too far forward will result in dramatically increased tyre wear, while tanks located too far aft will cause loss of steering authority.

A storage area between the cab and the tanks is useful for storing equipment such as plastic bins and buckets, pumps, hoses, etc. If such items are stored aft of the tanks, it is usually impossible to see if any items come loose or fall off.

### *Tank Design and Construction*

Tanks used for live fish transport in the US are generally rectangular in shape. Some years ago there was a trend towards using tanks that were elliptical in cross section because these tanks supposedly promoted better circulation of water within the tank and eliminated 'dead water' areas in the corners of rectangular tanks (McCraren and Millard 1978, Piper *et al.* 1982, Carmichael and Tomasso 1988). However, several operators commented that they had found no difference between elliptical and rectangular tanks, or in some cases, that elliptical tanks performed more poorly than rectangular tanks. Rectangular tanks are easier and cheaper to construct and are more space efficient. Consequently, elliptical tanks are now not generally used for transporting live fish.


**Figure 3** Live fish transport truck with equipment storage area behind cab.

The main features of tanks used for transporting live fish (Figure 4) are:

- insulated walls, floor and lid
- internal floor sloping to a central drain
- gate valves fitted internally, and 'Kamlock' or screw fittings externally on drains
- large lids allowing easy access to the tank

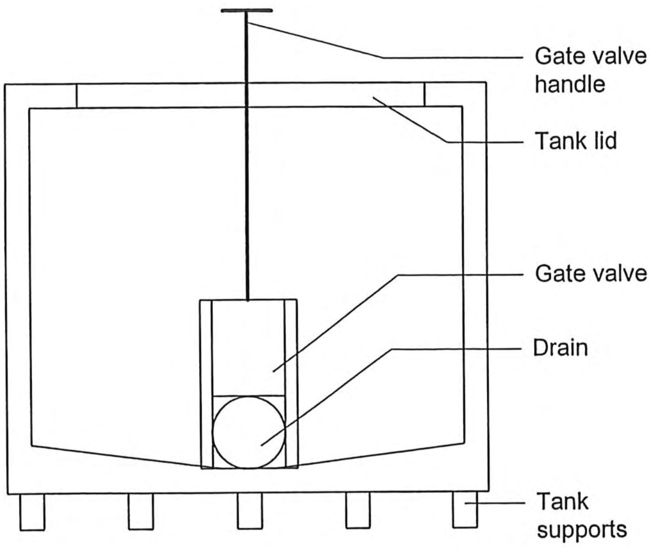



**Figure 4** Diagram showing the major features of live fish transport tank design, including insulated walls, floor sloping to central drain, and location of gate valve for unloading fish.

Tanks can be constructed from fibreglass, aluminium or stainless steel and generally incorporate insulation in the design (McCraren and Millard 1978, Piper *et al.* 1982, Carmichael and Tomasso 1988). Tanks used for salt water should be made from fibreglass, not from metal of any type. Most tanks now in use in the US are constructed from plywood and polyurethane insulation, which is then covered in fibreglass. An example of such construction, as used by a commercial tank manufacturer, is shown in Figure 5. Note the thick layer of insulation and the layer of Coremat® which increases the laminate thickness without adding as much extra weight as would result from a solid fibreglass laminate. One commercial operator who uses aluminium tanks for transporting freshwater fish commented that fish did not transport as well in aluminium tanks as they did in fibreglass tanks, but other operators expressed satisfaction with the performance of aluminium tanks. Food grade ('iso') gelcoat should be used to finish the inside surface of fibreglass tanks. An example of a set of specifications for the construction of fish transportation tanks is included as Appendix 2.

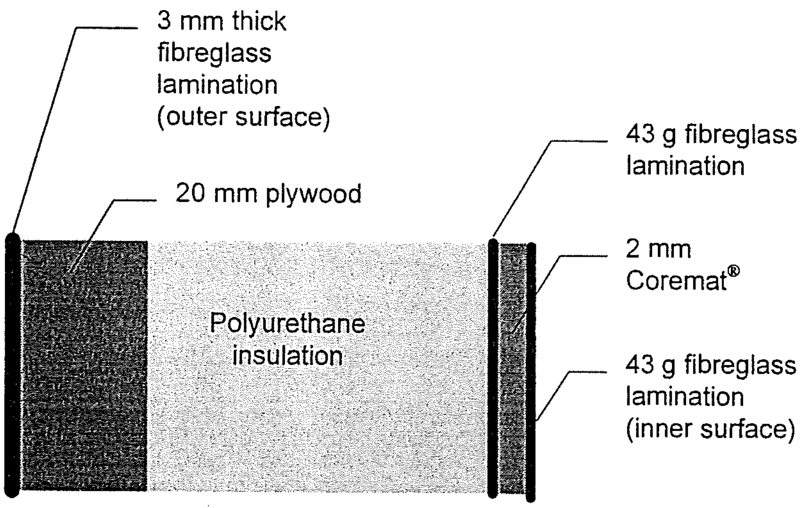
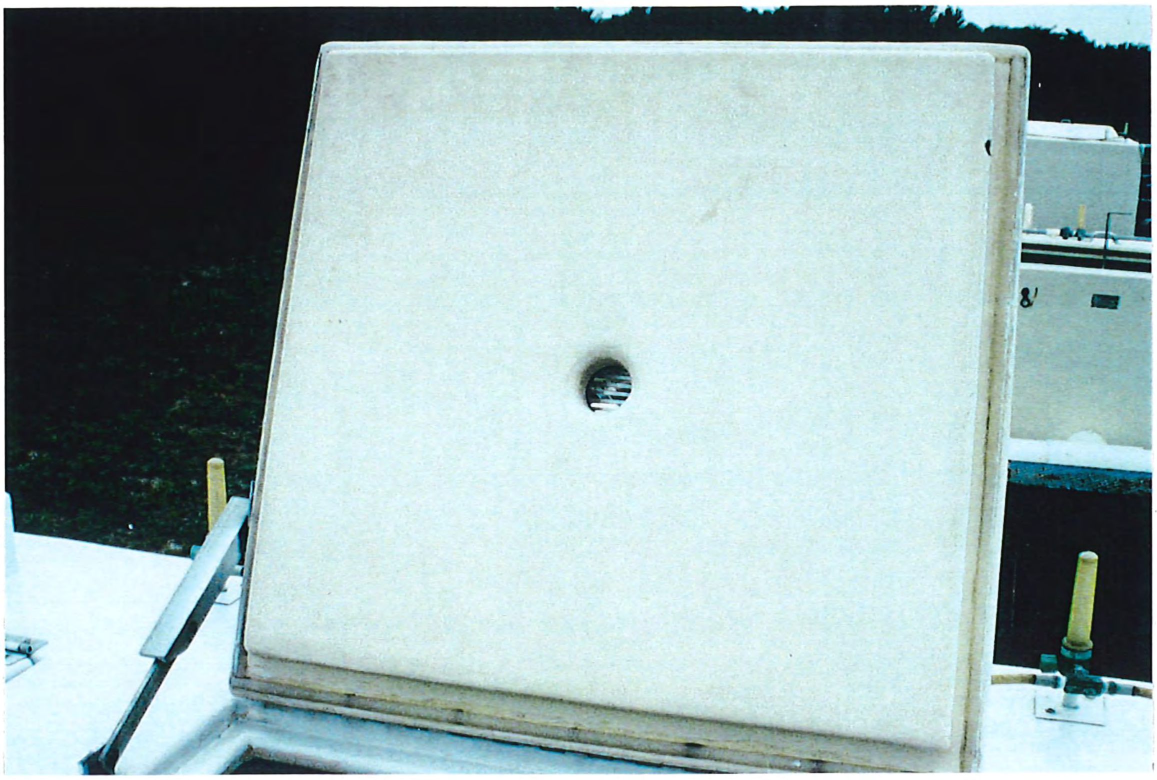



**Figure 5** Details of wall construction of live fish transport tanks made by Peterson Fibreglass Laminates Inc., Shell Lake, Wisconsin, USA. (Not to scale).

Tanks should be constructed with lids that allow easy access to load fish, but that seal firmly to prevent loss of water during transport (Figure 6). Leakage of water from live transport tanks onto passing vehicles is a major cause of complaint for operators in the US. A popular latch for live fish transport tanks in the US is the 'De-Sta-Co' latch (Figure 6).



