DEVELOPMENT OF A STOCK PROTECTION SYSTEM FOR FLEXIBLE OCEANIC PENS CONTAINING FINFISH

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TASMANIAN SALMONID GROWERS

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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APPENDICES

LEGEND

ADDs	Acoustic Deterrent Devices
AMC	Australian Maritime College
AS	Australian Standard
DPIWE	Department of Primary Industry, Water and Environment
FCPEP	Flexible Circular Polyethylene Pipe
FEA	Finite Element Analysis
FRDC	Fisheries Research Development Corporation
HAC	Huon Aquaculture Company
IA	In Air
IW	In Water
KPI	Key Performance Indicator
MARINTEK	Norwegian Marine Technology Research Institute
Morts	Mortality/Mortalities
NCB	Nature Conservation Branch
PA	Polyamide(Nylon)
PE	Polyethylene
PP	Polypropylene
SDR	Standard Dimension Ratio(refer AS 4130)
TAFI	Tasmanian Aquaculture & Fisheries Institute
TBOA	Tuna Boat Owners Association
TDR	Time Depth Recorder
TSGA	Tasmanian Salmonid Growers' Association
WD	Water Depth

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OBJECTIVES:
The primary objectives of the project were:
1. Design one or more passive "combined" (above and below water) anti-predator system models, based on industry experience, anti-predator expertise and operational/mechanical suitability;
2. Performance evaluation of (a)combined model systems under various flow and wave conditions, and (b)aerial anti-predator system designs under commercial conditions in SA and/or Tasmania; and
3. Provide plans/guidelines for the production of a commercial scale anti-predator system for testing under Tasmanian and SA conditions.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED
- A readily engineered, workable and economic proposal utilising the existing flexible pen and netting designs as detailed,
- Noted difficulties in achieving sufficient(and equal) tensioning through all base and side panels of existing flexible pen and net designs, under typical sea state conditions,
- Inadequate mort(as a result of seal strikes) count data availability, and exchange between farmers, relative to various flexible pen and net designs, and sea state conditions,
- Increased public awareness of seal – salmon/tuna farm interaction and the problems faced by salmon and tuna farmers,
- Production of a benchmark Australian salmon/tuna pen document that will promote common terminology and industry discussion based on pertinent predation factors of existing flexible pen systems and the mitigation thereof,
- Physical modelling of relatively "small" scale pens as fabricated under project require great geometric and hydraulic scaling accuracy under flow conditions - better results would be gained through "larger" scaled models,
- Acoustic Deterrent Devices require further independent investigation,
- A greater understanding, acceptance and response of engineered investigations and reports is required from industry,

This Project was funded by the Fisheries Research & Development Corporation(FRDC) for the "Development of a Stock Protection System for Flexible Oceanic Pens Containing Finfish". The Project has been developed in conjunction with the Tasmanian Salmonid Growers Association(TSGA) & the Tuna Boat Owners Association(TBOA).

Both salmon and tuna farmers have a particular problem with seal predation. Seal predation leads to loss of valuable stock and possibly expensive repairs. In the past, before net strength was increased, seal damage to salmon nets had resulted in larger numbers of farmed salmon escaping. Anecdotal evidence suggests seals indirectly cause a decrease in the growth rate through a reduction in feeding, although it must be pointed out that fish do habituate to the presence of divers in the pens and thus possibly seals outside. Similarly, the farmed fish appear untroubled by the presence of seals hunting wild fish in the area (3 observations to date within this project term). Seals are one of the chief problems facing salmon growers in Tasmania., along with jellyfish, diseases(such as gill amoeba), fouling of lease sites, and high water temperatures. The latter are a problem in summer and seals mainly in winter.

According to reference, D Pemberton and P.D. Shaughnessy, Interaction between seals and Marine Fish-Farms in Tasmania, both the Australian Fur Seal and the Leopard Seal are found in the waters of the Tasmanian salmon industry, though the New Zealand Fur Seal is known to be migrating to Tasmanian waters. The Southern Elephant Seal is also present in Tasmanian waters. In the waters of the tuna industry of Port Lincoln, the predominant seals are the Australian Sealion and the New Zealand Fur Seal.

Shark interaction with salmon farmers has occurred when pens have been towed across Storm Bay and when the pens have been moored on site by typically Blue Whaler and “doggie” sharks respectively. The incidences of shark interaction when towing is typically a summer occurrence where Blue Whaler sharks are attracted to the morts in the pen. The Huon River is a known “doggie” shark nursery and doggie shark interaction can be substantial in some seasons, though it is always dependent upon the number of morts left in the pens. This is a typical issue which can be rectified by efficient management practises. The above is taken from interviews with salmon farmers. The interaction between sharks & tuna farmers has been documented in the Marine Animal Interaction Working Group Workshop, 25-26 May 1998, Primary Industry & Resources SA, Fisheries and Aquaculture. This reference states that the nature and extent of shark interactions is detailed insufficiently.

In addition to predation from the water, fish farmers also face predation from birds. The cormorant is known to predate on commercially raised salmon, attempting to reach the salmon by aerial attacks, and many(up to 600 in 1999), are shot as a result. Silver Gulls also pose a problem for “smaller” salmon. Predation of tuna by birds is a non issue as the tuna are a much “larger” fish; the concern is more that the birds are accessing the feed stock prior to the tuna feeding. The vast numbers of gulls which feed both at tip sites and on farms pose a risk of disease transmission for both industries Management practises to reduce gull interactions are widely used and can be very effective

Flexible Oceanic Pens are the foundation of fish farm cage systems in Australia due to their robustness in inshore waters, their relative inexpensive capital cost, and their ability to be easily transported whilst stocked. This project was initiated due to the ever increasing predation problem on farmed salmon and tuna in Australia on Flexible Oceanic Pens.

A literature review confirmed that no engineering study had previously been performed on the effects and factors with respect to seal predation on Flexible Oceanic Pens.

The project concluded that there is no simplistic solution to the predation problem; rather a concerted multi-faceted effort should be undertaken across both the salmon and tuna industries. The predominant areas of weakness identified were:

- Low tension through the base of nets, as represented by depth present in typical grow-out and predator net bases; and
- Insufficient buffer between the stock and predator nets at the sides and base when using flexible netting materials such as nylon or polyester.

Maximising(adopt minimum 20% available buoyancy) the tensioning weight hung on the predator nets(and grow-out nets if possible) and increasing the typical buffer distance between the grow-out net and predator nets is recommended. Further research is required to determine the precise recommended buffer, though as predation continues at the salmon farm, which employs pens with a nominal 1.4m buffer, a minimum 2m buffer distance is recommended. For existing pens to attain this buffer, an additional pipe ring is required. Future pens should employ pipe collar stanchion spacers that provide a maximum buffer distance. Note, it is possible that Tasmanian legislation could be framed around the above two recommendations.

Further recommendations include:

- Minimum of 2.4Te weighting on typical 120m pen predator netting;
- Investigation required into the behaviour of farmed salmon;
- Investigation required into the predation methods of seals;
- Employ of separation stick between grow-out and predator net;
- False bottom in the grow-out net to prevent “easy” predator access to any morts that may occur;

- Jump fences to prevent seals interacting with farm personnel and entering the pens(2m high fence recommended for both tuna and salmon industries);
- Aerial netting to achieve the above and stop birds interacting with the farms;
- Further investigation by physical and computer modelling; and
- Implementation of common quality control system across the salmon and tuna industries.

Further independent investigation and research on some particular forms of netting and ADDs/Seal Scarers is required. The current use of Seal Scarers in Australia and internationally is promising for specific target-able interactions within salmon and tuna aquaculture, and within other fisheries where marine mammal interactions occur.

KEYWORDS:
Aquaculture, Anti-predation, Predation, Seals, Birds

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1.0 BACKGROUND

This Project is funded by the FRDC for the "Development of a Stock Protection System for Flexible Oceanic Pens Containing Finfish". The Project has been developed in conjunction with the TSGA & the TBOA.

Marine farming of Salmon and Tuna are relatively new industries in Australia, now generating revenues of some $300 million per annum and providing considerable and stable employment in remote regions which traditionally have high unemployment. Since the inception of the industry, predators such as seals and sharks have caused significant commercial losses through direct predation and stock escapes.

In 1988 the TSGA, in conjunction with the Department of Parks and Wildlife, funded a research project to investigate the interaction of Australian fur seals with caged finfish. The study highlighted the nature of the problem and resulted in the development of improved passive protection systems for sea cages(Pemberton et al 1991, Pemberton & Shaughnessy 1993, Kirkwood et al 1991). Considerable efforts were also made to inform the general public and address conservation generated concerns regarding the development of these systems. In addition, shooting as a management measure ceased in 1994. Since then the rate of interactions has increased, in conjunction with the growth in the size and number of sea farms. Live capture and relocation of seals was introduced as a management tool in 1991, but is under review because of concerns with disease, animal ethics, cost and effectiveness of the method. Summaries of this procedure and other gear developments are contained in reports to funding bodies(see Princess Melikoff Trust, Marine mammal research Report. Annual report 1990-1998, internal publication, Parks and Wildlife). The TBOA, in conjunction with Tasmanian Parks and Wildlife, has researched and implemented various deterrents(see Pemberton 1997) but they have been quickly superseded. Current preventative methods on sharks, using an extension of the shark pod system, are promising, however seals remain the largest problem and significant external research is required.

Although Predator nets(passive protection systems) have been used by the Tasmanian Salmon Growers' for a number of years, it is only recently that their use has become widespread. The use of this form of protection has meant losses incurred in the late 1980's were as high as 95% of fish, whereas currently figures of 2% are generally quoted. When only one or two individual farms used predator nets, they were found to be excellent seal deterrents. With industry wide use of predator nets, seals have demonstrated an ability to overcome the passive protection systems under certain conditions, particularly targeting those pens in areas of high water flow, strong wave action, or those with poor net design characteristics. The basic problem is that seals can push the two nets(predator and stock) together and bite fish through the resulting combined netting. The industry is now under pressure to develop more exposed sites for farming, as calmer inshore sites become limited under Tasmania's marine farm development plans.

The Southern Bluefin Tuna farming industry in South Australia, started in 1991, has already grown to an export value of $101 million in 1998. Existing predator deterrent methods have not proven effective for the farming conditions experienced by the industry, and the industry has made a commitment over recent years to trial new deterrent equipment as it becomes available. As both tuna and salmon farming are relatively new industries in Australia they have both used the same technology originally developed in the northern hemisphere for the farming of Atlantic Salmon. The 120m circumference floating collars are basically the same for both tuna and salmon farmers. Predator and grow-out netting design and manufacturing details vary markedly.

Recently, New Zealand fur seals have started to interact with Tasmanian fin fish farms. This species, along with Australian sea lions, also have a major impact on tuna farms at Port Lincoln. Fish in pens of West Australia are also considered to be at serious risk of attack. Typically, in South Australia, tuna are attacked by the seals accessing the pen, with stock being bitten on their backs. New Zealand fur seals represent a potentially greater threat, as unlike Australian fur seals, they are capable of climbing over conventional protection systems. As a result, systems will have to be redesigned to carry appropriate aerial nets. Currently aerial nets are only designed to stop gulls, commorants and other seabirds from competing for fish food and polluting the fish pens(for a summary of this problem refer Pemberton 1997). To date, designs of aerial nets for birds have only been successfully deployed in sheltered areas. Open sea sites in the industry have recently seen conventional systems destroyed by storm conditions due to the flexing and "contortions" of the pens.

Many fish farmers believe predators cause significant economic losses by injuring and consuming farmed fish, and through loss in growth due to stress. With the Australian aquaculture industry expanding to more environmentally exposed sites(stronger tidal flow, greater wave motion) further design considerations are necessary with respect to anti-predator systems as a new suite of predators will be encountered, such as “large” sharks and killer whales.

Fish farmers’ desire to resolve predator issues that satisfy public concerns of conserving these predatory species as wildlife is proving difficult and costly. Based upon the document, Trapping & Relocation of Seals from Fish Farms in Tasmania: 1990-1998. Tasmanian Parks & Wildlife Service, DPIWE, it has been shown that trapping and relocation of seals is an inappropriate long-term goal and that more permanent and effective methods, such as net protection, are required. At the same time, the general public supports protection of marine mammals.

In general, there is little reliable quantitative information on actual fish losses due to predators, making it difficult to estimate their true economic impact. Note: It is believed that fish loss information is available in some form across farms, but to date is uncollated. Note: A survey was conducted in 1988 where losses of 40% on one farm’s stock were reported, all salmon smolt on another farm(Pemberton 1989).

Sunderland Marine Mutual Insurance Co estimate that 5% of the world’s 1999 claims were “… attributable to seal predation, which can be a problem that is difficult to predict and prevent. There may be no history of seal predation at a particular site when, despite the installation of weighted predator nets and the use of seal scarers, losses still occur”.

Marine mammals are naturally attracted to food sources, such as seals are to salmon and tuna. This project is part of ongoing research efforts to develop non-lethal means of discouraging marine mammal, bird and shark interactions with fish farms.

2.0 NEED

In the financial year 1997/98 all Tasmanian fin fish farms experienced increasing levels of seal interaction resulting in tangible losses of around $1.5million, or around 2% of stock. 164 seals were trapped and relocated in 1996/97 compared with 37 the year before and 10 when management by trapping and relocation was first introduced. In response to the increase in interactions, the industry spent an estimated $1million on upgrading predator nets over the last financial year. Licensed shooting, trapping and relocation of seals has been used in the industry, in conjunction with the Department of Environment and Land Management, in previous years, but these methods are not considered to be either acceptable(because of risk of spreading disease, animal ethic concerns by the public and fishery management issues), or cost effective.

During the course of this project unwanted interactions between seals and farm personnel(below and above water) began. The explanation for commencement of these interactions is that particular seals maybe becoming “too” familiar with human activity due to being trapped, relocated and other forms of management that allow for habituation, such as feeding seals and teasing seals into traps with fish on lines. A number of these relocated seals also then return to the farm sites from which they were trapped.

The Tasmanian Atlantic Salmon industry is set to expand substantially in the short to medium term, with production projected to double within 5 years. With this expansion to new areas, both inshore and offshore, will be developed for marine farming. Seal predation will be at least, if not more, significant in these areas.

The development of some aquaculture projects in other states, notably Western Australia, has been postponed due to perceived problems with seals and the inadequacies in current protection systems and controversy of water/lease sites.

The Southern Bluefin Tuna farming industry in South Australia, while relatively new, already suffers large losses due to predation by sharks and seals. Losses due to predation by sharks and seals have a substantial impact on the industry, with annual direct losses estimated at $1.2million and growing rapidly. Existing predator deterrent methods have not proven to be effective for the farming or towing conditions experienced by the industry.

3.0 OBJECTIVES

The primary objectives of the project were:

1. Design one or more passive “combined” (above and below water) anti-predator system models, based on industry experience, anti-predator expertise and operational/mechanical suitability;
2. Performance evaluation of (a)combined model systems under various flow and wave conditions, and (b)aerial anti-predator system designs under commercial conditions in SA and/or Tasmania; and
3. Provide plans/guidelines for the production of a commercial scale anti-predator system for testing under Tasmanian and SA conditions.

4.0 METHODS

The methodology used to accomplish the project objectives is summarized as follows:

1. Review contemporary predator protection systems and select the most attractive features to develop an effective barrier to predators, taking into account industry experience, anti-predator expertise & operational/mechanical suitability;
2. Prepare scale model net plans;
3. Fabricate a scale model;
4. Test model under various flow & wave conditions;
5. Prepare final report on suitability for full scale application;
6. Develop guidelines for the development of a commercial unit on a typical 120m pen with salmon; and
7. Document and review alternate methods used to deter predators by fish farmers.

The Project will also take into account evolving fish farming technology such as net fabric, anti fouling, new types of materials/products available etc.

The Research Project will also attempt to investigate so called “Novel Methods” that have been raised throughout the industry. These include:

1. use of electricity as a behavioural deterrent(shark pods/electric above water fencing/electric underwater fencing); and
2. use of variable buoyancy talking killer whale model as a deterrent.

5.0 RESULTS / DISCUSSION

5.1 Seal Predation Method Description

No concise method of attack was reported by the Tasmanian salmon farmer's through-out the term of this project. Much anecdotal evidence exists as to the following:

- Seals rising up from base of predator net to grow-out net to access fish;
- Seals corkscrewing through predator netting side panels;
- Seal pectoral fins up & pushing against side panel to access fish, subsequent collection of fish from base;
- Predation concentrated on the gate area of the grow-out net;
- Seals gaining access between predator and grow-out nets from between the pipes rings of the pen structure at the surface(prior to introduction of predator skirt/net extension to handrail);
- Seals climbing over jump fence & handrail;
- Predation more pronounced at times of peak tidal movement when grow-out net billows against predator net;
- Any less weight than currently employed will not work;
- Seals will seek the easiest opportunity for access which may be the next pen or the next farm; and
- Seals are opportunistic & find weaknesses during execution of pen activities(crowding, swim-through, towing etc).

The theory of predation(on grow-out nets as predator net usage in infancy) at Tasmanian salmon farms in 1989(D. Pemberton 1989) was:

- Seal charges net from up to 50m away;
- Momentum enables the seal to push net up to 4m into the cage;
- Seal grabs at fish; and
- Attack results in small holes(holes distributed all over the nets).