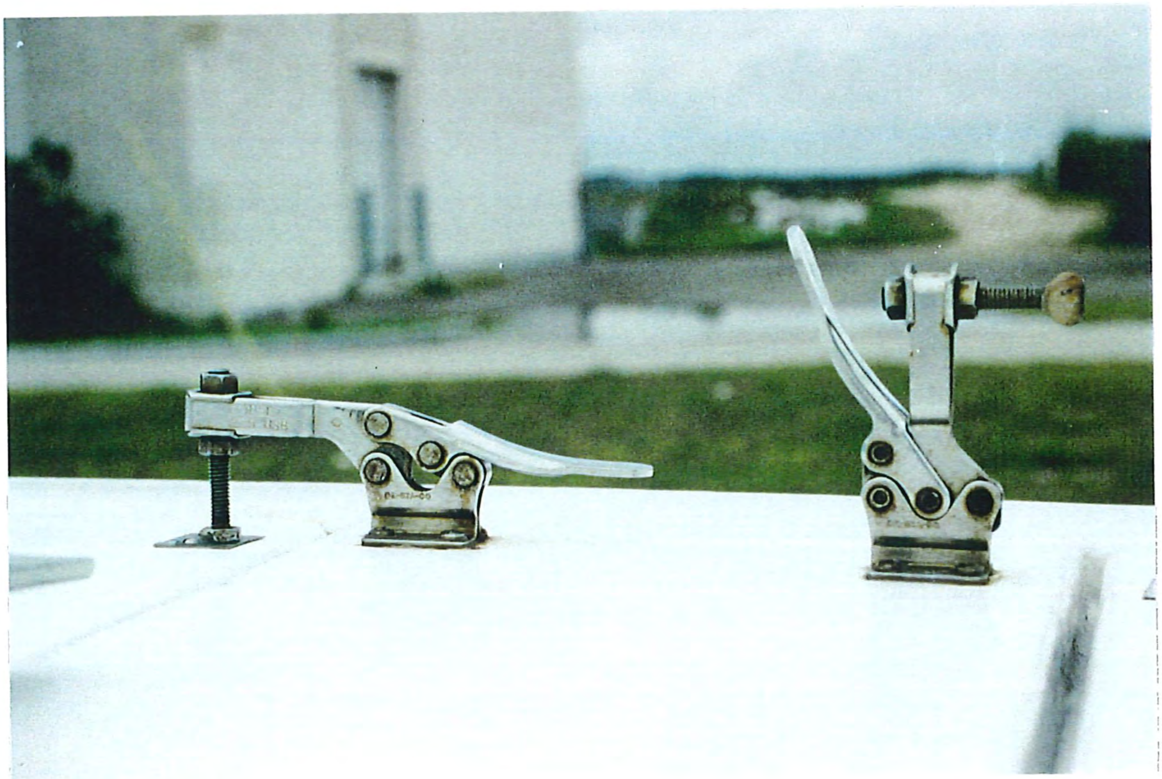


**Figure 6** (Above) lid of live fish transport tank, showing vent for gas exchange and locking prop. (Below) 'De-Sta-Co' latches in latched (left) and unlatched (right) positions.

Tanks should also be fitted with a gate valve to facilitate unloading the fish (Figure 7). This will allow unloading of the fish straight into holding tanks using PVC piping, without netting or otherwise handling the fish. Holding system design for live fish facilities is discussed in detail in de Guingand *et al.* (1995*a*). The gate valve(s) should be large enough to admit the largest fish that will be carried. Because gate valves may leak, particularly with wear, a secondary seal should be placed on the outside of the drain (Figure 8). 'Kamlock' or screw fittings are suitable for this purpose, provided that they fully seal the drain.

Surging (the 'sloshing' movement of the water within the tank) can be reduced by filling the tank completely with water, and by subdividing large tanks into smaller units. Surging may damage fish, by hitting them against the tank walls, and may decrease the driver's control of the truck. Surging is also reported to increase the rate of wear of the truck's clutch plates. Provision of baffles in large tanks, or subdivision of large tanks into smaller sections, will assist in reducing problems associated with surging (Piper *et al.* 1982). Most commercial operators in the US use a number of separate tanks on a single truck. This allows fish of different sizes or different species to be carried, or fish to be off-loaded at different sites. For example, Farm Cat Inc. (Arkansas) uses up to 12 individual tanks on a truck. Alternatively, tanks can be constructed with separate compartments incorporated into the tank design.

Tank sizes for food fish species are generally 1 - 1.5 $m^3$ (1,000 - 1,500 litres). Smaller tanks are used for baitfish.

**Figure 7** Inside view of live fish transport tank showing gate valve, drain trough, and oxygen diffusers constructed from rubber soaker hose.

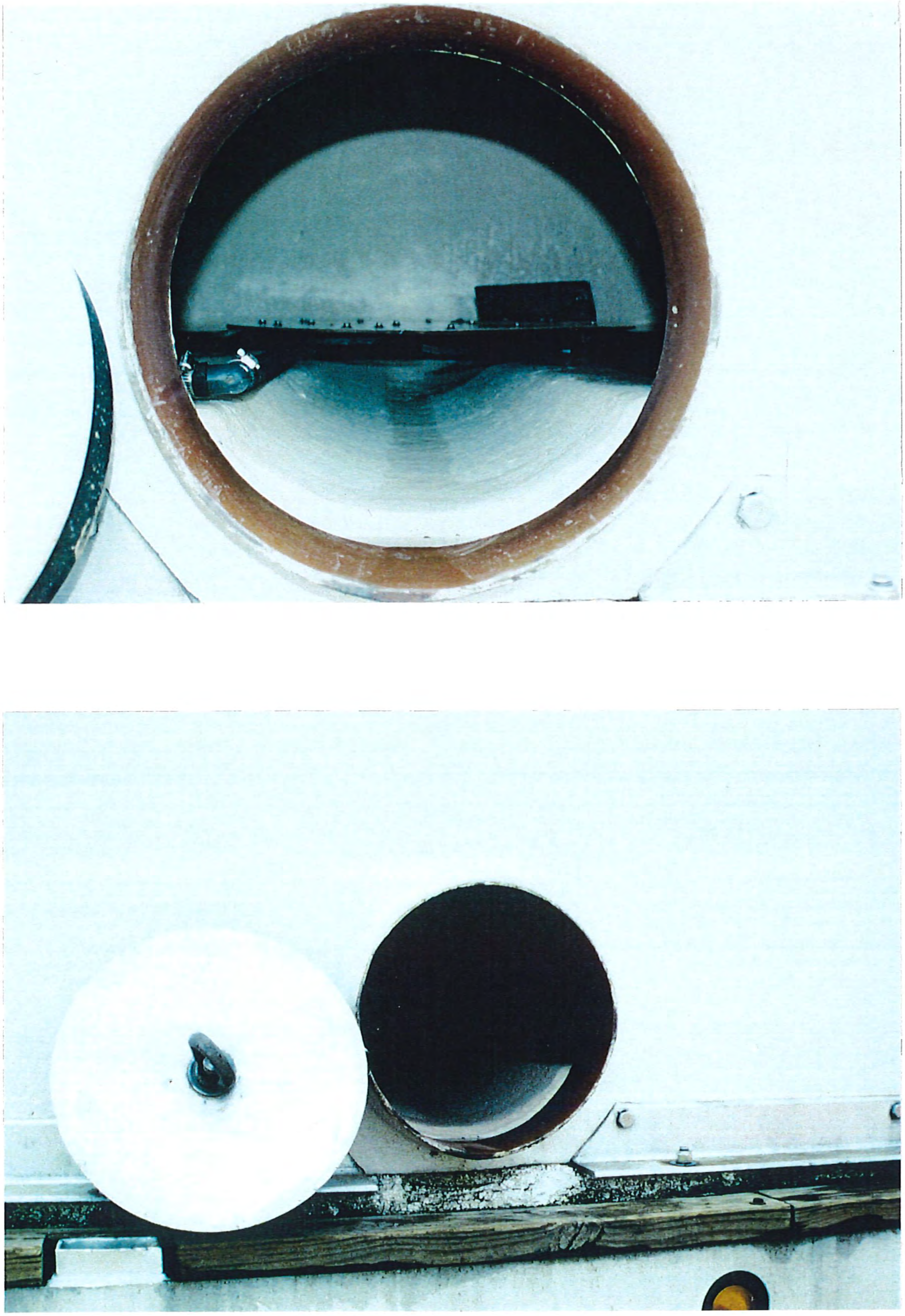


**Figure 8** (Above) View inside live fish transport tank, with gate valve removed, from drain. (Below) External view of tank drain with external plug removed.

Most live fish transport operators do not completely fill their transport tanks, but leave an airspace at the top of the tank. While this causes surge problems during transport, it may also assist in off-gassing excess gases, including carbon dioxide. Most tanks are constructed with a vent in the lid to allow gas exchange with the atmosphere. Operators that did not provide vents to allow gas exchange had problems transporting more sensitive fish species, such as salmonids. These problems were alleviated once vents were fitted to the transport tanks.

Transport tanks should be heavily insulated to allow control of water temperature. Texas Parks and Wildlife Department (TPWD) specify 1½ inch (38 mm) thick closed-cell slab polyurethane foam (c. 16 kg density per cubic metre), for the tank walls, and 4 inch (100 mm) thick foam for the tank floor (Appendix 2). The tanks should be elevated above the truck bed to allow the space between the truck bed and the tank to dry. This will reduce corrosion problems, and reduce water seepage into the tank floor in the event that the exterior fibreglass laminate is damaged.

**Farm Cat Inc.: a successful US live fish transport operation**

Farm Cat Inc. is a family owned and operated company that specialises in producing food fish (catfish, hybrid striped bass, largemouth bass) and baitfish, and in transporting fish live to markets throughout the US. Farm Cat has a fleet of 9 trucks, including several semi-trailer units. These trucks transport not only Farm Cat's aquacultured products, but are also contracted by other fish producers to transport live fish. From the company's home base in Lonoke, near Little Rock, Arkansas, Farm Cat's trucks transport fish to the east and west coasts of the US, and as far north as northern Canada. This entails trips of up to 5 days duration.

Fibreglass tanks should be constructed using coloured resin to exclude light from the tank when it is sealed. Transparent or translucent tanks should not be used because the high light levels in such tanks will substantially increase stress levels in the transported fish. Dark coloured tanks generally reduce stress in fish, but lighter colours make it easier to observe the fish in the tank. However, this is only relevant when the tank lid is open, allowing light to penetrate. For fish transport tanks, generally a mid-range blue or green colour is a suitable compromise. Many tanks in commercial use are white, and operators report no problems using such light coloured tanks.

### *Preparation Prior to Transport*

Commercial live fish operators list pre-transport preparation of fish as being critical to the success of each trip. In their experience, fish that are prepared properly for transport will travel much better, and arrive in better condition, than those not prepared for transport. The main procedures involved in preparation are starvation prior to loading, and tempering.

Starvation prior to transport is undertaken to allow emptying of the gastro-intestinal tract which decreases the rate of ammonia excretion during transport (Froese 1985, 1988, Piper *et al.* 1982). Unlike mammals, fish can live without food, and remain healthy, for relatively long periods of time (days or weeks). Because the time to empty the gut is related to body weight, large fish must be starved for longer than smaller fish prior to transport (Froese 1985, 1988). Froese (1985) recommends starving fish ≤3 g for 2 days and fish > 3 g for 3 days prior to transport.

Tempering is also an important part of pre-transport procedures. Fish should not be subjected to rapid changes in water quality, but should be gradually acclimated to different water conditions. Fish should be loaded into the transport tanks filled with water as similar as possible to the water from which they were removed. Once in the transport tanks, the water can be slowly changed to the conditions desired for transport, eg. reducing temperature or adding salt.

## *Water Quality*

Maintaining good water quality is of critical importance in the successful transport of live fish. Poor water quality will cause stress, which will increase the chances of the fish contracting disease, and severe water quality degradation can result in substantial or total mortality. For these reasons, an understanding of water quality and how various parameters affect fish is important in the successful operation of a live fish transport business.

### *Temperature*

Generally, fish are unable to regulate their own body temperature, so the temperature of the surrounding water directly affects their metabolic rate. The metabolic rate of fish is higher at higher temperatures, and thus as temperature increases they will use more oxygen, and produce more carbon dioxide and ammonia than at lower temperatures. Most live fish transport operations use temperature control to lower the metabolic rate of the fish during transport. Most commercial operators use ice to control temperature. Prior to leaving the loading area, blocks of ice are added to lower the temperature to the desired level (usually 20-25°C). For longer trips, additional ice is carried in insulated containers and is added to the transport tanks as necessary to maintain the desired temperature. Some larger fish transport units are fitted with integrated refrigerative cooling units (McCraren and Millard 1978) (Figure 9).

Care should be taken when using ice to lower the temperature of the transport water. Commercially available ice may be made from treated water and may contain substantial amounts of chlorine, which is lethal to fish. The addition of even moderate amounts of freshwater ice to a transport tank may drastically change the salinity of the water, causing additional stress for the fish.

If cooling units are used, any material in contact with the transport water should be inert, eg. plastic or titanium. Stainless steel may also be suitable for cooling units, although personal experience with stainless steel in cooling units exposed to sea water has been that its life is limited to only a few months.


**Figure 9** (Above) Refrigerative cooling system fitted to live fish transport truck. (Below) Cooling coils of refrigerative system in live fish transport tank. Note cloud of fine bubbles from oxygen diffuser. White tube at left is an agitator, with black plastic mesh screen fitted to protect small fish from agitator turbulence.

*Salinity*

The salinity of freshwater is 0 ppt and the salinity of full seawater is about 36 ppt. Fish should be transported at about the same salinity that they normally inhabit. However, freshwater fish should be transported in water to which about 5-10 grams of salt has been added for each litre of water (equivalent to 5-10 ppt). The addition of small amounts of salt to freshwater helps reduce stress, probably by reducing the osmotic load on freshwater fish (McCraren and Millard 1978). Similarly, a slight reduction in the salinity of sea water for the transport of salt water (to 32-33 ppt) species may be beneficial. Euryhaline species, such as farmed barramundi, should be transported at about the salinity at which they were grown.

Salinity is most easily measured using a salinity meter. Small portable salinity meters are readily available and are reliable if treated properly. Hydrometers are not accurate enough for use in live fish transport applications.

*Oxygen*

Fish use oxygen in the water for respiration. Consequently, oxygen must be provided constantly to fish during transport to make up for the loss of oxygen due to respiration. At high fish densities and without supplemental oxygen, fish may last only minutes before all the oxygen in the water is used and fish begin dying.

Dissolved oxygen (the concentration of oxygen dissolved in the water) is measured using a dissolved oxygen meter. These meters can be expensive, but are essential for any operation involved in road transport of live fish. Most meters measure both the actual concentration of oxygen in the water (in ppm or mg/l) and the relative amount of oxygen in the water (percent saturation). Some live fish transport units are fitted with dissolved oxygen sensors in each tank, and a readout unit in the cab to enable dissolved oxygen levels to be monitored at all times.

Saturation is a measure of the maximum amount of oxygen that water will hold under certain conditions. Oxygen saturation is a function of temperature, salinity and pressure (altitude) (Boyd 1990). Oxygen solubility decreases with increasing temperature, increasing salinity (Figure 10) and increasing altitude. (Oxygen saturation values for water at various combinations of temperature and salinity are listed in Appendix 3). Aeration of water (ie. by pumping air through water) will provide dissolved oxygen concentrations up to the saturation value for that temperature and salinity, but no higher. Pumping oxygen through water will allow supersaturation, ie. dissolved oxygen concentrations in excess of the saturation value. Supersaturation may be detrimental to some fish species. In general, the dissolved oxygen level should be kept as closely as possible to 100% saturation. Dissolved oxygen should not drop below 50% saturation, nor should it exceed 150% saturation. Commercial fish transport operators recommend that dissolved oxygen levels in the tanks be maintained at 8 - 11 mg/l.