And, from a workshop on predation in British Columbia(Tillapaugh, 1991) the described method of attack was that seals circle the pen until the fish become frightened enough to charge into the growing net (usually downward) in an attempt to escape. The seal is not strong enough to rip the growing nets and so must eat the fish through the mesh. The seal then grabs a fish between its front flippers, bites the abdomen of the fish and "sucks the guts" through the net. The dying fish is then released and the seal repeats the procedure. There is no evidence to suggest that this is the current case on Tasmanian salmonid farms. Rather, it is thought that the industry has employed many of the recommendations of the first local study(D. Pemberton 1989) and evolved to where it is today. In summary, this change has been due to the adoption of predator nets, heavier netting selection, heavier tensioning weights and improved tensioning methods.

Predation on tuna is discussed in a later section.

5.2 Farm Pen Arrangements

The majority of farms in Tasmania & Port Lincoln operate with flexible circular polyethylene pipe pens together with flexible synthetic netting. The circumference of the pen is normally used to designate the pen size, 120m circumference pens being the most common. There are three basic exceptions to the flexible pipe pens used together with flexible synthetic netting in Tasmania. These are the System Farm, Bag Pen & Onesteel Marinemesh.

Table 1 and 2 provide summaries of the Tasmanian salmon industries flexible circular pen, grow-out and predation netting details for the 1999 calendar year. General site details are also included. The information gathered in the table is by no means all encompassing but rather details general pen & netting details of the farms visited early in the project of which predation by seals is considered a concern.

A "typical pen" will be referred to throughout this report as it is by far the most current pen in use within the Tasmanian aquaculture industry. This is a 120m(inner ring from 10off 12m lengths) circumference pen where there are two pipe rings of 315OD with a nominal buffer distance of 1065mm. The pipe wall thickness varies between farms, being typically either 18.7WT(SDR 17) or 15.0WT(SDR21). The pipe is typically of a PE80 Type B compound(refer AS 4130), a high molecular weight MDPE co-polymer.

Figure 1 : Stanchion of typical pen

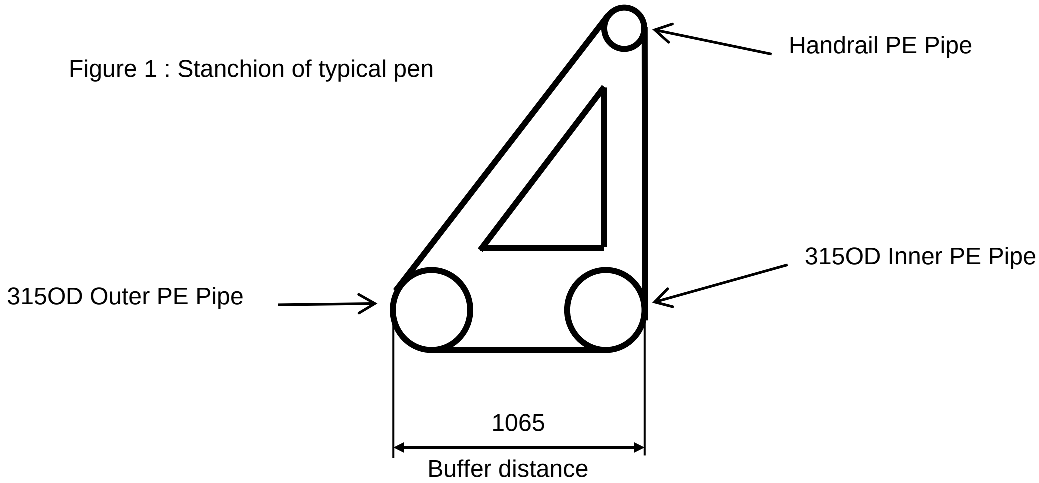


Figure 2 : Picture of typical pen

Stanchion spacing is typically one stanchion every 2.5m, 48off on a 120m pen. The current stanchions are roto-moulded from PE resin; older stanchions were of steel, but the clamping bolts suffered from corrosion and failed.

There are two major variations to the typical pen in use within the Tasmanian salmon industry. The first is a 120m circumference pen where the inner pipe ring is from 400OD PE pipe, the outer ring is from 315OD PE pipe and a nominal buffer distance of 1400mm. The second is a pen with 2off 355OD PE pipe rings, and a nominal buffer distance of 1000mm.

5.2.1 Grow-out Nets

Grow-out nets provide a contained enclosure to hold the fish stock. Grow-out nets are hung from the inner edge of the inner pipe ring. Framelines, typically PP material of 16 or 18mm diameter, are the load or tension lines within the net to which the netting is lashed. Soft eye loops are provided on the base circumference, for the hanging of weights, and at the water line, for attachment to the pen. Codends(doughnut sized plastic rings) are typically added throughout the net to aid in maintenance activities.

The choice of netting size and strength is dependent upon the size of the fish. Typically, for salmon, the following in PA material is observed:

- 80g+ 12mm inner mesh, 210/60
- 500g+ 19mm inner mesh, 210/96
- 1000g+ 25mm inner mesh, 210/150 or 210/168

These choices of netting ply, indicative of strength, have evolved over the last 10 years of the salmon industry. Early nets were of 30 ply netting; this was found to be inadequate as seals were damaging the net from barging and tearing the net at the surface.

This project has only investigated, with any detail, the use of the current larger mesh sizes as it is this netting that holds the fish stock with the most capital, and the stock that seals predate most frequently.

5.2.2 Jump Fence

A Jump Fence section of netting is added at the water surface to prevent fish jumping clear of the pen. Typically it is of identical material to that of the grow-out netting.

5.2.3 Predator Nets

Predator nets are typically used in the salmon industry when the fish attain a 300g weight. Predator nets totally surround the grow-out net forming a physical barrier and buffer between underwater predators and the stock held within the grow-out net. Predator nets are hung from outer edge of the outer pipe ring. No past papers addressing seal predation have been found that recommend a minimum distance/buffer from the grow-out net to the predation net. A. Ross 1988, recommends predator nets must be kept away from the fish cage, though the gap required will depend on the water current and movement of the net.

The choice of mesh size is a function of capital cost, reduced water flow considerations & entanglement issues. Framelines & codends similar to those of a grow-out net are typically provided. Predator skirts are added to prevent seals accessing the gap between the two pen pipes from the water surface.

	Site				Pen				Grow-out						
Farm	Title	WD	Current max	Wave	Circum.	OD	WT	Sep.	Netting	Braid dia	Depth	# Panels	Taper	Weights	Other
		m	knots	m	m	mm	mm	mm		mm	m		%	kg in water	
Tassal	Redcliffs	20 to 22		2+	120	2x315		1020	50mm str knotless nylon braid 210/150to180		8side 8base	24	10	100	Weights by shared method, if no Pred Net then full 100kg hung. 70kg in water Tombola. Swim thru gate with skirts.
	Creasies	16-20		2+	120	2x315		1020	50mm str knotless nylon braid 210/150to180		6.5side 6.5base	24	10	100	Weights by shared. 70kg in water Tombola. Swim thru gate with skirts.
Huon	Flathead		0.6@5m	=Redcliffs	120 & 80	4off 315? 400?		1440 1000nom	210/180		11 flat base	24	10	100	Weights by shared Due to stretch, panels fab oversize
	Police Pt		0.7@5m		120 & 80	315 & 400		1440 1000nom			11 flat base	24	10	100	Weights by shared Due to stretch, panels fab oversize
Aquatas	Shepards		4		120	2x315			210/ 15mmID bar		10side ?base	24	5		Weights by shared
			4		80				210/96 15mmID bar		6to7side 1.8base	8	10		Weights by shared
Seafarms	Satellite Is.	10 to 12	2 to 3	1 to 2	80				210/150&168 30ID bar		9 0base	16	15	16x100	Weights by shared net depth was 7.5side+1.5base
Nortas	Roberts	21 to 23	1 to 2	1 to 1.2	120/80				polyester		12	24/26	3 to 8%		Weights by "porthole" arrangement
Sevrup/ Petuna	Table Hd		2 to 3		80	280			198ply 25mm bar		7side 1.5base			3kg/m 20x20kg	bottom taut line rock filled bags "dropped in"
	Table Hd		2 to 3		2x120	280			198ply 25mm bar						
	Liberty Pt				80	280			300ply 40mm bar						
Sth Ocean	Cosy Cnr		3		4x100	420? 1ring					6		3	30x70kg double at front	pull out to wht thru block
			3		2x150	420? 1ring					6		3	30x70kg double at front	pull out to wht thru block

Table 1 : Grow-out net details 1999

	Site				Predator						
Farm	**Title**	**WD**	**Current max**	**Wave**	**Netting**	**Braid dia**	**Depth**	**# Panels**	**Taper**	**Weights**	**Other**
		m	knots	m		mm	m		%	kg in water	
Tassal	Redcliffs	20 to 22		2+	305mm str nylon braid 210/12x16 knotted		14	16	0	140	Weights by shared. 7x7skirt + 2x30kg side wts
	Redcliffs	20 to 22		2+	305mm str nylon braid 210/12x16 knotted			24	0	140	Weights by shared. 7x7skirt + 2x30kg side wts
	Creasies				305mm str nylon braid 210/12x16 knotted			24	0	140	Weights by shared
Huon	Flathead	19 to 22	0.6@5m	=Redcliffs	205mm str nylon braid 210/19x16 knotted		16.5side 0base	24	<10	100	Weights in sock
	Police Pt	19 to 22	0.7@5m		205mm str nylon braid 210/19x16 knotted		16.5side 0base	24	<10	100	Weights in sock
Aquatas	Shepards		4								
Seafarms	Satellite Is.	10 to 12	2 to 3	1 to 2	210/12x16 305str		10side 0base	16	0	8x100	plus 20kg "pinkies"
Nortas	Roberts	21 to 23	1 to 2	1 to 1.2	4mm PE 12" knotted		18 to 20	16	0	2x60	Attempting to antifoul
Sevrup/ Petuna	Table Hd		2 to 3		None						
	Table Hd		2 to 3		None						
	Liberty Pt				None						
Sth Ocean	Cosy Cnr		3		None						
			3		None						

Table 2 : Predator net details 1999

It can be seen that there is a wide variety of net designs, netting materials, current flow, wave action, water depth & weighting methods. It must be noted that all data collected is anecdotal, taken during farm visitation discussions with site personnel, without viewing documented evidence.

Seal predation is considered “high” among all farms, except the farms at Macquarie Harbour(Sevrup/Petuna & Southern Ocean).

Changes to the netting choice and net design for the 2000 year are largely unaltered. The typical 305mm stretched mesh of Tassal’s predator netting has been reduced to 254mm; this decision was taken due to the observation that seals were corkscrewing through the larger mesh size. Anecdotal evidence to date is that this reduction has been beneficial in reducing predation.

5.2.4 System Farm

Marine Construction as manufacture the System Farm. It is constructed from short platform sections of steel, joined together by hinges. With respect to seal predation the System Farm is advantageous due to the 2m(typical) wide outer platforms. Predator nets hang from the outer edge of the walkway platform to the seabed; these are known as curtain nets. The predator curtain netting is drawn away from the grow-out netting and weighted to the seabed by lead weights along its length, and in some instances “spot” weights to guarantee that the predator net is not displaced in “high” current flows. Typically some 8m of netting is always on the seabed.

Only two instances of seal predation to date have been reported.

Concerns with respect to the System Farm pen arrangement include oxygen depletion and design adequacy of the hinged sections for “rough” sea conditions.

5.2.5 Bag

Future SEA Technologies manufacture the SEA System ™. It can be basically described as a controlled growing environment consisting of a flexible, round, water-tight enclosure that is supplied with pumped water.

There have been no instances of seal predation, but a seal has “hauled-out” onto the support floats. Concern is only if a seal recognizes it can jump inside the bag/s, and for predation by birds.

5.2.6 Onesteel Marinemesh

Onesteel(previously BHP Wire) have been selling galvanised feed wire to Japanese steel net makers for the last 3 years. Japanese fish farmers typically utilise square steel cages of 10m x 10m size from which steel nets are hung up to depths of 8m. Onesteel can presently only manufacture 3.6m widths in Australia, but 10m widths are available from Japan. Mesh sizes available range from 25-100mm, in 1.6-4mm diameter.

Onesteel claim that without additional cathodic protection assistance(anodes attached to the netting) the life expectancy of Marinemesh will be greater than 2 years; with additional sacrificial anodes attached to the Marinemesh life expectancy is expected to increase significantly.

Figure 3 : Onesteel 100mm mesh, 4mm diameter

The first installation in Australia using Marinemesh was with a snapper farmer in Botany Bay, NSW. In Tasmania, Marinemesh(25mm, 3.2mm diameter) was attached to a standard 80m pen in March 2000 and is currently undergoing trials off Bruny Island.

Figure 4 : Onesteel Marinemesh fit-up onto 80m pen at Hobart

One advantage of the Onesteel Marinemesh is the reduction in marine growth. A possible explanation is that, unlike synthetic netting, the steel twine is non-porous and thus offers reduced attachment points for growth to begin. Other explanations as to the reduced marine growth are that the marine growth finds the sacrificial zinc coating toxic(increased pH of the exposed steel), and any marine growth that does becomes attached soon “falls way” with a local layer of the sacrificial zinc coating.

To date the results from the farm in Botany Bay and on Satellite Island have been positive; including as at mid-October 1999 the farmer at Botany Bay had not yet had to clean or change the nets after nearly 12 months in the water(when and if the need arises the farmer plans to brush the fouling off).

Trials of “ring-lock” type steel fencing on a Tasmanian salmon farm in 1988 proved effective against seal predation, but suffered from extreme corrosion as the wire soon lost the nominally small 50 g/m2 zinc coating.

The results of the ongoing trials at Botany Bay and Satellite Island will be received with interest. Interesting points of note will be:

- The extrapolated life. This will be largely dependent upon remaining zinc coating and loss of wire thickness at the abrasive "hanging" points. (Failure is likely to occur near the surface where wave action/abrasion and marine growth are at a maximum);
- Whether cleaning(by brushing or other methods) is recommended, as the removal of any marine growth may reduce the zinc coating thickness;
- Environmental concerns regarding zinc, in stock, on seabed;
- Fish transfer; and
- Buoyancy issues, both initial and as a result of any marine growth

Relative to the cost of synthetic netting the cost of Marinemesh is considered "high"; refer table below.

Aperture mm	Wire diameter mm	Galvanizing grams/m2	Approx. weight per sq meter kg/m2	Approx. supply cost $/m2
100	4	600	2.8	20
25	3.2	600	6.0	30

Table 3 : Basic approximate costs of Marinemesh for two mesh sizes

If however Marinemesh is proven at eliminating seal predation underwater, together with little required maintenance(negligible marine growth) then the capital cost per produced fish would approach that currently found using synthetic netting. Calculations to date indicate that if the current guarantee was extended to 5 years, then Marinemesh would be an attractive alternative to the use of synthetic netting.

Suitability for use on a 120m pen will also have to be considered. The capital cost of a lifting frame required to lift a 120m pen will need to be considered. The available buoyancy of the pen is another consideration, as typically the weight per square meter of the Marinemesh is higher than that of the current synthetic netting and tensioning weights for a typical 120m pen. The estimated total weight of the Marinemesh will be in the order of 9.2Te(120mx10m depth at 3.9kg/m2).

Another advantage would be the Marinemesh inherent high weight per square meter for "high" current sites in reducing net volume loss.

One point of current discussion is to whether the Marinemesh could be coated in plastic which would lengthen its life and retard marine growth, whilst providing some degree of buoyancy. The additional cost of any plastic coating may well negate its use.

The contact point for enquires regarding Onesteel Marinemesh is Matt Condon at condonm@onesteel.com .

5.3 Prepare & Fabricate Model

Consideration was given to the relative size, equipment, project allowance and availability at the AMC Flume and Wave tanks.

5.3.1 Dimensionless Scaling

Model testing took into account a choice of scale, which is a dimensionless number. There are two important dimensionless numbers, the Reynolds Number and the Froude Number. Defining subscript F as full scale, subscript M as the model scale, and S_L as the Scale Factor.

When fluids of similar kinematic viscosity are used for model and full scale, the Reynolds Number can be maintained only if a higher velocity is used for a smaller model size. This is typically impractical and models are rarely tested at a constant Reynolds Number.

The Froude Number(Fr) represents the relation between the inertia forces and the gravity forces. The generalized Froude Number can be written,

$$Fr = V / \sqrt{(g \, . \, L)}$$

where L is the characteristic linear dimension(typically the netting twine diameter). So conservation of the Froude Number is $Fr_F = Fr_M$ or by selecting a combination of scaling factors,

$S_L = L_M / L_F$ and

$S_V^2 = V_M / V_F = \sqrt{S_L}$

That is the ratio between the flow speeds is equal to the square of S_L.

Model nets have traditionally been constructed using constant Froude number modelling rules. The model will be built as close as possible to these rules. A model of 20:1 scale was manufactured for the rigid frame model. It is the author's belief that this model size is larger than all previous pen models fabricated for testing at the AMC Flume Tank, as a result sizing discrepancies should be reduced.

Parameter	Expression	Target Factor
Current Speed	= V	$S_L^{1/2}$
Twine thickness	= d	S_L
Bar length	= a	1
Number meshes perimeter	= n	1
Number meshes depth	= r	1
Overall section dimensions	α an	S_L
Solidity	= d/a	1
Weight in air	= W	S_L^3

Table 4 : Scale Factors

The model netting solidity was considered the most important parameter to scale correctly for. In order to model the solidity correctly, the ratio of the twine diameter, d, to the bar length, a, should be the same for the full scale and its model equivalent.

It must be noted that model twine diameters and mesh sizes are not available, nor practical, at a scale of 20:1.

5.3.2 Twine Diameter Calculation

Equations have been derived to assist in the calculation of the netting twine diameter given parameters typically supplied by the netting manufacturer(denier and ply/# fibres).

Rtex = (denier / 9 x no fibres) . 1.1

d = Kdt $\sqrt{}$ (Rtex / (1000 x Kt))
= 1.35 $\sqrt{}$ (Rtex / (1000 x 1.115))
Where 1.1, 1.35 & 1.115 are figures from Fridman A. 1986.

5.3.3 Rigid Frame Model

As a consequence of the various pen systems in use, and in an effort to utilize the project funds effectively, a rigid frame model of a 120m pen was tested initially. It was envisaged that this testing would greatly assist in the determination of further model testing and project direction.

The rigid frame model was fabricated from aluminium, consisting of a 2" support pipe structure, 16mm bar to represent the inner pipe ring, and non-rigid tubing(Aquapore) to represent the outer pipe ring. By utilising the non-rigid tubing the buffer zone distance between the two pipe rings could be adjusted without the requirement for a completely new model structure.

Gross assumptions for modelling in the Flume Tank include: a constant velocity flow over depth and a perfectly circular double ring pen.

Rigid frame model:
- 120m circumference pen
- 210/168 nylon braided knotless grow-out net
- 210/12x16 150mesh size nylon knotted predator net
- 24 panel
- non-tarred

Parameters to be varied:
- Flow velocity

5.3.4 Salmon Grow-out Netting

From Table 5 below it can be seen that the solidity ratio for typical grow-out netting ranges from 0.080 to 0.095. 210/6 netting with “a” equalling 7 was chosen for the scale model netting as its solidity ratio(0.0717) is a good approximation and gives a netting where side tapers can be easily incorporated. This netting is knotted, but no close approximation of knotless netting has been found to be available to date.

Typical Grow-out Full Size	**Bar length, a mm**		**Avg Twine thickness, d mm**		**Solidity d/a**	
210/168 KL Nets	*Measured 42.1*		*3.36867*		0.080	
210/168 KL Netcraft	Spec. 39 *Measured 40*		*3.7195*		0.095 0.093	
Adopted values	40		3.5		0.087	
Model Netting						
Target scale factor		**20**		**20**		**1**
210/6 K	7	5.71	0.50171	6.98	0.0717	1.21

Table 5 : Scale Factors(full scale/model scale) for major parameters of grow-out netting

KEY: K = Knotted
KL = knotless
Italized = measured

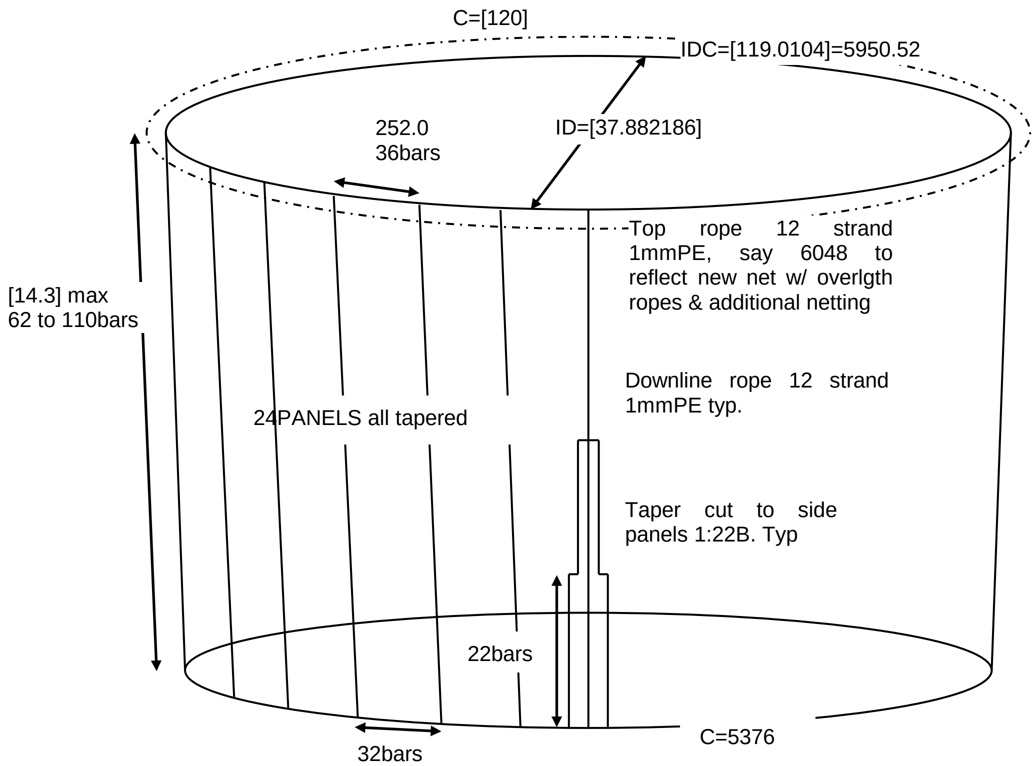


Figure 5 : Model Grow-out Netting Arrangement
210/6, a=7mm, knotted

The scaled circumference is not exactly S_L as this is not possible for a model with 24 panels and a=7mm. A marginally larger circumference, approximately 2%, was adopted(this imitates the full size netting in that full size netting is typically manufactured oversize to account for shrinkage effects).

For the rigid frame model a panel taper of 11.1% on the "oversize" netting was chosen as this allows the loss of an even number of bars per panel on the circumference, refer Table 6 below.

Taper over IDC 5950.5	Taper on o.s. netting 6048	Bottom C	#bars	#bars/panel	Change bars on bottom C
9.6%	**11.1%**	**5376**	**768**	**32**	**4**

Table 6 : Model Taper Details

The model bottom will be of a "pie-cutter" type. This arrangement is most typical of that found in industry. Refer Figure 6 below.

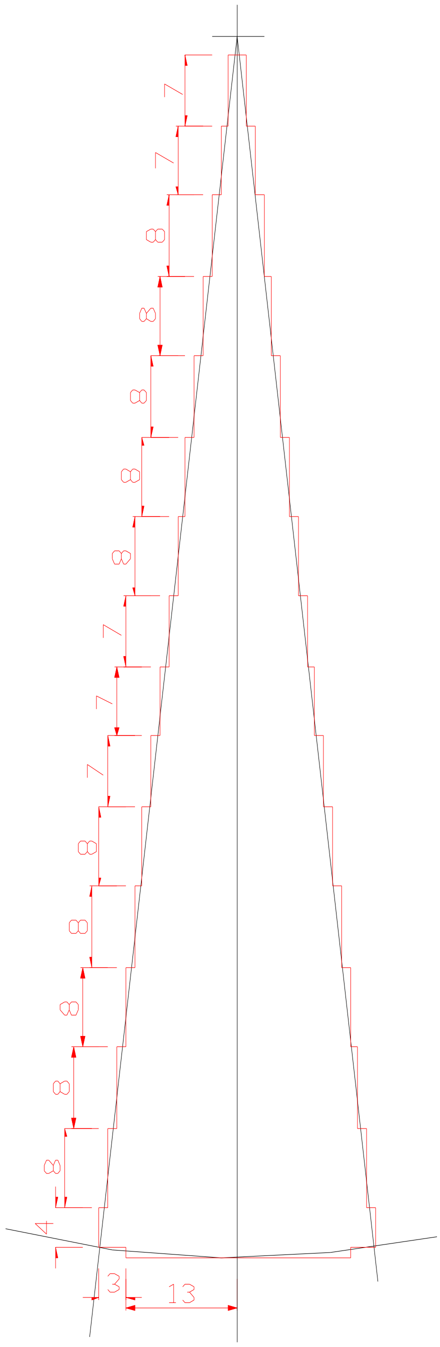


Figure 6 : Grow-out bottom pie piece taper details

PP ropes of 18 to 20mm diameter are typically utilised for all framelines in nets; PP/PES blend ropes being also common. The scaled model grow-out net ropes were from 1.4mm diameter, 12 ply, PE material(venetian cord). This is because scaled PP twine of such a "small" diameter is not readily available(PE twine, 12ply, is available but was considered to have excessive stiffness and thus the model would not react conservatively). A "nominal" tension was applied during model net attachment to the ropes to replicate that used during full net making manufacture.

5.3.5 Salmon Predator Netting

From Table 7 below it can be seen that the solidity ratio for the typical predator netting ranges from 0.0199 to 0.0252. 210/3 netting, with "a" equalling 16 was chosen for the scale model netting as its solidity ratio(0.02217) was the closest approximation.

Typical Predator Full Size	Bar length, a mm		Avg Twine thickness, d mm		Solidity d/a	
210/12x16 Nets	*152.5*		*2.399&3.671 =3.035*		0.0199	
210/19x16 Netcraft	*152.5*		*2.964&4.729 =3.8465*		0.0252	
Model Netting						
Target scale factor		**20**		**20**		**1**
210/6 K	16	9.53	0.3547	9.59	0.02217	1.02

Table 7 : Scale Factors(full scale/model scale) for major parameters of predator netting

Panels of bar width, alternating 17 then 16, giving a total circumference equal to that of the waterline will be chosen, that is no taper was to be given to the panels. This was necessary due to the scaling and the requirement to obtain a “reasonable” buffer distance for the model. The effect of tensioning weight loss from the vertical aspect was thought to be negligible over this depth.

The predator netting base was manufactured in a manner similar to that of the grow-out netting base, the difference being that the tapers were cut into to pieces of “pie” to match two side panels This is due to the restriction on the taper from the relatively large number of bars.

The model predator frameline ropes were of PA(No 8, tex 880, bricklayers twine).

5.3.6 Salmon pen net weighting

Typically 100kgIW weights are utilised for the tensioning of net panels of both grow-out and predator netting. The model shall initially utilise scaled point masses that replicate these full size weights.

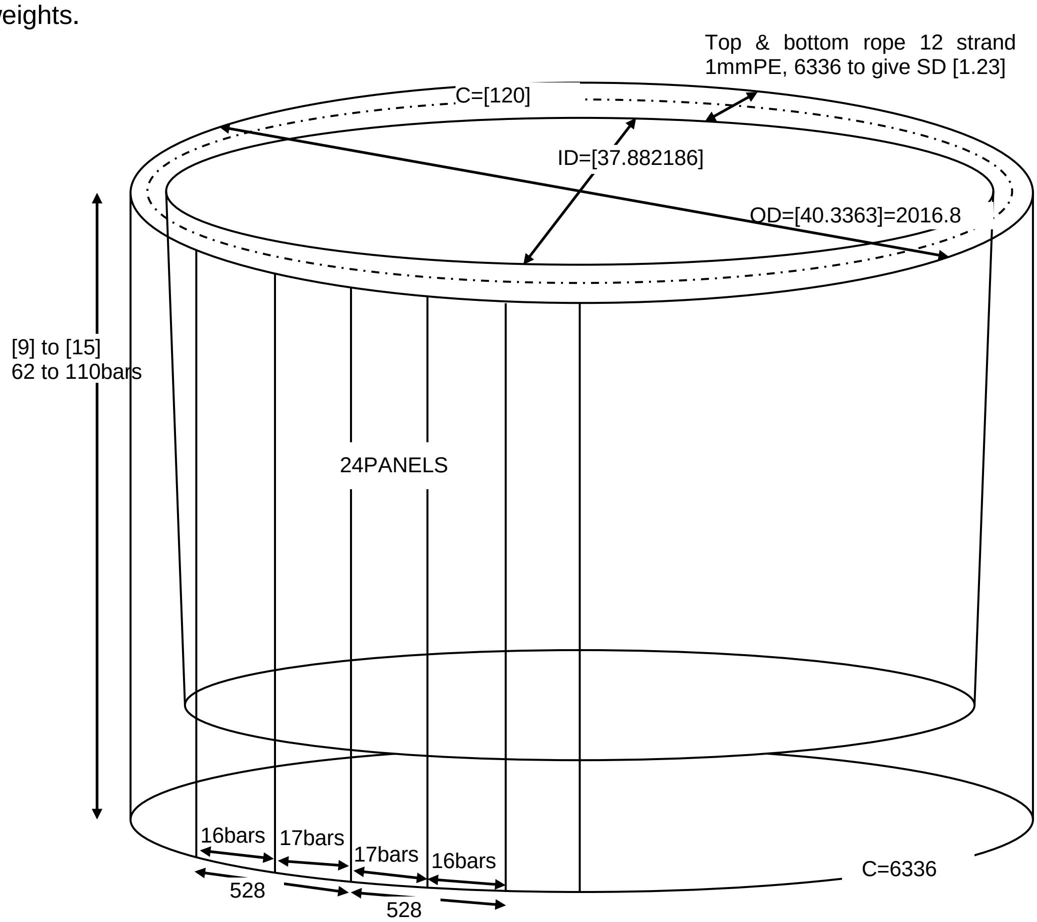


Figure 7: Model Predator Netting Arrangement
210/3, a=16 knotted

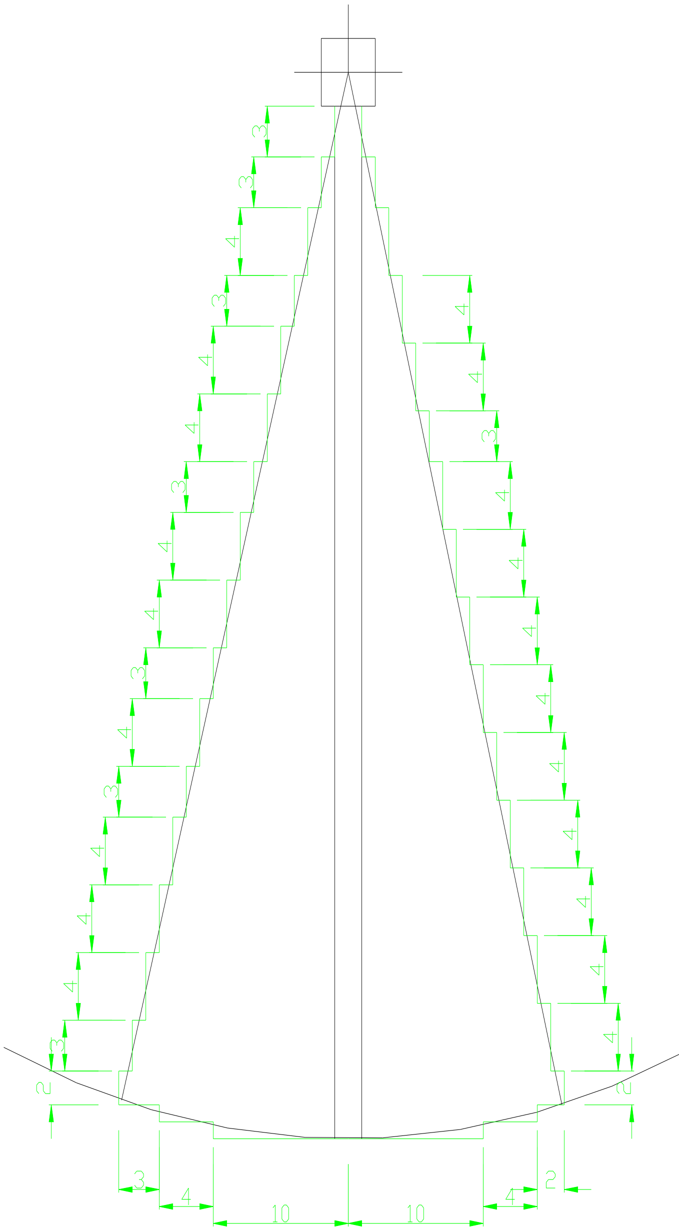


Figure 8 : Pred bottom pie piece taper details

5.3.7 Flexible Frame Model

Further to the testing of the rigid frame model, a flexible frame model was constructed. Cylindrical buoyancy elements from Divinycell were utilised to represent the hydrodynamic forces, whilst steel wire was used to represent the PE pipe stiffness. This is as has been previously constructed by MARINTEK to enable verification of their in-house developed software, OH Slaattelid, 1990.

5.4 Model testing

Firstly, it must be stated that an obvious observation when attaching the grow-out and predator nets to the rigid frame was that in comparison to the diameter of the pen and depth of the typical grow-out net, there is relatively little buffer distance.

From the first day of the model testing in the Flume Tank it was clear that the bases of the grow-out and predator nets needed some modifications.