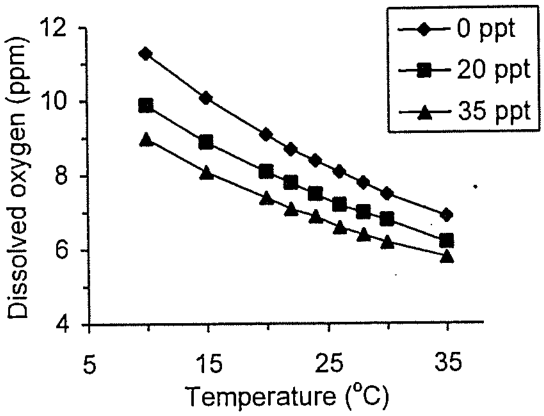



**Figure 10** Saturation values of dissolved oxygen in water at 3 different salinities (0, 20 and 35 ppt) and a range of temperatures (Boyd 1990).

An adequate level of dissolved oxygen in transport tanks is maintained by pumping oxygen into the transport water. Provision of adequate amounts of oxygen is particularly important in transporting fish long distances. Fish that have been captured and loaded into transport tanks are severely stressed. One manifestation of this stress is that their metabolic rate increases, and this causes dramatically increased oxygen consumption.

Aeration alone, using centrifugal air blowers, is generally not used in road transport of live fish. Aeration will not cope with the high oxygen demand of fish transported at high density; only the provision of oxygen will enable adequate dissolved oxygen levels to be maintained. Another disadvantage to using aeration is that the heat developed by the blowers increases water temperature significantly, leading to an increased metabolic rate of the transported fish, and consequent increases in oxygen usage and carbon dioxide production. In addition, the high volumes of air required result in severe turbulence in the tanks which may cause physical damage to the fish.

Small-scale fish transporters, such as those used to transport broodfish or fingerlings for restocking, use bottled oxygen (Figure 1). These transporters are used over relatively short distances, up to 12 hours from their base of operations. Larger transporters, which may be away from base for several days or even weeks, use liquid oxygen (Figure 13). Liquid oxygen has several advantages over bottled oxygen:

- liquid oxygen is more dense and thus takes up less space on the truck
- liquid oxygen is cold and its provision to tanks assists in lowering the temperature of the transport water
- liquid oxygen is cheaper than an equivalent amount of bottled oxygen gas.

Most large fish transport operations have a large storage container of liquid oxygen at their base, which is used to fill the tanks on the trucks as required (Figure 13). The storage container is in turn filled by the local supplier, usually once per week. Operators suggest that liquid oxygen tanks on the trucks should be topped up after each trip, rather than being left until almost empty before being refilled. On at least one occasion, the latter approach has resulted in the loss of a load of fish when the tank wasn't refilled and oxygen ran out during the trip. Like other liquefied gases, liquid oxygen will vaporise at ambient temperatures. Unlike bottled oxygen gas, unused containers of liquid oxygen will eventually empty as the oxygen vaporises into the atmosphere. One operator estimated the loss of liquid oxygen in this manner at about 2% per day.

For bottled oxygen, industrial grade oxygen, rather than the more expensive medical grade, is adequate for fish transportation. The flow of oxygen is regulated using commercially available flow regulators, but a more accurate and reliable medical flow gauge should also be fitted (Figure 14). This allows finer control of the oxygen flow rate than the standard regulator, thus preventing wastage of oxygen which can result in premature exhaustion of the oxygen supply. Typically, live fish transport tanks are fitted with one or more liquid oxygen cylinders. Oxygen from this tank is piped to the fish tanks, each of which is fitted with an individual flow gauge to allow fine control of the oxygen supply to that tank (Figure 14). If individual diffusers are fitted, a flow control should be fitted to each diffuser, because individual diffusers differ substantially in porosity and thus require individual adjustment.

Many live fish transport units have the main oxygen supply line running down the length of the tank, and terminating in a pressure gauge that is located near the rear window so that the driver can monitor oxygen pressure by checking the gauge in the rear view mirror. More sophisticated units have a pressure sensor and alarm fitted to the oxygen supply, and dissolved oxygen sensors in each tank with a display unit located in the cab of the truck (Figure 15).

Oxygen concentration in transport tanks should be relatively high before the fish are placed in the tank. For the first ½ hour to 1 hour after loading, the fish will use

*The effect of bubble size on oxygen diffusion*

A volume of small oxygen bubbles has a larger surface area than an equivalent volume of larger bubbles, and thus will transfer oxygen to water more efficiently. For example, a 1 mm diameter bubble has a surface area of 3 $mm^2$ and a volume of 0.5 $mm^3$ of oxygen. A 3 mm bubble has a surface area of 28 $mm^2$ and a volume of 14 $mm^3$. Twenty eight 1 mm diameter bubbles contain as much oxygen as one 3 mm bubble, but have a surface area of 88 $mm^2$, which is 3 times the surface area of the 3 mm bubble. The larger surface area of the smaller bubbles means that potentially 3 times as much oxygen can be added to the water using 1 mm diameter bubbles than with the equivalent volume of 3 mm diameter bubbles.

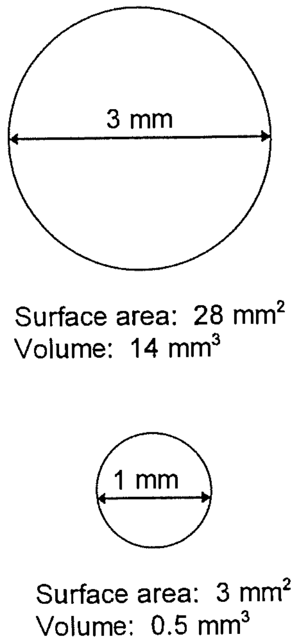



**Figure 11** Surface area and volume for 1 and 3 mm diameter oxygen bubbles.

substantially more oxygen than they will during the rest of the journey (Johnson 1979). This dramatic increase in oxygen consumption usually results in a drop in oxygen concentration in the transport tank immediately after loading (Figure 12). If this higher rate of oxygen consumption is not taken into account, and the oxygen flow increased to compensate, this drop in oxygen concentration may prove lethal to the fish (Johnson 1979).

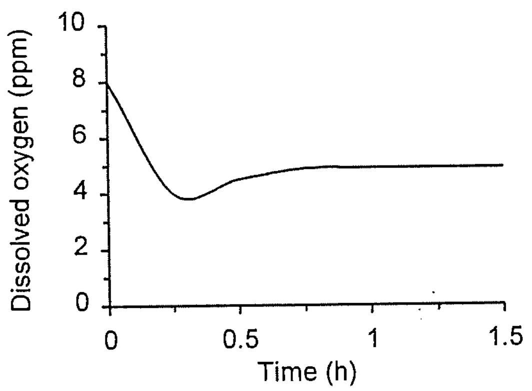



**Figure 12** Dissolved oxygen concentration in transport tank after loading fish (Johnson 1979).

### *Carbon dioxide*

Some live fish transport units incorporate agitators (usually 12V units) in the transport tanks to blow off carbon dioxide which is produced as a product of respiration (Piper *et al.* 1982, Carmichael and Tomasso 1988). Carbon dioxide is toxic at high concentrations, and at low concentrations will substantially reduce the pH of the transport water (McCraren and Millard 1978). Low pH contributes to fish stress and will reduce the ability of the fish to take up oxygen, even when dissolved oxygen levels are high (McCraren and Millard 1978). Consequently, the removal of carbon dioxide is an important component of reducing the stress of fish transported live. Agitators also help to off-gas excess oxygen, thus precluding any problems that may result from extremely high dissolved oxygen levels (supersaturation). When agitators are used (Figure 14), some operators use them constantly, while others switch them on intermittently, eg. for 10 minutes every hour. It is important that the transport tanks are vented to the outside atmosphere to allow gas exchange with the atmosphere (Piper *et al.* 1982, Carmichael and Tomasso 1988).

Many commercial live fish transport operators do not use agitators. Because most tanks are not filled completely, some off-gassing of carbon dioxide may occur in these tanks as the water surges and is splashed around inside the tank. However, some destinations reported receiving fish in relatively poor condition due to high carbon dioxide levels in tanks that were not fitted with mechanical agitators or vents.

Agitators may exhaust or physically damage small fish and fingerlings because of the high water velocities they produce in the tank. To better control the amount of water movement provided by agitators, rheostats can be used to vary the speed of individual agitators. Alternatively, the agitators can be operated intermittently rather than constantly to avoid exhausting the fish. Because of the use of salt even when transporting freshwater fish, operators recommend using agitators designed for use in saltwater.

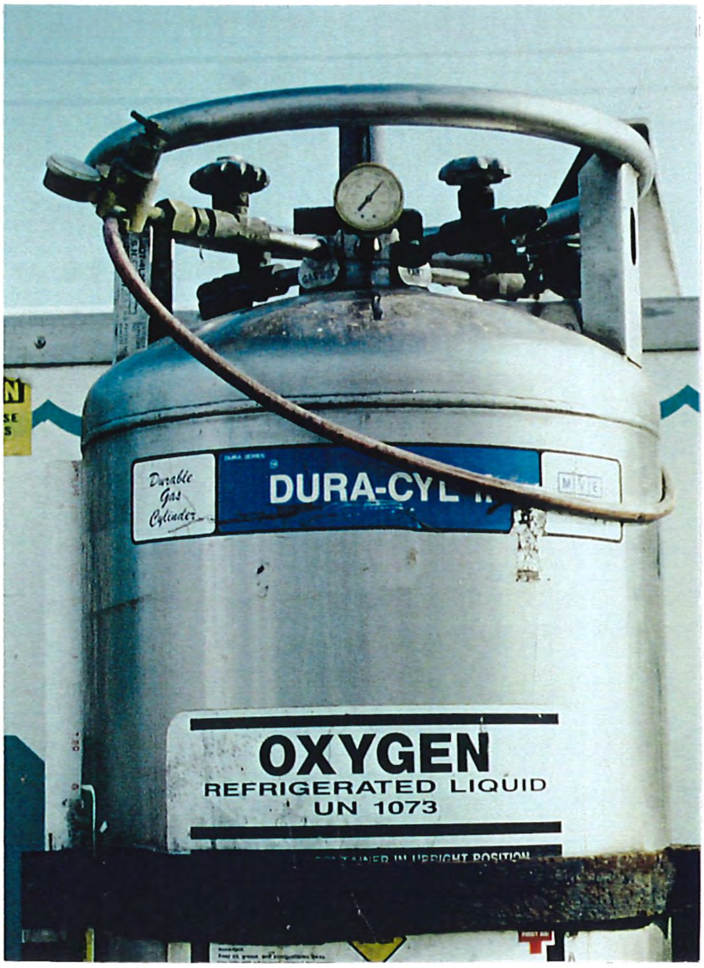




**Figure 13** (Above) Liquid oxygen tank fitted to live fish transport truck. (Below) Liquid oxygen storage tank.

**Figure 14** (Above) Controls for live fish transport tank, including: individual flow controls for each air diffuser, oxygen supply system pressure gauge, individual switches for agitators. Note agitator held in place with 'De-Sta-Co' latches, plugged into waterproof 12V power supply. (Below) Oxygen supply system pressure gauge, located to be visible in driver's rear view mirror.

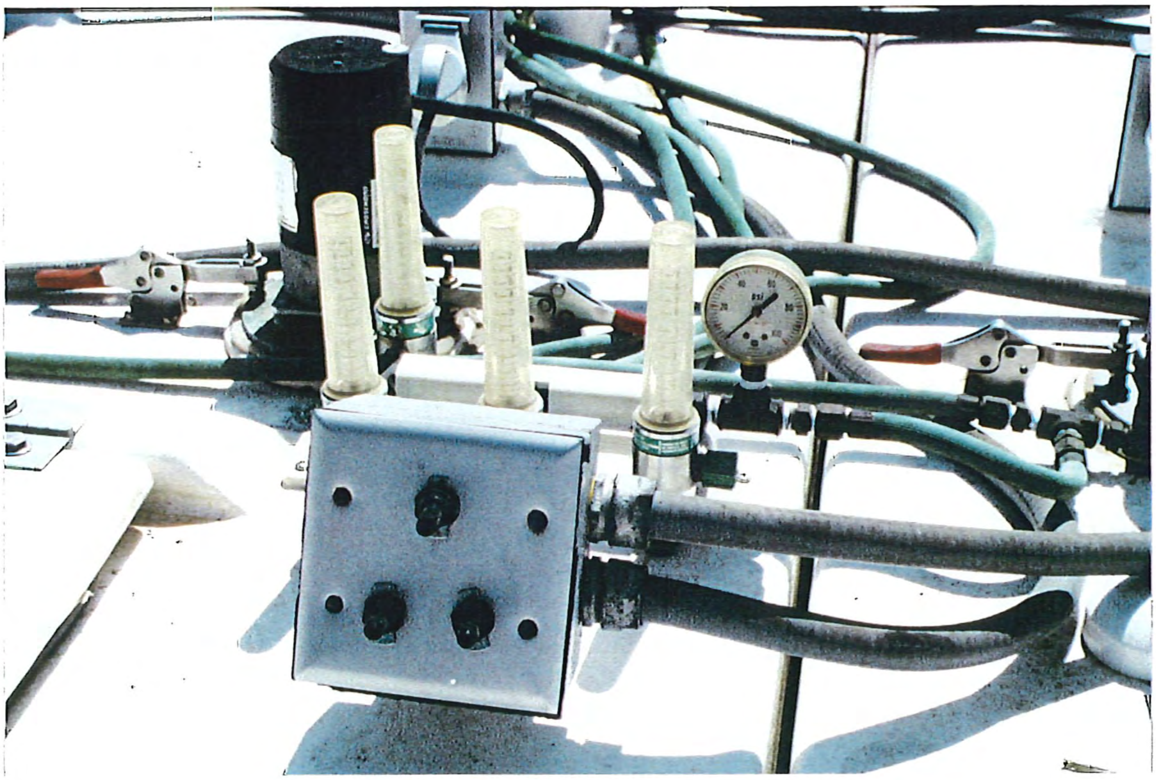


**Figure 15** (Above) Cab of live fish transport truck showing display unit for dissolved oxygen sensors fitted to tanks, and low oxygen pressure alarm. (Below) Live fish transport tanks showing oxygen supply system and individual flow controls for each diffuser, agitators (3 per tank) and switches.

### *pH*

pH is a measure of the acidity or alkalinity of water. A neutral pH is 7.0; lower pH values indicate acid conditions and higher pH values indicate alkaline conditions.

The pH of salt water is usually about 8.0 and the pH of freshwater is about 7.0. Because of the large buffering capacity of salt water, pH in salt or brackish water generally varies less than in freshwater. pH may drop dramatically in fish transport tanks, if carbon dioxide is allowed to accumulate in the water. Low pH causes a range of physiological problems in fish, but primarily affects the fishes' ability to utilise oxygen for respiration. Thus at low pH and high carbon dioxide concentrations, fish may suffer severe respiratory stress even though dissolved oxygen levels are high.

The use of agitators to remove carbon dioxide, and the provision of vents in the tanks to allow excess gases to escape to the atmosphere, will prevent drastic changes in the pH of the transport water.

### *Ammonia*

Ammonia is the main nitrogenous compound excreted by fish and will accumulate during transport. Ammonia has two forms, unionised ammonia ($NH_3$) which is toxic to fish and ionised ammonia ($NH_4^+$) which is effectively non-toxic. The relative proportions of each form depend primarily on water temperature and pH. The higher the pH and temperature, the more ammonia will be present in the toxic $NH_3$ form (Boyd 1990). Most test kits measure total ammonia, ie. the combined total of $NH_3$ and $NH_4^+$. The proportion of $NH_3$ must then be derived from published tables of ammonia dissociation (Appendix 4) to determine the concentration of the toxic form in the water.

Ammonia is transformed to nitrite and nitrate during the process of nitrification which is undertaken by bacteria under aerobic conditions (Spotte 1970), as occurs in biological filters (de Guingand *et al.* 1995*b*). Nitrite is toxic to fish at very high concentrations, but nitrate is effectively not toxic. None of these nitrogenous products is of particular concern during fish transport. High levels of ammonia will adversely affect fish health and growth, but only over a period of time longer than that typically used for fish transport.