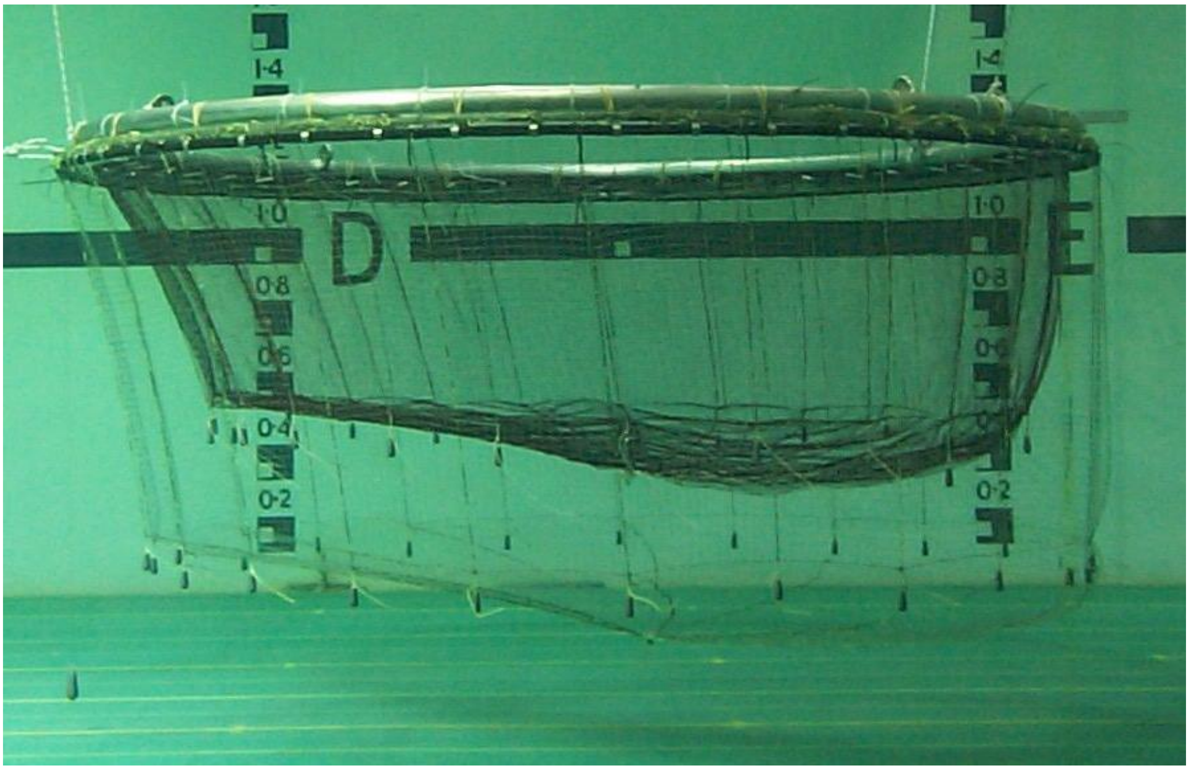


Figure 9 : Original model grow-out & predator netting design at circa 0.06m/s flow.

These modifications were required because, with the scaled point masses on both nets, there was significant sag/depth to the bases. Depth that, under even relatively low flow conditions, resulted in a bag of netting(similar to a purse seine) at the trailing edge. As there was no evidence of this occurring in practice several explanations were purported, including:

- Model & netting incorrectly made;
- Excessive weight of model net bases in comparison to scaled full size; and
- Excessive drag due to incorrectly chosen model netting(mesh & twine size etc).

Knowledge of commercial pen typical currents was unknown also, as such it was difficult to determine what flow speed should be adopted for the flume tank study and what influence did the weight of the model netting posed. That is, at relatively "high" flows the inaccuracy in the exact chosen scaled model netting weight can be ignored as the primary force on the netting is drag. At relatively "low" flows the chosen netting is more dependent upon an exact scaled weight.

Identical model and full size netting areas were cut and weighed to determine the approximate weight scaling factor. As the two projected areas were identical(equal solidity ratios), and both materials were of PA, the weight difference factor was expected to be identical to the twine diameter difference factor. Refer table below.

	Weight grams	**Twine diameter** mm
FS Grow-out netting	209	3.7
Model Grow-out netting	32.1	0.5017
Grow-out Factors	**6.5**	**7.4**

Table 8 : Weight & diameter difference factors for model & full size nets of identical areas.

Thus it was clear that from this basic test that the grow-out model netting was "over" weight. This is most easily attributed to the use of knotted netting for the model. The model knotted netting overall length being circa 1.14 times the full size knotless netting. [Another test was performed when the base was cut off & weighed at 229g, calculation of the weight IA of a typical full size base is 414+kg(based on 0.45kg/m2), scaled, the model base should have weighed circa 52g – one eighth of the actual model base weight]

The identical areas of model and full size netting were hung along one edge and tested under flow conditions to determine if there was a major difference in drag due to the weight difference, and the effect of the knots in the model netting. This test proved that at the flows seen by the full size pens, circa 1 knot, that approximately 26% additional weighting is required.

In summary, the grow-out model netting choice was not adequately representing the full size grow-out netting. The base parameter in the choice of model netting was the solidity ratio; the choice of the model netting should have also taken into account:

- Weight of model netting scaled to full size netting; and
- Additional drag effect from knotted netting.

In retrospect, from the above two simple tests, the weight of the chosen model netting should have received as a high a level of design consideration as the solidity ratio.

Discussions were also held with several local netmakers, notably Nets, who advised that typically 3-5% of the base diameter is removed to provide tension through the base. The original base was then removed, an additional taper on the side framelines was added to lower the hanging point and thus promote tension through the base, and one bar was removed from the base radius such that the base was undersize by approximately 3%.

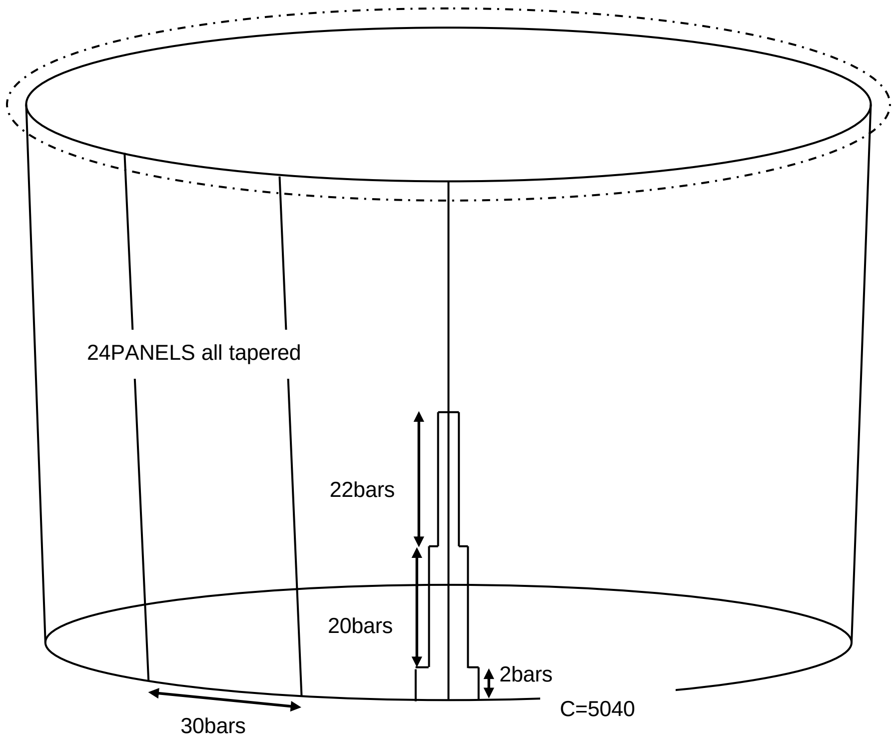


Figure 10 : Model Grow-out Netting modifications

These modifications were successful in that with the scaled weights the base depth was greatly reduced, even approaching that of the current full size nets where the grow-out net base has a typical depth of 2m.

Similar modifications were performed to the predator net, however as the choice of percentage reduction in the base diameter was limited to the bar length, nine bars from the radius were removed from the base, such that the base was undersize by approximately 4%. This proved excessive as the base then became flat, but the base circumference, and thus the side panels, lost all tension.

Substantiation of the model netting under flow conditions, to that of full size netting under scaled flow conditions, was then determined to be a major factor in progressing with the model with any degree of confidence. Data of full size netting in static and flow conditions was gained from 2 sites being Aquatas-Sheppards, and HAC-Garden Island. Due to the inaccuracies involved in the reading of the HAC-Garden Island flow speeds(propeller log variation thought to be due to pen heave) the HAC-Garden Island deflections were discounted. TDRs(accuracy ± 0.5m) were also attached to the Aquatas grow-out netting at four points on the grow-out net base; these results concurred with those taken by the divers in that the depth doesn’t change with the maximum current flow seen at this site. The Aquatas-Sheppards data is provided in the table in the following section.

5.5 Full Size Pen Measurements at Aquatas – Sheppards

Site/Environmental	
Site title of pen location	South eastern most pen on The Sheppards lease
Water depth in meters under pen	24 m total depth
Pen	
Pen size	120m
Separation distance between grow-out & Predator	Nominal 1m
Number, location and sizing of mooring points on pen	4
Grow-out	
Material(eg. Nylon, polyester, HMWPE)	Nylon
Denier/Ply(eg. 210/150)	210/180
Stretch mesh distance in mm	40ID bar
Surface treatment(antifouled?, tarred?, other-specify). Detail age of any treatment.	White(Untarred, not antifouled)
Depth(eg. 8mside+2mbase)	10m
Taper	5%
Number of panels	24
Describe ballast weighting system(shared, porthole, other-specify)	Air bag deflated for duration of measurements
Number and weight(in kg) of ballast weights fitted.	24x100kgIA approx 70kgIW concrete tyre weights, shared method.
Gate arrangement?, describe. Position relative to leading or trailing water flow.	Trailing
Predator Note: No netting specification's sighted	
Material(eg. Nylon, polyester, polyethylene, HMWPE)	Nylon
Denier/Ply(eg. 210/12x16)	210/12x16
Stretch mesh distance in mm	305
Surface treatment(antifouled?, tarred?, other-specify). Detail age of any treatment.	Black-tarred, unantifouled.
Depth(eg. 8mside+2mbase)	15m
Taper	Advised as 0%[as 1.6m in static from plumb, taper is nominally 7.9%]
Number of panels	24
Describe ballast weighting system(shared, porthole, other-specify)	directly hung.
Number and weight(in kg) of ballast weights fitted.	24x100kgIA (approx 70kgIW) pendulum + 24x50kgIA(approx 30kgIW) pendulum concrete tyre weights..
Gate arrangement if any, describe.	None.

Table 9 : Full Size Pen Specifications at Aquatas – Sheppards

Note: An air bag is a fabric bag with tie strops that is capable of holding air and providing a degree of positive buoyancy.

No	Required measurement	Measurement entry			
1	Current flow	Static(2.2cm/s) at 10mdepth			
2	Base depth around circumference of grow-out net	9.75m flow in-line	10.0 normal to flow	10.1m flow in-line	10.1m normal to flow
3	Diametric measurement of grow-out net at bottom circumference	33.1m flow in-line		32.8m normal to flow	
4	Centre depth of grow-out net	12.8m			
5	Measurement from vertical plumb-line on outside of outer pipe to base circumference of grow-out net	3.45m. 1.60 to predator net			
6	Diametric measurement of inner HDPE pipe at surface(inside pipe to inside pipe)	37m. flow in-line pipe ring not perfect circle!		34.9m. normal to flow	

Table 10 : Static Measurements of Full Size Pen at Aquatas – Sheppards

No	Required measurement	Measurement entry			
1	Current flow	37.5cm/s at 10mdepth			
2	Base depth around circumference of grow-out net	8.5m flow in-line	10.0 normal to flow	10.2m flow in-line	10.5m normal to flow
3	Diametric measurement of grow-out net at bottom circumference	31.5m flow in-line		32.7m normal to flow	
4	Centre depth of grow-out net	13.0m			
5	Measurement from vertical plumb-line on outside of outer pipe to base circumference of grow-out net	8.1m. Predator net was touching the grow-out net for most of its depth			
6	Diametric measurement of inner HDPE pipe at surface(inside pipe to inside pipe)	38.4m flow in-line pipe ring not perfect circle		34.6m. normal to flow	

Table 11 : Flow Measurements of Full Size Pen at Aquatas – Sheppards

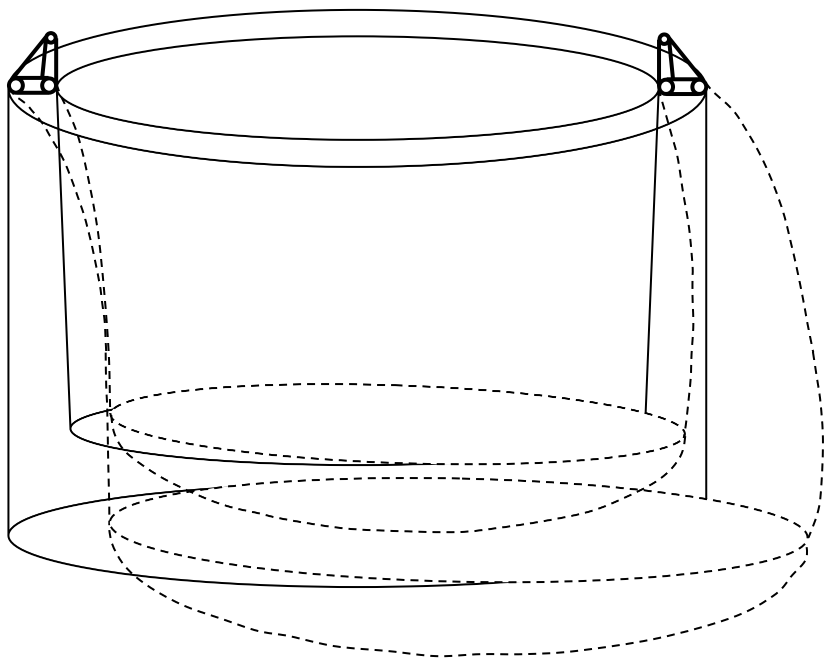


Figure 8 : Depiction of pen under “max” flow at Sheppards site

The gross result from these site measurements is that the volume loss from current flow is not as significant as previously thought. As the volume calculation of a parallelpiped is the base area multiplied by the vertical height, and there is no significant change in the depth at this current flow, it can be concluded that there is no appreciable loss in volume.

5.6 Matching of Model to Full Size Measurements

Testing was then performed in the flume tank to try and match the model netting deflections to those seen by the netting of the Aquatas full size pen. The methodology was by trialling different weights on the model nets to achieve similar deflections.

Flow m/s	Horizontal deflection mm	Vertical deflection mm
Full Size Aquatas grow-out.		
0.375*(1/20)^0.5=0.084	(8.1-3.45)/20=232.5	((9.75+10+10.1+10.1)/4-8.5)/20=74
Model grow-out. 72 bars depth, approx 6.6% taper, 24off 18.5gIW weights		
0.085	179	103
Full Size Aquatas predator.		
0.375*(1/20)^0.5=0.084	(8.1-1.6)/20=325 minimum as contacting grow-out net	Not recorded.
Model predator. 76 bars depth, approx 19% taper(no tension in side panels), 24off 8.3gIW weights		
0.085	270	124

Table 12 : Full size Aquatas net deflections tabled against model deflections

Upon scaling the model grow-out net weights, there is no correspondence with the full size weights that were hanging during the measurements. The predator net scaled weights however do correspond closely with those of the full size predator net(24x0.0083x20^3≈1560) when it is considered that there are several factors that cannot be taken into account, namely the marine growth on the full size predator net and the additional drag from the concrete tyres(in difference to the point masses used on the model).

Variations in the drag coefficient are significant when marine fouling is present. This is tabled in Milne P.H. 1972, and one case example is extracted below.

Material	Bar length, a mm	Netting state	Twine diameter, d mm	Solidity	Cd
PA, diamond	25.4	clean	2.29	0.090	1.416
		fouled	10.16	0.4	3.985

Table 14 : Indicative drag coefficient variation(source Milne 1972)

Figure 11 : Model representation of Aquatas-Sheppards at maximum flow(37.5cm/s)

5.6.1 Flexible Frame Model

The flexible frame model was constructed where the stiffness of the PE pipe was represented by steel wire(OH Slaattelid, 1990). The calculations have been provided for posterity.

The flexible model was tested in the Flume Tank and drag measurements were taken from two mooring points at 45 degrees to the flow using 350N strain gauges. Visual observations showed that the model stiffness under flow conditions represented that of a full size pen.

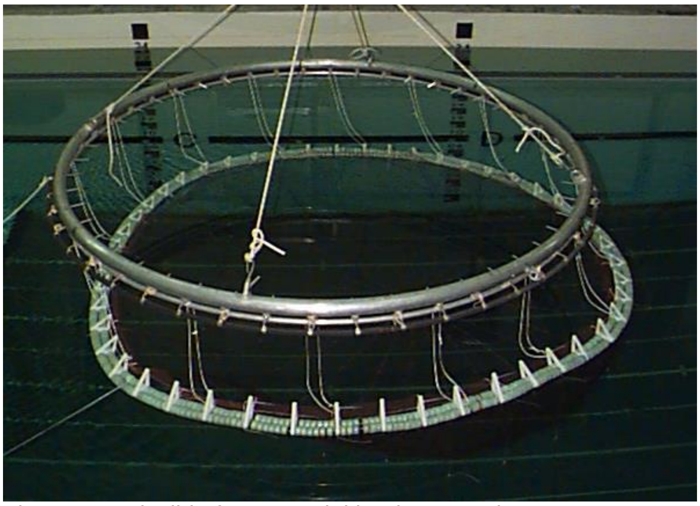


Figure 12 : Flexible frame model in Flume Tank

Flow speed m/s	Mooring line	Model Drag(Grow-out net only) grams force	Full Size Drag N
5.6% ≈ 0.085	1	0.172	95.6
	2	0.128	71.2
7% ≈ 0.105	1	0.257	93.7
	2	0.214	78.0
9% ≈ 0.15	1	0.382	68.2
	2	0.344	61.4

Table 14 : Mooring loads on grow-out netting for 1 knot full size current.