Biological filtration is not used in road transport applications, because of the difficulty of properly maintaining biological filters under these conditions. Biological filters must be maintained with a constant load of ammonia in order for them to function efficiently (de Guingand *et al.* 1995*b*), and such maintenance is usually incompatible with their use in road transport applications. In addition, the production of ammonia is rarely the limiting factor in transport of fish, so its removal is usually not cost-effective.

A more practical technique for reducing ammonia accumulation during transport is to starve the fish for several days prior to transport (see 'Starvation prior to transport' discussion). In addition, partial water changes during the transport period will lower ammonia and help alleviate other adverse water quality parameters.

*Measuring Water Quality Parameters*

Different water quality parameters are measured using different devices. Dissolved oxygen, salinity and pH are measured using specialised meters. Several companies make multi-purpose meters that allow the operator to measure several variables with one instrument. Such multi-parameter meters are easier to handle than several individual meters, and often provide a cost saving over the purchase of separate meters. The main disadvantage of multi-parameter meters is that, should the meter break down, the operator is left with no means of testing any water quality parameters.

For road transport of live fish, the following test equipment is recommended:

1. A good quality dissolved oxygen (DO) meter.
2. A pH meter or colourimetric test kit.
3. A colourimetric test kit for carbon dioxide ($CO_2$).
4. A colourimetric test kit for ammonia ($NH_3$ / $NH_4^+$) or ammonia-nitrogen ($NH_3$-N / $NH_4^+$-N).
5. A salinity meter.

All water quality meters should be maintained according to the manufacturers instructions. Dissolved oxygen meters are particularly sensitive and require regular maintenance, including frequent replacement of probe membranes, if they are to remain accurate. All probes should be rinsed with fresh water and stored carefully after each use. pH, carbon dioxide, ammonia, nitrite, and nitrate can be tested with acceptable accuracy using colourimetric test kits designed for aquarium use. The reagents in these kits have a limited life span and should be regularly replaced if they are not used up.

Some test kits measure ammonia, nitrite, and nitrate ($NH_3$, $NO_2$, and $NO_3$) as the nitrogen equivalent forms ($NH_3$-N, $NO_2$-N, and $NO_3$-N). This measurement can be converted to the standard form using the following relationships:

1 mg/l $NH_3$-N = 1.2 mg/l $NH_3$

1 mg/l $NO_2$-N = 3.3 mg/l $NO_2$

1 mg/l $NO_3$-N = 4.4 mg/l $NO_3$

The Austasia Aquaculture Trade Directory (see 'Further Information' section) provides a list of manufacturers and suppliers of water quality testing equipment.

## Anaesthetics and Chemical Additives

There are currently no chemicals registered for use on food fish in Australia. Technically, this means that no chemicals, including anaesthetics and antibiotics, can be used on fish destined for human consumption. The National Registration Authority (NRA) has produced a preliminary list of chemicals and probable restrictions that will be applied once the registration process is completed. Under this protocol, the use of many chemicals, including anaesthetics, will involve extensive with-holding periods following treatment. This will make the use of such chemicals impractical for use in transporting fish live.

Buffers will most likely not have such restrictive procedures associated with their use. Buffers, as the name suggest, reduce pH fluctuation by buffering the water. A buffer commonly used for fish transport is 'tris' buffer (tris-hydroxymethyl-amino-methane). 'Tris' is available in a range of pH values for use on freshwater and marine fish. Levels of 1.3-2.6 g/l are recommended for fish transport applications (McCraren and Millard 1978). However, 'tris' buffer is expensive and because of this, is not generally used in road transport of live fish.

As noted in the discussion on salinity, above, the addition of salt is widely used for transporting freshwater fish.

Antifoaming agents are generally not used. One operator noted that adding antifoaming agents to the transport tanks led to an immediate and drastic decrease in dissolved oxygen levels, often by as much as 50%.

### *Loading Density*

Precise loading densities for every road transport system are difficult to derive, due to the substantial differences between different operations. In addition, the carrying capacity of a particular unit will depend on the efficiency of the aeration system, duration of transport, water temperature, fish size, and fish species (Piper *et al.* 1982). Most of the published information that is available is limited to food fish and bait fish species that are transported in the US, and this is of limited application to transporting Australian fish species. The most commonly transported warmwater foodfish in the US are catfish and tilapia, neither of which is a good model for Australian fish species because of the extreme hardiness and tolerance to adverse water quality of both catfish and tilapia.

There are several important factors that must be considered when considering loading densities.

- Per unit weight, fewer small fish can be carried than large fish (Table 1, Table 2). Smaller fish consume more oxygen, respire more carbon dioxide, and excrete more ammonia than an equivalent weight of larger fish (Piper *et al.* 1982, Froese 1985). For example, catfish with an average weight of 455 g can be transported at 0.76 kg of fish per litre of water (for 8 hours at 18°C), but catfish with an average weight of 114 g can be transported at only 0.60 kg per litre, and 0.9 g fingerlings can be transported at only 0.21 kg per litre (McCraren and Millard 1978).
- Longer transport requires reduced loading density (Table 1). Again using catfish as an example, fish with an average weight of 455 g can be transported at a density of 0.76 kg of fish per litre of water for 8 hours, but when the transport duration is increased to 12 hours density is reduced to 0.67 kg per litre, and is further reduced to 0.58 kg per litre for 16 hours of transport (McCraren and Millard 1978).
- Temperature also affects loading density. Decreasing water temperature will reduce fish metabolism, decreasing the rate of oxygen consumption and the rate of carbon dioxide excretion, and also reducing the rate of ammonia accumulation. As a general rule, for each 1°C decrease in temperature, the load can be increased by about 10% (Piper *et al.* 1982). Obviously, some knowledge of the temperature limits of the species being transported is required to ensure that the temperature remains above the minimal thermal tolerance for that species.

US operators routinely transport catfish at water:fish ratios of around 1:1 (750 kg of fish in a 1500 litre tank).

For Australian operators, a good strategy is to start at much lower densities than those listed here (for example, about ¼ of these densities) and increase the density gradually as the operators become more experienced. It is doubtful that any Australian fish species can be transported at the extremely high densities at which catfish and tilapia are transported in the US.

**Table 1** Stocking rate (kilograms of fish per litre of transport water) for catfish transported at 18°C for 8 - 16 hours (McCraren and Millard 1978).

| Average weight of fish (g) | Transit period (hours) | | |
|---|---|---|---|
| | 8 | 12 | 16 |
| 455 | 0.76 | 0.67 | 0.58 |
| 228 | 0.71 | 0.58 | 0.41 |
| 114 | 0.60 | 0.49 | 0.35 |
| 9.1 | 0.41 | 0.30 | 0.25 |
| 3.6 | 0.35 | 0.26 | 0.22 |
| 1.8 | 0.26 | 0.21 | 0.18 |
| 0.9 | 0.21 | 0.20 | 0.15 |
| 0.5 | 0.15 | 0.12 | 0.08 |
| 0.05 | 0.02 | 0.02 | 0.02 |

**Table 2** Stocking rate (kilograms of fish per litre of transport water) for live northern pike and walleye transported for 8 hours at 13-18°C (Piper *et al.* 1982).

| Fish weight (g) | Size (mm) | Stocking rate (kg/l) |
|---|---|---|
| 7.6 | 76 | 0.16 |
| 0.9 | 51 | 0.08 |
| 0.5 | 25 | 0.07 |

### *Acclimation*

Sudden changes in water quality, particularly temperature, salinity, and pH, may stress fish. Consequently, care should be taken to ensure that variations in water quality are minimised when fish are transferred from one tank to another. Minimal handling will reduce fish stress, and one innovative loading system is illustrated in Figure 16.

After transport, fish should be acclimated slowly to conditions in their new environment because physicochemical conditions in the transport medium and in the receiving environment may differ substantially. New water should be added to the transport containers in small amounts over a period of about 30 minutes, until the final volume exceeds the initial quantity by 2-3 times (Froese 1985). Only when this acclimation is complete should the fish be introduced to their new holding tanks.