Calculated according to Fridman A. 1986.

$F_p = F_m \cdot S_f$

$\quad = F_m \cdot (S_\rho \cdot S_v^2 \cdot S_L^2 \cdot S_d / S_m)$

Now,

$S_\rho \approx 1$

$S_v = 0.515/Vm$ (1 knot/recorded flow)

$S_L = 20$

$S_d = 6.98$

$S_m = 414/0.229$ (calculated full size base weight/weight model base)

Note: the above figures are unchecked.

EQUIVALENT MODEL CALCULATION					
General					
Model scale	S	=	20		
Model steel Youngs Mod	eM	=	2.06E+11	MPa	
HDPE Youngs Mod	E	=	1200	MPa	ASTMPE80B 1070MPa at 23deg+/-2deg.Marintek 1500MPa 10deg/T=5-8sec/11MPa stress amp limit
Stiffness - Inner Pipe					
EI	EIi	=	230146.3	Nm^2	E*PI()/64*(IPOD^4-(IPOD-2*IPWT)^4)/1E6
Equiv model bend stiffness	eiMi	=	0.0719	Nm^2	EIi/S^5
steel diameter	sdMi	=	1.63	mm	1000*(64*eiMi/PI()/eM)^0.25
Adopt inner model wire dia	IWD	=	1.60	mm	3.15/2.0/1.6/1.25mm available
Stiffness - Outer Pipe					
EI	EIo	=	230146.3	Nm^2	E*PI()/64*(OPOD^4-(OPOD-2*OPWT)^4)/1E6
Equiv model bend stiffness	eiMo	=	0.0719	Nm^2	EIo/S^5
steel diameter	sdMo	=	1.63	mm	1000*(64*eiMo/PI()/eM)^0.25
Adopt outer model wire dia	OWD	=	1.60	mm	3.15/2.0/1.6/1.25mm available
Stiffness - Handrail					
EI	EIhr	=	5123.8	Nm^2	E*PI()/64*(HOD^4-(HOD-2*HWT)^4)/1E6
Equiv model bend stiffness	eiMhr	=	0.0016	Nm^2	EIhr/S^5
steel diameter	sdMhr	=	0.63	mm	1000*(64*eiMhr/PI()/eM)^0.25
Adopt model wire diameter		=	0.60	mm	3.15/2.0/1.6/1.25mm available
Wire					
Inner wire pen dia	IWCD	=	1922.1	mm	
Inner wire circum	IWC	=	6038.455239	mm	PI()*IWCD
Outer wire pen dia	OWCD	=	1988.8	mm	
Outer wire circum	OWC	=	6247.999469	mm	PI()*OWCD
Crimp	CRPM		0.030	kg	
Stanchion					
Stanchion area	SA	=	1962.2325	mm^2	
Stanchion plate thickness	Splt	=	10.0	mm	
Stanchion material density	Sden	=	985	kg/m^3	
Stanchion mass	Smass	=	0.0193	kg	
Inner radius	SIR	=	10.8	mm	
Outer radius	SOR	=	10.8	mm	
Distance between radii centers	SCC	=	39.8	mm	Redrilled as larger divinycell cylinder diameters used on account of expected bomb weight increase.
Divinycell - Inner					
Divinycell cylinder diam	DCDi	=	27.5	mm	"Gamflex" hole saws avail OD/ID=(20)19/16.8,(22)21.6/19,(25)24.6/22,(30)29.4/26.4,(32)31.1/28.1. Adopt size 32 with 27.5ID as conservative
Divinycell cylinder lgth	DCLi	=	14.5	mm	Adopt 14.5mm as water absorption on outer sheet…
Divinycell cylinder wire hole dia	DCHDi	=	2	mm	Adopt 2.0 as conservative
Divinycell cylinder vol	DCVi	=	8.56683E-06	m^3	
Total no divinycell cyls	DCNi	=	288		48*4@20mmLG20Pl. 48*6@15mmLG10Pl.
Total vol	DCVtoti	=	0.002467247	m^3	

Divinycell - Outer					
Divinycell cylinder diam	DCDo	=	27.5	mm	"Gamflex" hole saws avail OD/ID=(20)19/16.8,(22)21.6/19,(25)24.6/22,(30)29.4/26.4,(32)31.1/28.1. Adopt size 32 with 27.5ID as conservative
Divinycell cylinder lgth	DCLo	=	14.5	mm	Adopt 14.5mm as water absorption on outer sheet…
Divinycell cylinder wire hole dia	DCHDo	=	2	mm	Adopt 2.0 as conservative
Divinycell cylinder vol	DCVo	=	8.56683E-06	m^3	
Total no divinycell cyls	DCNo	=	288		48*4@20mmLG20Pl. 48*6@15mmLG10Pl.
Total vol	DCVtoto	=	0.002467247	m^3	
Bombs					
No off	BMN	=	0	off	
Weight in water	BMW	=	0	g	0.924*45.1g
O-ring spacers					
BS004	ORN	=	1344	off	(14inner+14outer)*48=1344
Weight	ORW	=	0.04371	g	1350off weigh 59g
Densities					
Proposed divinycell density	DCden	=	65	kg/m^3	Nominal values. DC:H45=48kg/m3, H60=60kg/m3. EPS: SL=13.5kg/m3 H=24kg/m3
Flume/Wave Tank water density	Wden	=	1000	kg/m^3	
Totals					
Inner wire mass	IWM	=	0.0953	kg	PI()*IWD^2/4*IWC/1E9*7850
Outer wire mass	OWM	=	0.0986	kg	PI()*OWD^2/4*OWC/1E9*7850
Crimps	CrM		0.0600	kg	
Total stanchion mass	SmassTot		0.928	kg	SN*Smass
Total divinycell mass	DCM	=	0.3207	kg	(DCVtoti+DCVtoto)*DCden
Total bomb mass	BMtot	=	0.0000	kg	
Stanchion buoyancy	SB		0.0196	kg	SA*Splt/1000000000*Wden
Divinycell buoyancy	DCB	=	4.934	kg	(DCNi*DCVi+DCNo*DCVi)*Wden
Total negative mass	NMmod		1.502	kg	
Total buoyancy	Bmod		4.95	kg	SB+DCB
Floatation Height Determination					
Is water ht above cl?			no		IF(NMmod>Bmod/2,"yes","no")
Choose pheta	pmod		138.00	deg	If yes then pmod>180, if no then pmod<180
If yes(or approx 180deg), solve for 0			0.008		takes account of dc center hole and "full" wire diameters
If no(or approx 180deg), solve for 0			-0.098		
Depth of floatation relative to cl	DFMrelcl		-4.9276	mm	-COS(pmod*PI()/180/2)*DCDi/2
Depth of floatation above bottom	DFMbot		8.8224	mm	DCDi/2+DFMrelcl
Floatation ht % off bott			32.0816	%	DFMbot/DCDo*100

Table 15 : Flexible Frame Model Calculations

5.7 Net Tensioning

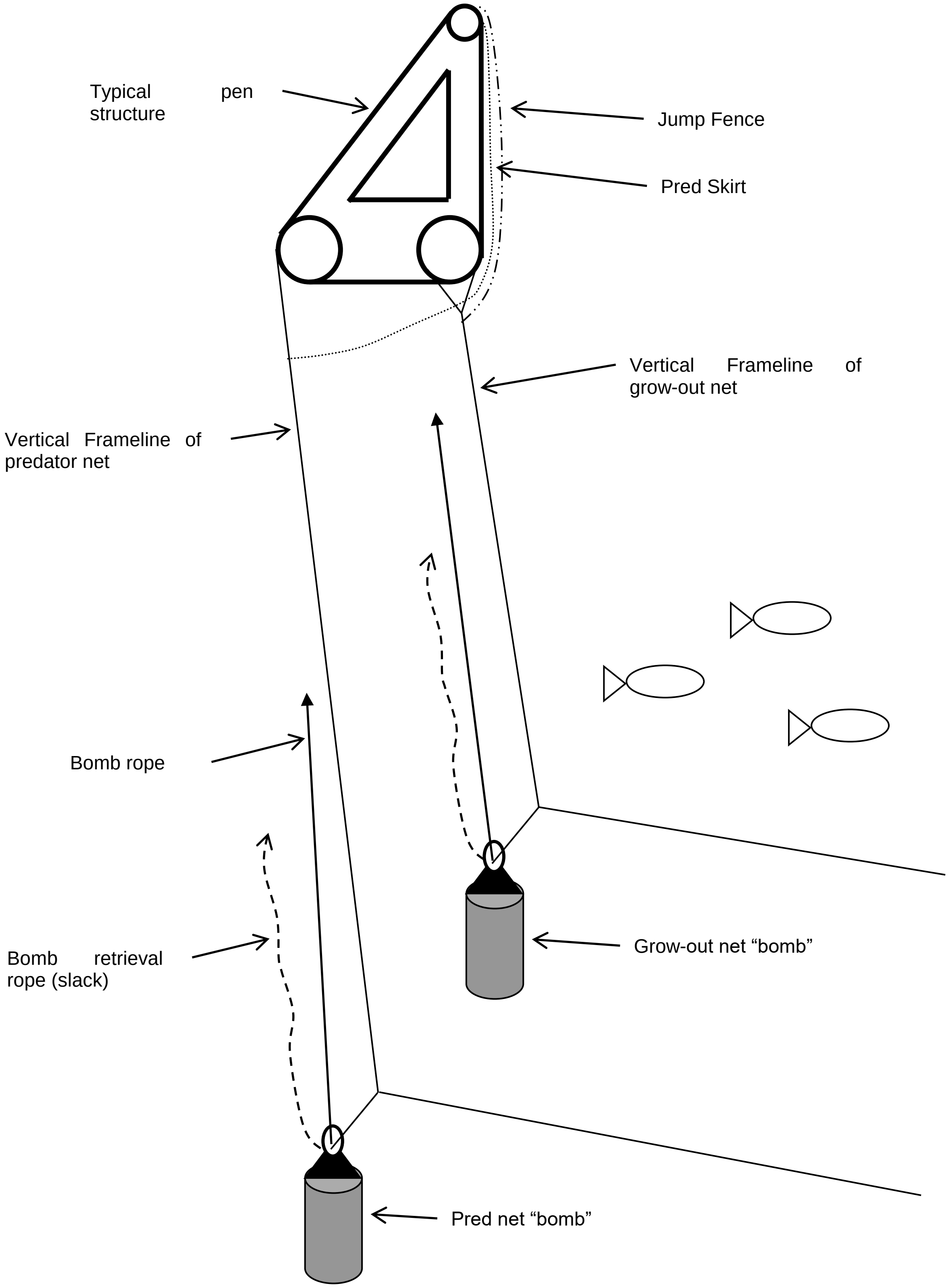
Net tensioning, through the hanging of weights to the base circumference, on the grow-out netting is primarily required to hold the netting taut such that the fish stock have a defined volume within which to live. Predator netting likewise requires weighting to hold the netting taut such that predators find a barrier to which access to the fish stock is made difficult.

Correctly designed and tensioned nets thus maximize the volume for the fish, reduce any possible stress to the fish from “free” boundaries and make it far less likely for any fish to be trapped in an ill-taut section of netting by a seal. Ultimately, the salmon industry wish for a design that is adequately manageable and taut such that only a grow-out net is required.

There are several methods used in tensioning the current netting systems. These are described schematically below. Typically 100kgIW weights are utilised; these are called “bombs” due to their shape and colour. Alternatively, tyres filled with concrete are utilised.
Note: “Slender” bomb like shapes are hydro-dynamically preferable to concrete filled tyres due to area and drag force coefficient differences.

5.7.1 Shared Method

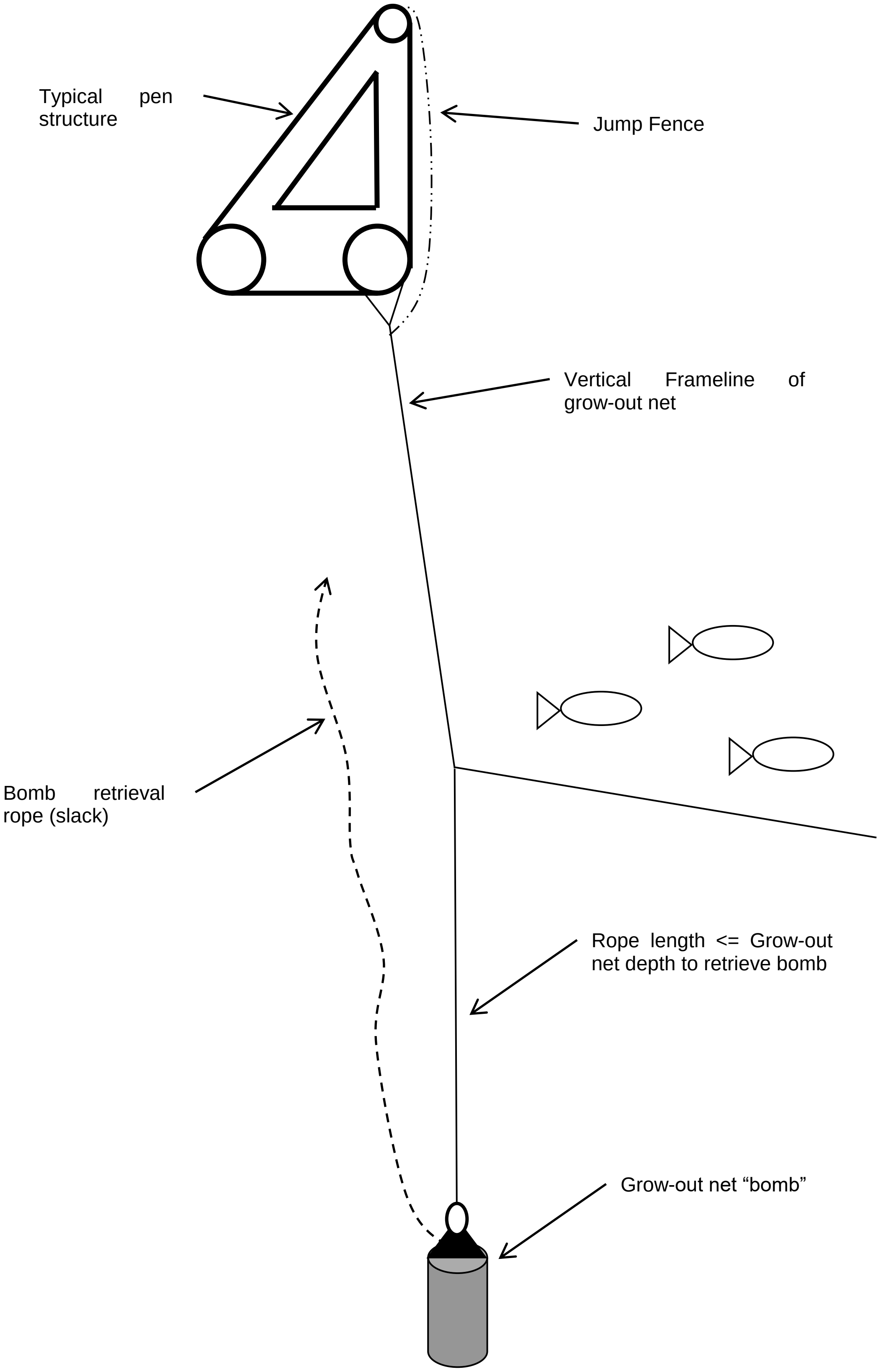
This is typically where half the bomb weight is utilised as it is hung on a rope from the vertical frameline back up to the pen structure where it is tied off. This is the most typical arrangement across the Tasmanian aquaculture industry.



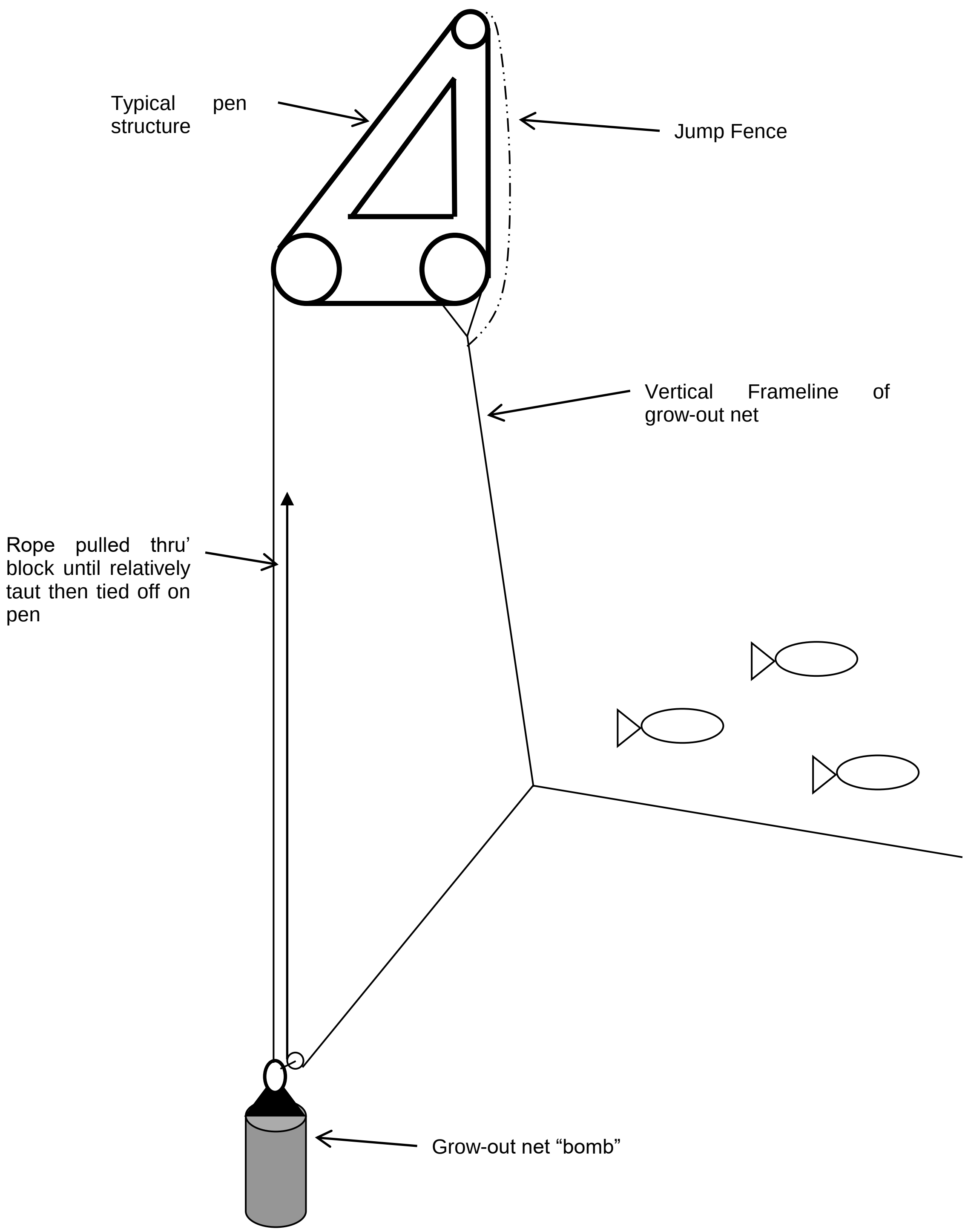
One disadvantage of this system is that the bomb weights on the grow-out net have the potential to foul/hole the predator net should they become unrestrained.

5.7.2 Pendulum Method

This method provides greater weighting to a net as it utilises 100% of the bomb weight, but can only be achieved in relatively deep water sites.



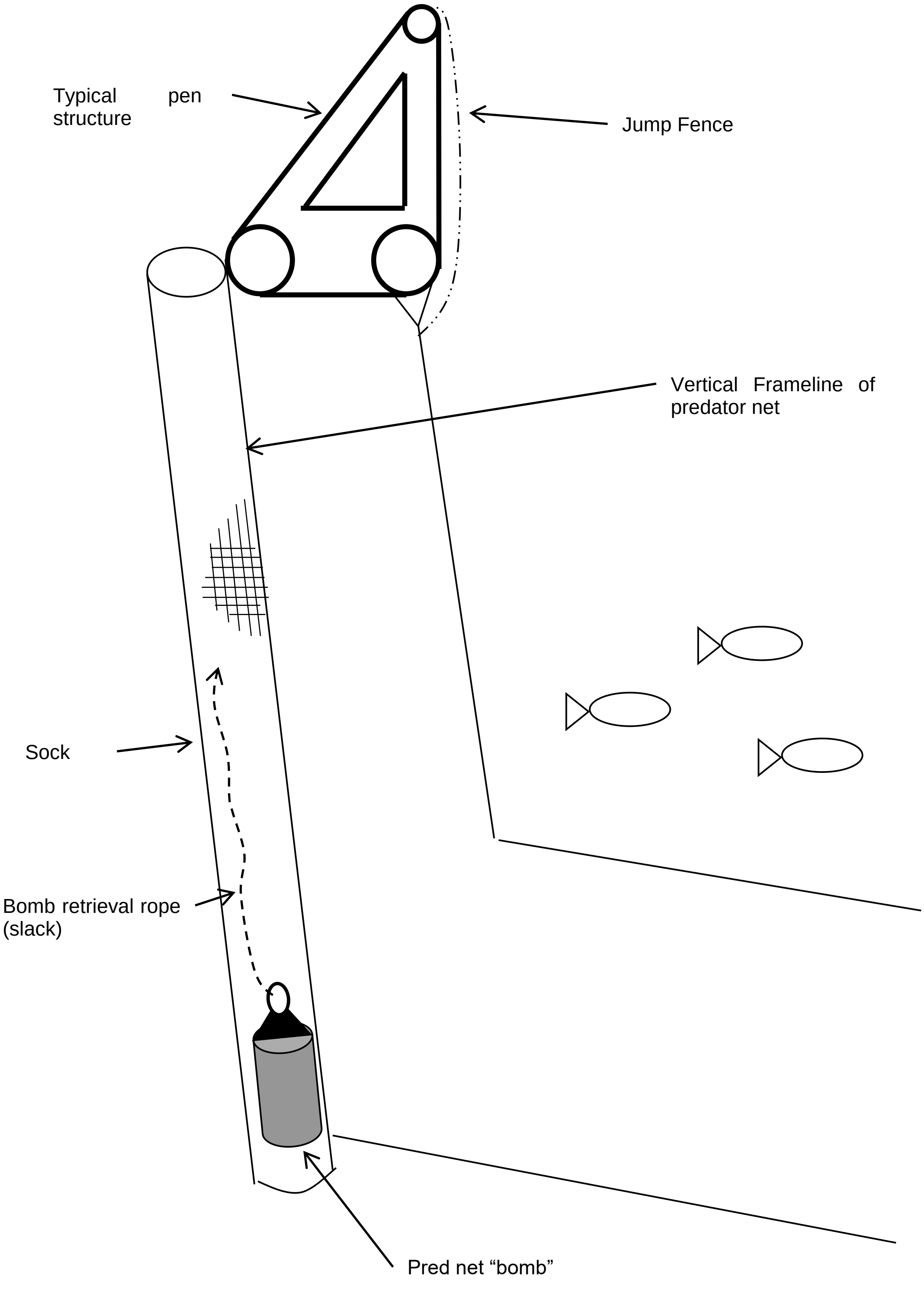
5.7.3 Free Hanging Method



With this method the bomb is typically hung 1m below the grow-out net and the bomb weight is transferred onto the grow-out net when tension is taken up on the vertical rope. The method is in fact a variation of the Shared Method. This method is employed by a salmon farmer in Macquarie Harbour and by the tuna industry typically.

5.7.4 Sock Method

This is where the bomb weight is dropped into a sock of netting attached to the outside of the net. 100% of the bomb weight is utilised. Typically weights by the Shared Method, explained in a previous section, are attached to the grow-out net.

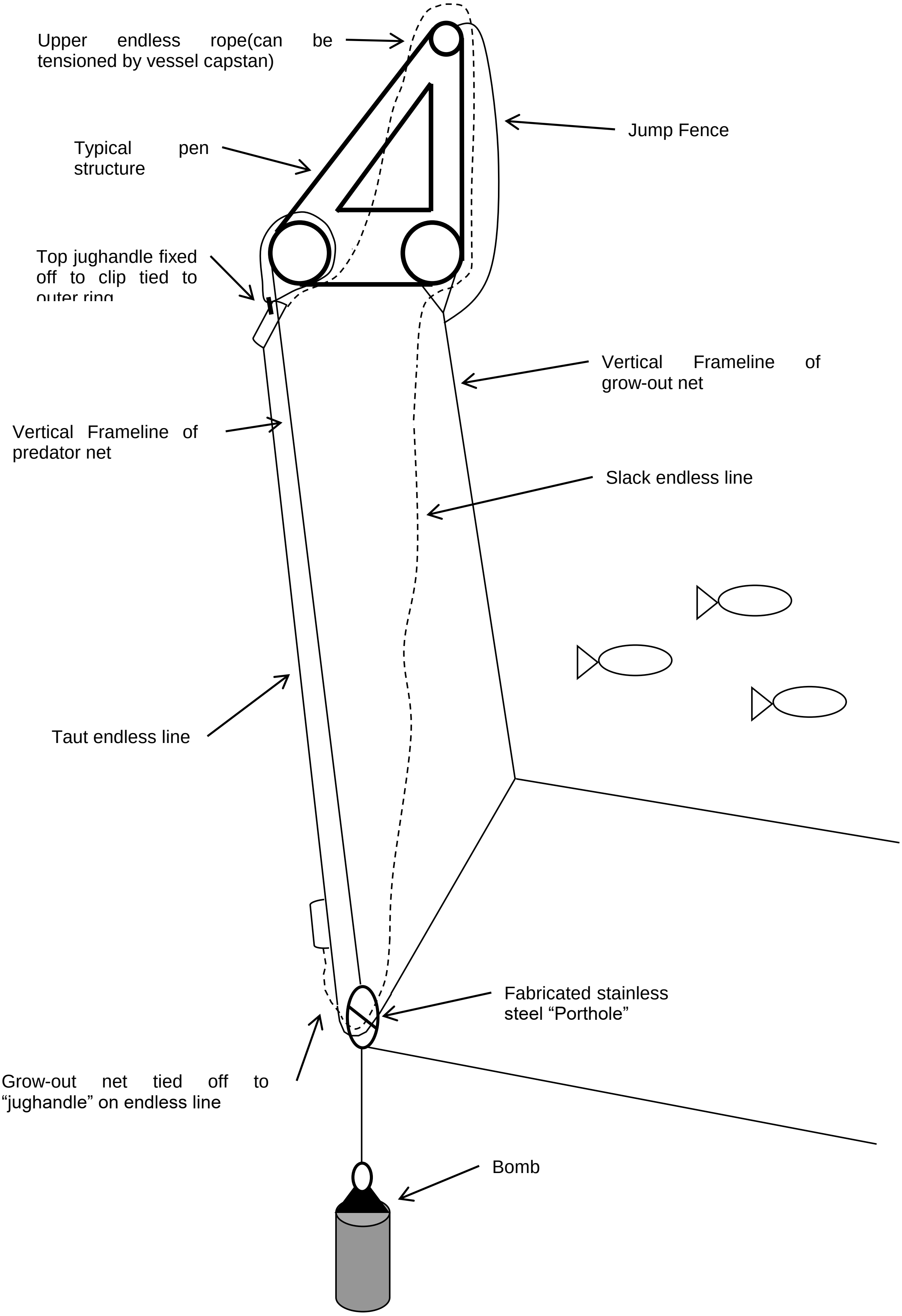


There have been reports of difficulties experienced in removing the bomb weights from the sock.

Typically double mesh is provided in the bottom section of the sock to prevent possible tearing should the bomb be released unrestrained into the sock from the surface.

5.7.5 Porthole Method

This is where weights are hung only off the predator net, the grow-out net being tied at a fixed distance from the predator net.



The predator net can be described as tensioned relatively taut due to the direct tensioning from the bomb weights; whereas the grow-out net could be described as relatively slack. The tension transferred to the grow-out net is determined by the tension applied to the endless line. Tension is normally applied through use of a vessel capstan winch. The advantage of the system is the articulation of the grow-out to the predator net, so in relatively high flow or wave conditions the grow-out net and predator net remain separated at the base circumferences.

As an example of lengths required; if the grow-out net were 6.5m depth, then the connection rope from the grow-out base to the lower jughandle would be circa 9m long. It must be noted that the distance between the two jughandles is very important as it governs the stiffness of the coupling between the grow-out net and predator net.

5.7.6 Concertina Bomb Attachment

A simple method of attaching 100% of the bomb weight, as an alternative to the sock method, and without the requirement for divers, was trialled late this year at Tassal Nubeena on the Porthole arrangement. It involves the sequenced attachment of the bomb weights. Firstly, 12off weights are attached to the predator net and lowered approximately half the full depth; then the remaining 12off weights are attached and lowered to the full depth, the first 12 weights are then fully lowered. The method is dependent upon the degree of taper in the predator netting and attaching the bomb weight to the predator net with sufficient slack to enable connection at the surface.

5.8 Net Making

5.8.1 Net Design and Manufacture

To ultimately stop seals the netting needs to be taut, similar to a barrier fence, whether it be the predator or grow-out netting, or both To achieve tautness, even tension throughout the whole netting panels is required. Imagine grow-out netting so taut that a seal cannot "fold it over" and access a fish - a predator net would then not be required. Tarred/Antifouled nets attempt to mimic this through increased net stiffness.

In summary, the problem in attaining this is that there are three distinct areas of net design. These are :

1. the side framelines and the base circumferential rope,
2. the base diametrical framelines(largely based on the base circumferential rope), and
3. the netting(typically considered as infill panels).

Simplistic determination of the exact load paths between the three design areas is difficult.

Starting with the side framing ropes, bomb weights typically hang down the tapered side ropes and attempt to obtain their equilibrium position by moving out and directly under their hanging point. In doing this the bottom circumferential rope is made relatively taut. Adding the base diametric framing ropes now appears easy, yet there are two major considerations to take into account.

The first consideration is whether the bomb weights have provided sufficient tension in the bottom circumferential rope such that the theoretical base diameter has been obtained. As an indication of the amount of stretch in ropes typically used in 120m FCPEP pen net manufacture, refer to the table below. Considering a bottom circumferential rope is circa 120m there could be a relatively small, or large, elongation over the whole circumference, dependant upon what degree of tension is imparted to the rope from the bomb weights.

Rope particulars	Elongation	
	Time=0	Time=11hours
PP 18mm dia 10m length	250mm	295mm
PP “Superdan” 20mm dia 10m length	325mm	330mm

Table 16 : Stretch test results of typical frameline material

The second consideration is to what degree does the total weight of the base(frame-lines and netting) cause the bomb weights to move in and decrease the base diameter. Typically net-makers adopt a reduced base diameter of between 5-8% to account for this. The evolvement of these net designs and their understanding to this point has taken many years and is a credit to the Tasmanian net-makers.

To date local net-makers provide as flat a base as possible(1-2m sag/depth between outside & center of base) whilst attempting not to impinge on the tension in the bottom circumferential rope. Even if a more than adequate buffer distance between the predator and grow-out nets exist at the side panels, the problem with insufficiently tensioned bases would continue to exist.[Note, the bomb weights could be increased to say 500kgIW and a sufficient force could be transferred into the base frame-lines though such relatively large weights are hardly practical.]

Even if a net-maker achieves a “good” balance between the side and base frame-lines, such a net design is difficult to achieve to perfection as:

- Materials change within an order and even within batch runs;
- PA material shrinks and stretches; and
- Manufacturing inaccuracies.

Matching the tensioned frame-lines to the netting material is also important and can affect the tension through the overall structure. To make netting taut one needs to tension every vertical and horizontal bar. Now, net makers attempt to give farmers a net that is functional and possesses the required longevity. For example, the number of bars to be counted between side frame-lines is calculated theoretically, based on the net manufacturer supplied information. Also, when making nets, a nominal tension is typically hung off one end of the framing rope and the netting is “brought up to” and made fast to the framing-rope. Net-makers typically use a nominal tension weight, approximately half the typical 100kgIW bomb weight, implying that once the net is in the water and “set” with the 100kgIW weights that a proportion of the net will be tensioned also. It is thought that any further attempts to pretension the netting would ultimately result in torn netting and the loss of the net-makers reputation.

Often, the farming industry requests modifications to the netmakers design, or affects changes onsite, which can impede and/or aid predation. Typically:

- Lengths of lead line sown into the base frameropes. Eg. 5m cross on the predator base centre of 3kg/m leadline;
- Airbag to center of grow-out net;
- “pinkie”(concrete ball) in centre of grow-out net; and
- Sinker ring in centre of grow-out net(typically on smaller pens, “lightweight” ring 8kg/m).

Qualifying such modifications and/or changes as definitively beneficial to reducing predation is difficult. As an example, adding an airbag to the grow-out net base centre raises the base, implying that a seal would require more effort to lift the predator net further to gain access to any fish/morts lying in the grow-out net base; but then any morts would not be lying in the centre of the base due to the air bag but rather in a moat around the base circumference, so a seal would be required to lift the predator netting base relatively close to any bomb weighting.

5.8.2 Base Design

Base design has evolved over the years from a simplistic polygon cut out from one piece of netting, to the current “pie cutter” type design. The current pie cutter design is not 24off “pieces of pie” to match the typical 24off sidepanels, but rather an eight sided polygon where each of the eight pieces match three panels in a 24 side panelled net. The two outside diametric frameline of a piece of such a pie is made to the base diameter(minus 3-5%). Such a design greatly reduces the manufacturing time, and thus the cost, for a base.