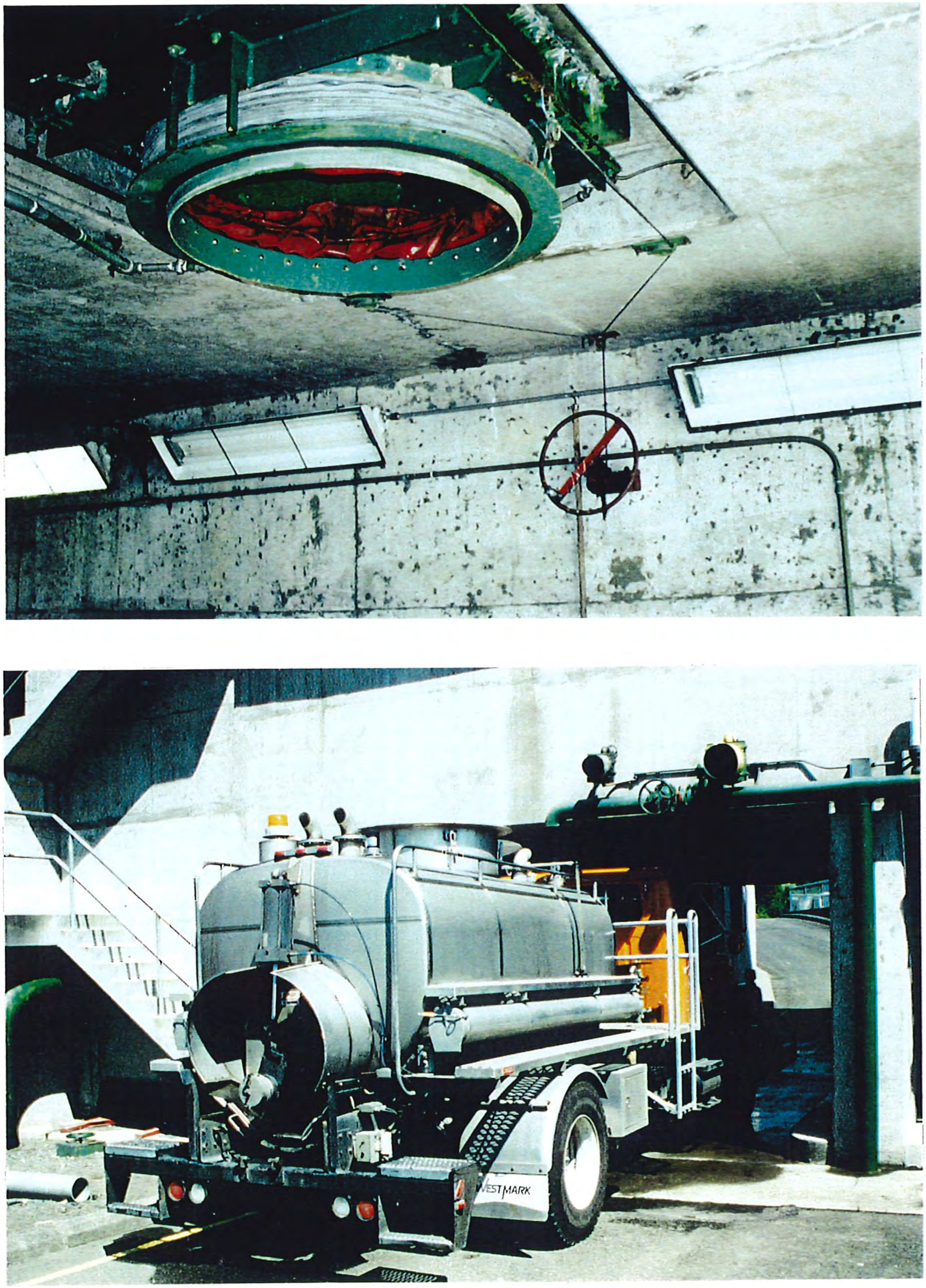


**Figure 16** Handling free loading system in use at Kalama State Fish Hatchery, Washington. Fish are loaded from an overhead tank via a flexible coupling (above) that connects to a hatch on the top of the transport tank (below). When the valves on the truck tank are opened, the water and fish in the overhead tank drain into the truck tank.

### *Further Information*

Much of the equipment required for live fish transport is similar to that used for aquaculture, and can be obtained from suppliers involved in the aquaculture industry. A good source of information on aquaculture suppliers is 'Austasia Aquaculture', a bimonthly magazine that covers aquaculture in Australia, New Zealand and Asia. The publisher of this magazine also produces an annual Aquaculture Trade Directory which is a useful reference for aquaculture equipment and services, including many items of relevance to live fish transport. For further details, contact Austasia Aquaculture Magazine, PO Box 279, Sandy Bay, Tasmania 7005.

The author of this report has several equipment catalogs from US suppliers. For further details, contact Mike Rimmer at Northern Fisheries Centre, PO Box 5396 Cairns, Queensland, 4870; phone: (070) 529809, fax: (070) 351401, e-mail: rimmerm@dpi.qld.gov.au

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## Glossary

*Aeration*

The application of air (*not* oxygen; see 'oxygenation') to water to increase the concentration of dissolved oxygen in the water by diffusion. Air generally contains about 21% oxygen; water contains much less, so oxygen diffuses from the air to the water.

*Aerobic*

In the presence of oxygen; requiring oxygen. The opposite is anaerobic.

*Buffering*

Various compounds in water, particularly carbonate and bicarbonate ions, reduce pH fluctuation. This process is termed buffering.

*Euryhaline*

Able to tolerate a wide range of salinities, eg. barramundi.

*Nitrification*

The process of conversion of ammonia to nitrite and then to nitrate, undertaken by bacteria under aerobic conditions.

*Osmosis*

The movement of water across a membrane to a solution of stronger osmotic pressure. Fish must maintain a consistent internal osmotic pressure by actively pumping salts or water from their body tissues.

*Oxygenation*

The application of oxygen to increase the dissolved oxygen content of water. Unlike aeration, oxygenation may increase the levels of dissolved oxygen in water to greater than saturation values.

*pH*

pH is a measure of the acidity or alkalinity of a solution. Technically, pH is the negative logarithm of the concentration of hydrogen ions in the solution. The pH scale ranges from 0 (most acidic) to 14 (most alkaline); a neutral pH is 7.0.

*ppm*

Parts per million. Equivalent to milligrams (thousandths of a gram) per litre.

*ppt*

Parts per thousand. Equivalent to grams per litre.

*Respiration*

Respiration is a biochemical process carried out by all living organisms which uses oxygen and produces carbon dioxide. To compensate for these processes, oxygen must be added to and carbon dioxide removed from live fish transport tanks.

*Saturation*

For any given set of conditions (temperature, pressure, etc.) water will hold only a certain amount of any gas in solution. When the amount of gas in solution reaches its maximal value for those conditions, the solution is saturated with the gas. A solution may be forced to take up even more of the gas, in which case it is termed 'supersaturated'. In the live fish transport field, the concepts of saturation and supersaturation are usually related to oxygen.

*Supersaturation* (See 'saturation').

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## *Appendix 1 Check list for road transport operations*

*Truck*

- Suitable for purpose, particularly re. pond access
- Tank location on truck
- Storage area for pumps, hoses, buckets, etc.
- Provision of liquid oxygen, or bottled oxygen (short trips only)
- Driver visible oxygen pressure gauge

*Tanks*

- Fibreglass tanks, rectangular in shape
- Tanks insulated to control temperature
- Closed tank excludes all light
- Easy tank access to add or remove fish
- Wide drains and gate valves
- Tank sealed to prevent water loss or surging
- Tanks vented to allow off-gassing
- Agitators to assist with off-gassing
- Flow control gauges for oxygen diffusers
- Rheostats or switches for intermittent use of agitators
- Ice or cooling system for temperature control

*Other*

- Starve fish prior to transport
- Dissolved oxygen (DO) meter
- Test kits for pH, carbon dioxide ($CO_2$), ammonia ($NH_3$ / $NH_4^+$)

## *Appendix 2 - Texas Parks and Wildlife Department specifications for fish transportation tanks*

The following is a copy of the Texas Parks and Wildlife Department tender document that details the construction of the tanks used by that department for live fish transport. Tanks used for live fish transport throughout the US are basically similar in construction to these tanks, although details differ, as described in the main section of this report.

### CUSTOM MADE FIBREGLASS FISH TRANSPORTATION TANK:

Dimensions: 11' long x 4' wide x 40" tall with 3 separate compartments.

Wall construction: framing to be Douglas fir or spruce, clean/kiln -dried with 10% or less moisture content, no less than 2 x 2 interior and 2 x 4 corner braces, exterior covered with ¾" A/C exterior grade Douglas fir plywood or marine grade, 1½" closed-cell slab Polyurethane foam (two-pound density per cubic foot) inside to be glued to interior side of ¾ inch plywood, R value not less than 11, floor 4" thick foam, bottom rails 2" x 4" running full length of tank closed on ends with additional 2" x 4" lumber spaced on 12" centers, all core material to be glued and screwed together, fibreglass lamination polyester resins non-toxic (food grade) to aquatic life, exterior surface 1/8" thick on walls and ¼" at corners, interior walls composite laminate with alternate layers of 2 oz. fibreglass (Owen Corning or equal) along with 2mm Cormat, adhesive used shall be nontoxic and waterproof. White colored resin on outside and light blue colored blue resin on inside to be free of any lead or cadmium products, all surfaces to be completely encased in fibreglass lamination. Fibreglass laminate shall be finished to a washable smooth finish. Floor of each compartment to be sloped to discharge drain.

Door and hatch features: Not less than 36" x 30" doors to be flush mounted in deck of tank, constructed and insulated with same materials as walls, 2 holddown per hatch to be 'De-Sta-Co' stainless steel toggle clamps, mod. 225-USS (500 pound capacity) or equal, 2 per hatch aluminium jack-knife safety lid supports, 3" 'Perko' stainless steel polished locker ventilators in center of each hatch, 6" chrome handles, continuous 3" open aluminium hinges with ¼" diameter stainless steel pin, ½" diameter half-round extruded silicon rubber door gaskets.

Tank holddowns: 3" x 3" x ¼" structural aluminium angle iron holddown bolted to ends of tank's support rail framework with ½" stainless steel bolts.

Drains: Each compartment to have 6" diameter schedule 80 PVC threaded side drains screwed and laminated to tank exterior over a previously fibreglasssed hole equipped with 'Kamlock' 633A aluminium adaptor and 'Kamlock' 634-B aluminium caps. Each drain to have a polyurethane, stainless steel or aluminium internal water-tight slide-gate assembly with inside compartment pull rod. Drains to be located in back corner of each compartment. Overflow drains in each compartment at 28" water level to be 2" diameter 'Snap-Tite' marine drain plug screened on inside with PVC perforated disc having ¼" holes, each compartment to have 2" bleeder valve 6" from bottom of tank equipped with PVC gate valve and screened on inside with PVC perforated disc having ¼" holes.

Agitator porthole: Each compartment to have on 4.75" diameter porthole equipped with two 'De-Sta-Co' holddowns.

The construction of the tank shall result in a solid composite of all materials. All pipes, conduits, etc. passing through walls, floors, decks, and bottoms of tank shall be watertight. All ports hall be fibreglassed to prevent leakage into walls, floors, and tops of tank.

Electrical hook-up: Wiring to be routed through PVC conduit embedded within deck of tank, weatherproof junction box positioned on front end of tank and outlet boxes in close proximity to agitator porthole, all electrical items used to be weatherproof and designed especially for outdoor use.

Oxygenation: To include plastic piping (Schedule 80 PC) from front of tank to a 'Smith' oxygen dispersion material at each compartment, from flowmeter to inside of each compartment a 5/16" dia. O.D. LDPE flexible tubing (2 feet long) to include oxygen diffuser in each compartment.

Tanks to have a minimum limited 5 year warranty on materials and workmanship. Tank will be replaced at bidder expense due to de-lamination or leakage to interior walls or outside of tank (repairs will not be acceptable).

## *Appendix 3 - Saturation values for dissolved oxygen*

Solubility of oxygen (mg/l) in water over a range of temperatures at different salinites. DO values are 100% saturation in water exposed to water-saturated air at sea level (Merrick and Lambert 1991).

| Temp. | Salinity in parts per thousand | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| 0 | 14.6 | 14.1 | 13.6 | 13.2 | 12.7 | 12.3 | 11.9 | 11.5 | 11.1 | 10.7 |
| 5 | 12.8 | 12.3 | 11.9 | 11.6 | 11.2 | 10.8 | 10.5 | 10.1 | 9.8 | 9.5 |
| 10 | 11.3 | 10.9 | 10.6 | 10.3 | 9.9 | 9.6 | 9.3 | 9.0 | 8.8 | 8.5 |
| 15 | 10.1 | 9.8 | 9.5 | 9.2 | 8.9 | 8.6 | 8.4 | 8.1 | 7.9 | 7.6 |
| 20 | 9.1 | 8.8 | 8.6 | 8.3 | 8.1 | 7.8 | 7.6 | 7.4 | 7.2 | 7.0 |
| 25 | 8.2 | 8.0 | 7.8 | 7.6 | 7.4 | 7.2 | 7.0 | 6.8 | 6.6 | 6.4 |
| 30 | 7.5 | 7.3 | 7.1 | 6.9 | 6.8 | 6.6 | 6.4 | 6.2 | 6.1 | 5.9 |
| 35 | 6.9 | 6.8 | 6.6 | 6.4 | 6.2 | 6.1 | 5.9 | 5.8 | 5.6 | 5.5 |
| 40 | 6.4 | 6.3 | 6.1 | 5.9 | 5.8 | 5.6 | 5.5 | 5.4 | 5.2 | 5.1 |

## *Appendix 4 - Proportion of unionised ($NH_3$) ammonia*

Percentage of total ammonia ($NH_3$ + $NH_4^+$) present as un-ionised ammonia ($NH_3$) in aqueous solution at different pH values and termperatures (Boyd 1990).

| | Temperature ($^oC$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| pH | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| 7.0 | 0.3 | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 |
| 7.2 | 0.5 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.1 | 1.3 | 1.5 |
| 7.4 | 0.7 | 0.9 | 1.0 | 1.1 | 1.3 | 1.5 | 1.7 | 2.0 | 2.4 |
| 7.6 | 1.2 | 1.4 | 1.6 | 1.8 | 2.1 | 2.4 | 2.7 | 3.1 | 3.7 |
| 7.8 | 1.8 | 2.1 | 2.5 | 2.8 | 3.2 | 3.7 | 4.2 | 4.9 | 5.7 |
| 8.0 | 2.9 | 3.3 | 3.8 | 4.4 | 5.0 | 5.7 | 6.6 | 7.5 | 8.8 |
| 8.2 | 4.5 | 5.2 | 5.9 | 6.8 | 7.7 | 8.8 | 10.0 | 11.4 | 13.2 |
| 8.4 | 6.9 | 7.9 | 9.1 | 10.3 | 11.7 | 13.2 | 15.0 | 17.0 | 19.5 |
| 8.6 | 10.6 | 12.0 | 13.7 | 15.4 | 17.3 | 19.4 | 21.8 | 24.5 | 27.7 |
| 8.8 | 15.8 | 17.8 | 20.1 | 22.4 | 24.9 | 27.6 | 30.7 | 33.9 | 37.8 |
| 9.0 | 22.9 | 25.6 | 28.5 | 31.4 | 34.4 | 37.7 | 41.2 | 44.8 | 49.0 |
| 9.2 | 32.0 | 35.3 | 38.7 | 42.0 | 45.4 | 49.0 | 52.7 | 56.3 | 60.4 |
| 9.4 | 42.7 | 46.3 | 50.0 | 53.5 | 56.9 | 60.3 | 63.8 | 67.1 | 70.7 |
| 9.6 | 54.1 | 57.8 | 61.3 | 64.5 | 67.6 | 70.7 | 73.6 | 76.4 | 79.3 |
| 9.8 | 65.2 | 68.4 | 71.5 | 74.3 | 76.8 | 79.3 | 81.6 | 83.7 | 85.9 |
| 10.0 | 74.8 | 77.5 | 79.9 | 82.1 | 84.0 | 85.8 | 87.5 | 89.1 | 90.6 |
| 10.2 | 82.5 | 84.5 | 86.3 | 87.9 | 89.3 | 90.6 | 91.8 | 92.8 | 93.8 |