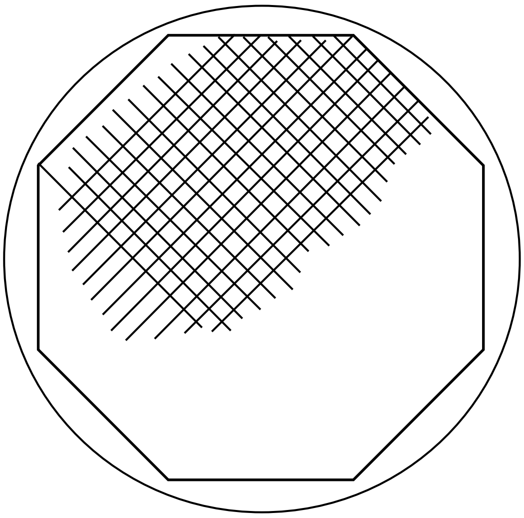


Figure 13: One piece base design with theoretical circumference shown.

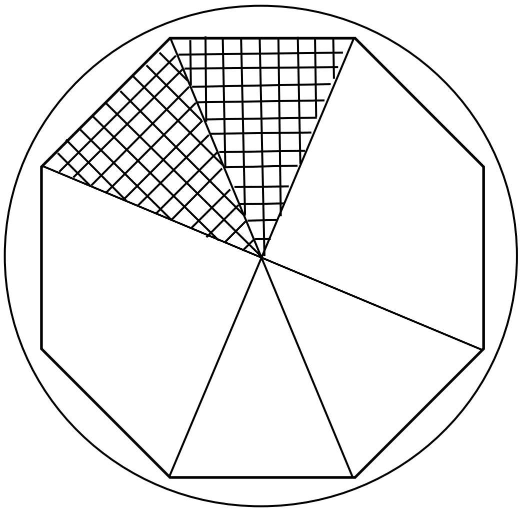


Figure 14: “Pie cutter” base design with theoretical circumference shown.

The reason for changing to a “pie cutter” design is thought to have been due to the one piece design being too flexible, that is tension was not evenly distributed across the netting as it was free to move to its equilibrium position.

5.8.3 Taper

Tapers are typically employed on both grow-out and predator nets. Their effect is to distribute the bomb weight between the side frameline/netting panels and the base framelines/netting panels. This can be seen below where a comparison of 5% and 10% tapers is shown for a 120m pen at the typical grow-out net depth of 10m. The base is assumed to be flat/horizontal. It can be likened to the lifting of a mass at two points, where it is recommended that the included lift angle be always less than 60 degrees, otherwise the tension in the lift lines becomes “excessive”.

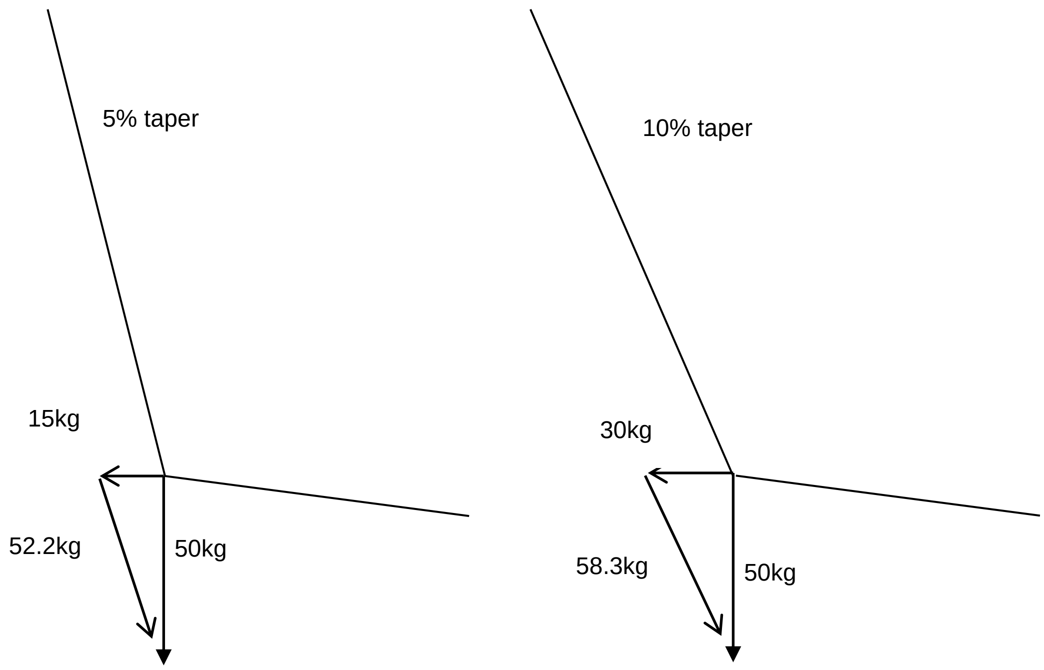


Figure 15: Simplistic bomb weight force distribution diagram depicting difference in base tension from 5% to 10% taper

It must be noted however that the horizontal tension is distributed between the diagonal framelines and the base circumferential frameline.

Adding tapers to the side panels reduces the grow-out volume by approximately the taper angle adopted(refer to the table below).

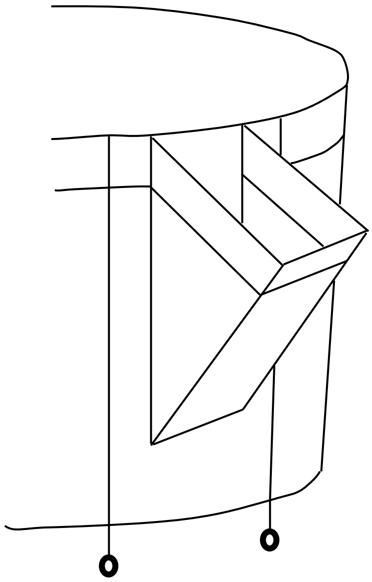
Taper % 	Top diameter m	Bottom diameter m	Volume m3	Change in volume from zero taper %
0	37.8822	37.8822	11270.9	0
10	37.8822	34.09397	10181	9.7
20	37.8822	30.30575	9167	18.7

Table 17 : Volume change for various tapers of typical pen with 10m depth grow-out net

5.8.4 Swim Through Gates

Swim through gates are common place on grow-out nets. The gates are fold out rectangular flaps of netting that enable fish to be transferred from pen to pen/pen to fresh water liner. They are typically fitted into a side panel and are a size of 5m drop and 2.5m wide.

Figure 16: Typical swim-through gate arrangement



When not in use the extra netting material in the gates is drawn together and made taut, then fastened onto the parent netting material in the panel.

Zippered sections of netting have been trialled in the past without success as the zips failed.

5.9 Stocking Densities

Although obvious, it is often overlooked that stocking densities play an important part in predation attacks. The higher the stocking density, the higher the rate of attack probability, as it is more difficult for the fish to escape to free water within the pen. For salmon aquaculturlists stocking densities vary as per the table below:

Density kg/m^3	Category
15 – 20	Heavy
10	Average
5	Low

Table 18 : Salmon industry accepted stocking density labels

Densities within Tasmanian farms are <15kg/m^3, typically <10kg/m^3.

The tuna industry typically farms with densities of up to 4kg/m^3. This reduced density, in comparison to salmon, is because tuna are ram ventilators and require much larger amounts of oxygen to survive.

5.10 Buoyancy Considerations

The buoyancy of the pen structures is important as it governs the maximum weight that can be employed in tensioning the net. It was noted from a site visit to Tassal Redcliffs, and discussions with Tassal personnel, that just prior to a net change(marine growth considered a maximum) when there was a degree of wave action, that a 120m pen, 2x 315Ø pipes, total 48off 100kg weights on grow-out and predator nets(hang by shared method) was considered the maximum weight that could be suspended, without submerging the pen; naturally in such a situation there are numerous safety concerns to be remembered when farm personnel are on the pen! Albeit such an arrangement, by theoretical calculations, equates to the water level being some 20mm below the pipe centre. The explanation for this is largely due to the typical mooring arrangements of the pens, and the amount of marine growth on the nets resulting in a relatively "high" drag force bearing on the leading edge of the pen. Figures illustrating a typical grid mooring and mainline mooring arrangement are provided for illustrative purposes only below.

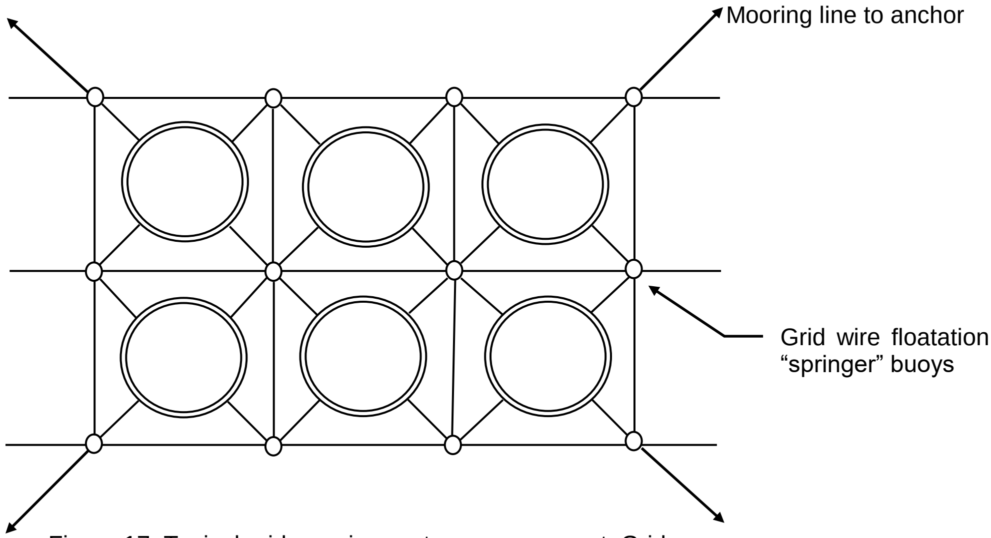


Figure 17: Typical grid mooring system arrangement. Grid wires typically at 5m WD.

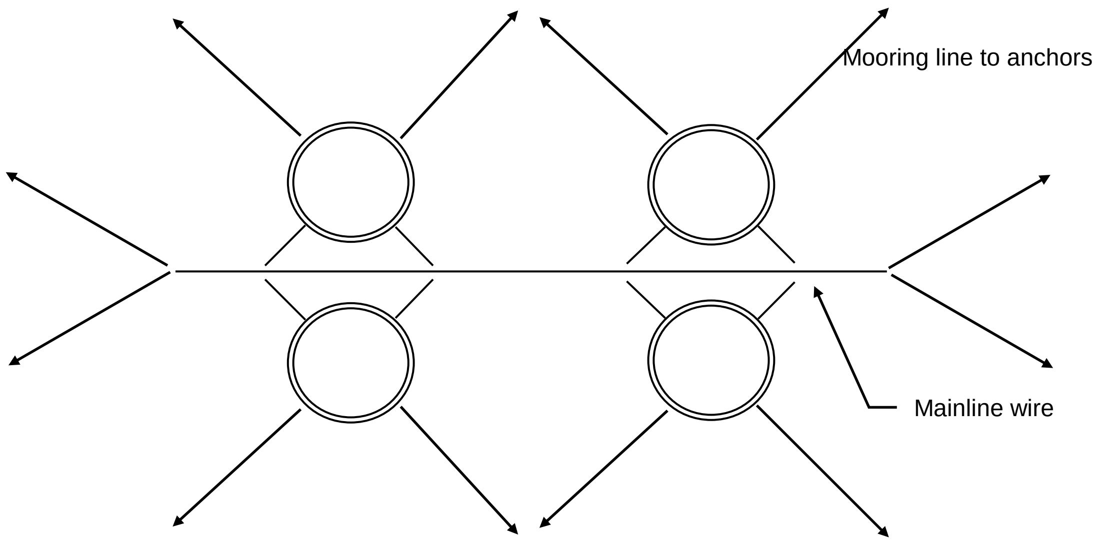


Figure 18: Typical mainline mooring system. Wire typically at 10m WD

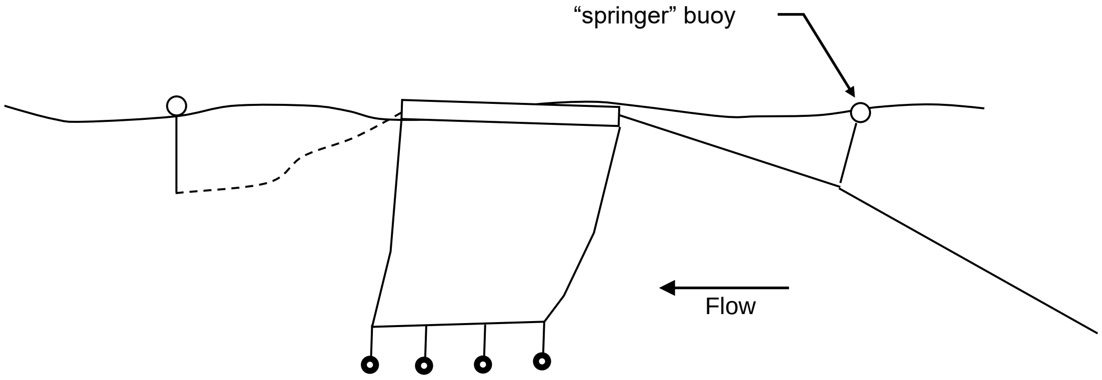


Figure 19 : Typical profile of grid mooring arrangement of pen

Note: tying off the leading edge mooring lines has an important effect.

[Note: check calculations were also performed to determine to what significant effect should both the 315Ø pipes be "holed". No significant effect was calculated as the pipes are filled with polystyrene foam, though it does prove the significance of using polystyrene foam].

In summary, the configuration of 24 off 100kg IW bomb weights hung in a shared manner on a typical 120m pen(grow-out and predator nets), is the maximum weighting in consideration of personnel safety.

With reference to the above, it is recommended that 20% of the Pen Buoyancy be adopted as the recommended weighting amount available for net tensioning. The Pen Buoyancy can be defined as the buoyancy supplied by the pipe rings minus the pen negative masses. That is the total pipe, handrail, polystyrene, security chain, stanchion and bird pole mass. These calculations are reflected in the table below.

A simplification of the calculation for a 120m, 2x315Ø, 19mmWT, pipe pen is expressed below, where a 10% deduction for the pen negative masses is made.

Pen Buoyancy ≈ 2*circumference*(PipeOD^2*seawater density – weight pipes)*0.9
≈ $2*120*(\pi*0.315^2/4*1025 - \pi/4*(0.315^2-(0.315-2*0.019)^2)*950)*0.9$
≈ 13628kg
Recommended available for net tensioning = 20%*13628kg = 2726kg

Note: It is insufficient to simply quote weightings per meter of pen circumference unless the buoyancy of the pen(pipe diameters and length, pipe WT) are also given. Generally however the average weighting per meter of pen circumference on 120m pens in Tasmania is 19.6kg/m.

From anecdotal evidence available, when the 100kgIW bombs are not hung in the shared manner but rather fully utilised through a “sock” arrangement, less seal strikes occur. Buoyancy calculations for this type of pen structure where the inner pipe is 400 OD and the outer pipe is 315 OD also concur with the recommended 20% of the Pen Buoyancy allowable for net tensioning.

FULL SIZE PEN BUOYANCY					
Densities					
PE density	PEden	=	950	kg/m3	Polyethylene density=950kg/m3
PS density	PSden	=	15	kg/m3	Polystyrene density=15kg/m3
Seawater density	SWden	=	1025	kg/m3	Salt water density=1020kg/m3
Netting,GO&Pred density	NETden	=	1140	kg/m3	Net material density, nylon=1040kg/m3
Inner Pipe					
Circum	IPC	=	120	m	10lgths 12m pipe
OD	IPOD	=	315	mm	Note:Plastic Fab Mk10/11 400OD
WT	IPWT	=	19	mm	MMitchell typ. SDR17 WT=18.7. Global typ. PN6.3 SDR 21 WT15-16.6
PS OD	IPPSOD	=	250	mm	
Outer Pipe					
Circum	OPC	=	124.7	m	
OD	OPOD	=	315	mm	
WT	OPWT	=	19	mm	MMitchell typ. SDR17 WT=18.7. Global typ. PN6.3 SDR 21 WT15-16.6
PS OD	OPPSOD	=	250	mm	
Handrail					
Circum	HC	=	120	m	
OD	HOD	=	110	mm	
WT	HWT	=	11.1	mm	Global typ PN12.5 SDR11 WT10-11.1max
Stanchion					
No off	SN	=	24	off	
Weight	SW	=	26	kg	Mmitchell typ 20kg.Adopt 26kg as conservative across "base" manufacturer stanchions
Chain/Spacer Pipe					
Circum	CC	=	122	m	
Weight/m	CW	=	8	kg/m	Typ Tassal 16mm(5.6kg/m), HAC/Nortas 13mm(3.8kg/m). Adopt 8kg/m as conservative.
Bird Poles					
No off	BPN	=	8	off	
Length	BPL	=	3	m	
OD	BPOD	=	110	mm	
WT	BPWT	=	11.1	mm	
Netting					
GO depth	GOD	=	10	m	
GO weight factor, paint/ropes/mg	GOx	=	1.20		>=1
GO weight/m2	GWpm2	=	0.45	kg/m2	Adjust as necessary(sample 17barx17bar,a=40mm,0.462m2=0.209kg)
GO weight in air, estim calc	GWA	=	1273.5	kg	
GO weight in water, estim calc	GWW	=	156.39	kg	
Pred depth	PredD	=	15	m	
Pred weight factor, paint/ropes/mg	Predx	=	1.20		>=1
Pred weight/m2	PredWpm2	=	0.22	kg/m2	Adjust as necessary(sample 210/19x16 305str(12"),0.58m2=0.127kg)
Pred weight in air, estim calc	PredWA	=	816.6	kg	
Pred weight in water, estim calc	PredWW	=	100.29	kg	
Bombs					
No off	BN	=	24		
Weight in water	BW	=	100	kg	Typ 140/100kg or 100/70kg air/water
Totals					
Inner Pipe mass	IPM	=	2014.2	kg	PI()/4*(IPOD^2-(IPOD-2*IPWT)^2)/10^6*PEden*IPC
Outer Pipe mass	OPM	=	2093.1	kg	PI()/4*(OPOD^2-(OPOD-2*OPWT)^2)/10^6*PEden*OPC

Handrail mass	HM	=	393.2	kg	PI()/4*(HOD^2-(HOD-2*HWT)^2)/10^6*PEden*HC
Inner PS mass	IPSM	=	88.4	kg	PI()/4*IPPSOD^2/10^6*PSden*IPC
Outer PS mass	OPSM	=	91.8	kg	PI()/4*OPPSOD^2/10^6*PSden*OPC
Chain mass	CM	=	976.0	kg	CC*CW
Stanchion mass	STM	=	624	kg	SW*SN
Bird Pole mass	BPM	=	78.6	kg	PI()/4*(BPOD^2-(BPOD-2*BPWT)^2)/10^6*PEden*BPL*BPN
Netting mass	NettingM	=	256.7	kg	GWW+PredWW
Bomb mass	BM	=	2400	kg	BN*BW
Total negative mass pen	NegMpen	=	6359.2	kg	IPM+OPM+HM+IPSM+OPSM+CM+STM+BPM
Total negative mass pen incl netg+bombs	NegMtotal	=	9015.9	kg	IPM+OPM+HM+IPSM+OPSM+CM+STM+BPM+NettingM+BM
Inner+Outer Pipe buoyancy	PipeB	=	19546.5	kg	PI()/4*(IPOD^2*IPC+OPOD^2*OPC)/10^6*SWden
Pen buoyancy	PenB	=	13187.3	kg	+PI()/4*(IPOD^2*IPC+OPOD^2*OPC)/10^6*SWden-NegMpen
Pen buoyancy with netg+bombs	PenBtotal	=	10530.6	kg	PI()/4*(IPOD^2*IPC+OPOD^2*OPC)/10^6*SWden-NegMtotal
%bomb mass/Pen buoyancy		=	18.2	%	100*BM/PenB. **Recommended not to exceed 20%**
Floatation Height Determination if consider pipe integrity OK					
Is water ht above cl?			no		IF(NegMtotal>PipeB/2,"yes","no")
Choose pheta	px		173.15	deg	If yes then px>180, if no then px<180
& solve for zero			14.70		SWden/1000000/8*(IPC*(IPOD^2*px*PI()/180+IPOD^2*SIN((360-px)*PI()/180))+ OPC*(OPOD^2*px*PI()/180+OPOD^2*SIN((360-px)*PI()/180)))-NegMtotal
Depth of floatation relative to IP cl	DFrelcl		-9.4	mm	-COS(px*PI()/180/2)*IPOD/2
Depth of floatation above IP bottom	DFbot		148.0950	mm	IPOD/2+DFrelcl
Floatation ht % off bottom of pipe			47.0143	%	DFbot/IPOD*100
Floatation Height Determination if consider pipe integrity HOLED					
Is water ht above cl?			no		IF(NegMtotal>PipeB/2,"yes","no")
Choose pheta	pxHOLED		186.40	deg	If yes then px>180, if no then px<180
& solve for zero			0.00		SWden/1000000/8*(IPC*(IPOD^2*pxHOLED*PI()/180+IPOD^2*SIN((360-pxHOLED)*PI()/180))+ OPC*(OPOD^2*pxHOLED*PI()/180+OPOD^2*SIN((360-pxHOLED)*PI()/180)))-NegMtotal- SWden/1000000*(IPC*((IPOD-2*IPWT)-IPPSOD)/2*((IPPSOD+IPOD-2*IPWT)*pxHOLED*PI()/180/4)+OPC*((OPOD-2*OPWT)-OPPSOD)/2*((OPPSOD+OPOD-2*OPWT)*pxHOLED*PI()/180/4))
Depth of floatation relative to IP cl	DFrelclHOLED		8.8	mm	-COS(px*PI()/180/2)*IPOD/2
Depth of floatation above IP bottom	DFbotHOLED		166.2883	mm	IPOD/2+DFrelcl
Floatation ht % off bottom of pipe			52.7899	%	DFbot/IPOD*100
Notes:					
-ignoring any bouyant effect x stanchions etc to remain conservative					

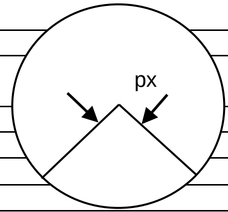


Table 19 : Buoyancy Spreadsheet

5.11 Netting Materials

Typically all grow-out & predator nets within the Tasmanian aquaculture industry are manufactured from PA material. PA is generically described as nylon. Grow-out nets are typically from knotless netting, whereas predator netting is knotted. Colour is insignificant for rearing salmon and as such black netting is the preferred choice as it typically offers better ultraviolet protection.

Knotless netting is chosen for the grow-out nets as it is of less weight than equivalent sized knotted netting, thus cheaper, and offers less resistance to drag. Knotted netting is typically chosen for the predator netting.

Netting is typically designated by a Denier/Ply(eg. 210/150) figure together with the stretched mesh size length. Denier is the weight in grams of 9000m of a single filament. Ply is the total number of filaments that make up the twine. Specifying nets without reference to the breaking strength is not recommended as breaking strengths can differ markedly dependent upon the manufacturer, variations in plastics(eg. Nylon 6 or Nylon 66), the manufacturing technique, and whether expressed as 'wet', 'dry', 'point to point' or 'bar'. European standards typically specify 'point to point', (breaking strain on the diagonal where the ply is knotted or crosses), American standards typically specify 'bar' (taken on the square or halfway between knots). Farmers should be familiar with the above and for quality control specify a minimum breaking strength(wet or dry?) and type of test when ordering netting.

The choice of Denier and Ply is largely dependent upon the environmental conditions at the farm site & the expected life of the net in consideration of weighting arrangements, shrinkage, general handling, washing, UV exposure, marine fouling, breakage etc. Early in the salmon industry increases in ply were a direct result of seals holing nets, with 200 holes in one night commonplace.

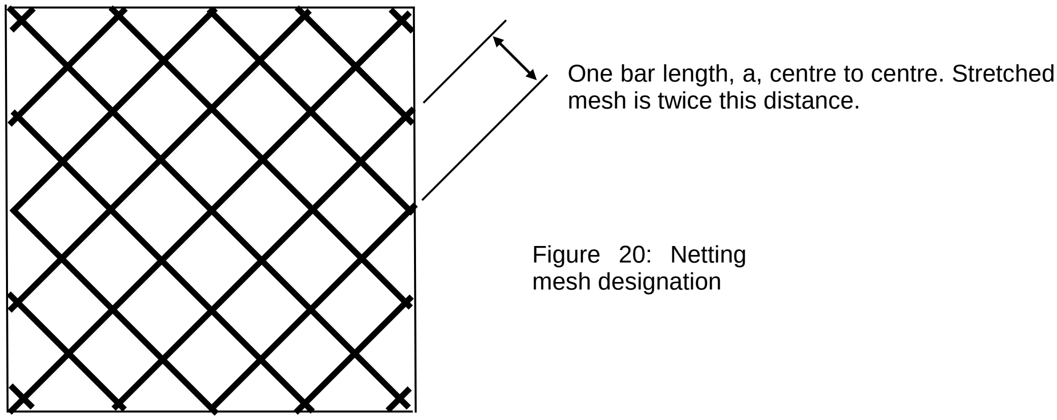


Figure 20: Netting mesh designation

Specification of the bar length/stretched mesh length/mesh size is primarily dependent upon the stock size and required net strength. For example, large mesh netting of relatively heavy ply is appropriate for tuna, as they are a relatively large fish and as strength is required during tow operations and the threat of predation by sharks and seals.

The true generic labels for rope and netting fibres, polyamide(PA), polyester(PES), polyethylene(PE), & polypropylene(PP) are taken form the polymers from which they are spun. Each polymer fibre has its own characteristics. PA(nylons) are durable and extremely elastic, capable of stretching up to 30% of their original length before breaking. PE are similar in strength to PA, but typically have less elasticity. PP and high density PE are buoyant and have good abrasion resistance, but rank low in terms of strength. Reference should be made to Fibre Ropes for Fishing Gear(chapter 14) and Netting Materials for Fishing, G. Klust, for specific details pertaining to the different available rope/netting materials.

There are also "exotic" fibres available now, typically marketed under the trade names of spectra or dyneema; these are spun from ultra-high molecular weight polyethylene(UHMWPE), a polymer commonly used in plastics due to its high durability and strength.

Additionally, netting manufacturers are also supplying combination type twines where annealed stainless steel wire makes up a proportion of the total ply. Indicative details when combined with PE are provided in the table below.

Denier 210/	Strands	PE ply	stainless steel details	overall twine diameter, mm	Breaking strength, kg
400	2	52	8ply@0.19mm diameter	2.6	99
400	3	54	3ply@0.47mm diameter	2.8	122
400	2	104	16ply@0.19mm diameter	4.6	198
400	2	108	6ply@0.47mm diameter	5.0	245
400	3	162	9ply@0.47mm diameter	2.8	367

Table 20 : Indicative details of combination type twine netting(PE and stainless wire)

5.11.1 Netting and Frameline Material Shrinkage

Netting materials within the Tasmanian salmon industry are purchased from several different manufacturers through-out the world, including Philfish, Namyang, Ching Fa and Bandinotti. The different manufacturers also purchase their twine material from different suppliers.

Netting shrinkage differs between manufacturers, dependent upon the knotless knot employed and the manufacturing technique(tight weave?). Typically salmon farmers allow for shrinkage with PA netting of some 3% over size. The exception is Bandinotti netting where farmers allow for 4 - 6% shrinkage; it is thought that this is due to the relatively tight weave typical of Bandinotti netting.

Frameline ropes are typically of PP material. Shrinkage for these ropes is unknown.

5.11.2 Extruded plastic netting

Extruded plastic netting has been used by one salmon farm with success against predation by seals. This is most likely due to the greater stiffness(similar to newly tarred netting) compared to woven nets which would make it marginally more difficult for a seal to fold the netting in their mouth. Further consideration is needed to be given to the use of such netting for a 120m pen as many of the issues relevant to the Marinemesh are also of a concern here, mainly marine fouling and manageability.

Figure 21: Extruded plastic netting

Extruded plastic netting, Aquagrid, is available from Fukui North America(www.fukuina.com), who claim a life span of 6 to 10 years and elimination, in almost all cases, of the need for a predator net. Claimed tensile strength comparison to 210/80 PA netting is some 3 times greater.

5.11.3 Netting Materials & Predation

Firstly, it is not considered that any minor reduction in the netting ply, thus twine diameter, would greatly affect the balance of effort(drag force) that the seal requires to push the predator net against the grow-out net.

The strength of netting materials used over the past 10 years has increased so as to prevent seals damaging the net from barging and tearing the net at the surface. The strength of the materials used today are adequate for this purpose.

Recommendations could be made to the use of materials such as Spectra or Dyneema but these are relatively expensive compared to PA material and it is doubtful that their material properties of minimal stretch and equal strength for smaller diameters compared to PA would prove their worth based on life cycle costs of predation on a typical 120m pen. Rather recommendations based on the existing use of PA netting were sought.

5.12 Antifoulants

Antifoulants reduce the build-up of marine organisms and thereby reduce the need for net changes during a grow out period, but becomes a useful(albeit expensive) addition to long term (salmon) grow outs. Antifouling can enhance a net's life by reducing the UV degradation and by reducing wear and tear experienced during cleaning.

The table below lists approximate change periods of netting. It can easily be observed that the use of antifoulants would significantly reduce net maintenance costs even if change periods were doubled.

Net	Change time	Season	Change period
Grow-out	2.5 hours	summer	3-4 weeks
		winter	6 weeks
Predator	4 hours	summer	3 months (max)
		winter	6 months

Table 21 : Approximate change periods and times for nets

Note: Greater hours are required to change the predator nets because the grow-out net weights must be lifted to the surface such that there is no possibility of “snagging” with the predator net when it is removed/reinstated. Due to this fact, predator nets are only changed when absolutely necessary(bathing, grading and harvesting).

Several antifoulants are currently on trial throughout the Tasmania industry, as such specifics will not be discussed within this report. Antifoulants are not only considered for their antifoulant properties but also for their inherent stiffening and weight properties, thus reducing predation by seals.

For a 120m pen antifoulants typically cost $15000(paint take-up approx 1kg/750ml to 1kg nylon netting), but this is largely dependent upon the volume of antifoulant required to coat a net and the durability of the antifoulant. Should antifoulants be successful in reducing seal predation then it is likely that they will solely be used on grow-out nets, the predator netting being redundant. To date, the life expectancy of antifoulants is not expected to be more than 2 years.

Points of consideration with respect to antifoulants include:

- Stiffer net resulting in greatly reduced predation by seals;
- Heavier net per square meter, could use less weights relative to an un-antifouled net;
- Lower operating costs from reduced labour time in cleaning and maintenance;
- Provides the netting with greater UV protection;
- Increases the netting resistance to abrasion; and
- Adverse effects of pollution by large quantities of chemicals.

Ironically, marine fouling offers good results against predation. This is because once the nets become fouled they provide an element of visual screening making it more difficult for a seal to attack accurately. The additional weight and drag from the increased net area are also probable explanations. However, excessively fouled nets offer a poor growing environment(lower flow through the net, lower dissolved oxygen levels, less removal of excess food and waste from pen footprint) and are demanding on farm equipment.

Measurement of a nettings flexural stiffness relative to other nets by various methods is under investigation. The method described by G. Klust, 1982. could be adopted for a set area of netting, or alternatively different antifoulings could be applied on a section of nylon rope, preferably of a soft lay construction, as this would give results that would represent the stiffness of the antifouling, not of the rope construction.

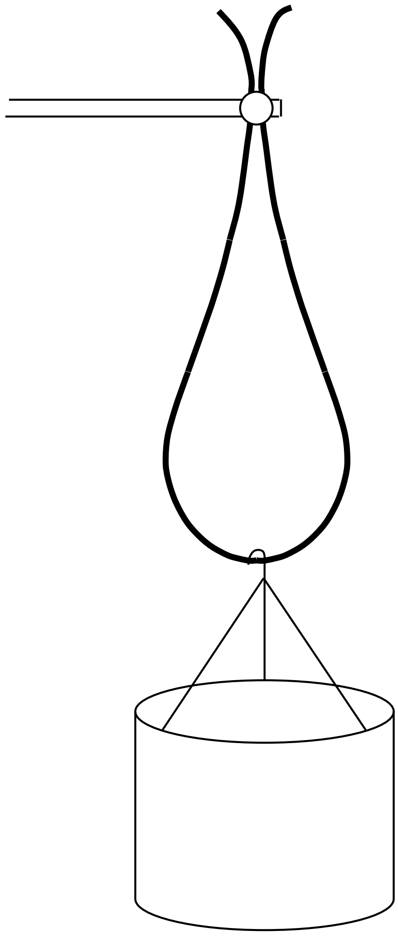


Figure 22 : Apparatus for measuring flexural stiffness

Method: using length of yarn 20cm, add water to container until widest opening between A & B is 5mm. Weight of container and water give flexural stiffness in grams

5.13 Typical Current flows

TAFI provided a brief summary of the current data for the lower Huon estuary (Hideaway Bay region);

- Current meter set at 5 m subsurface for a period of 90 days (July-October1996) - average current speed 3.62 +/- 3.25 cm/sec (max 30 cm/s). Generally 96.8% of readings within range 1.5-12 cm/sec and 75.9% < 5cm/s. Predominantly the direction north-west and south-east (ie parallel to shore).
- ADCP current meter set in 36 m water depth for a period of 52 days (Jan-March 1998) - average current speed of 10-20 m depth range 4.47 +/- 2.32cm/s. Maximum current speed 22.6 cm/s, min 1.2 cm/s (n=2327, 30 min interval averages). Similarly, current flow direction parallel to shore

This was confirmed during the site measurements at the Aquatas-Sheppards lease site, where a maximum flow of 37.5cm/sec was observed over a period of 8 weeks.

In summary, it appears that salmon industry farms typically see flow ranging from 0 to 38cm/s, dependent upon the site. No flows of 4 knots, as foretold anecdotally, were found.

5.14 Acoustic Deterrent Devices(ADDs)

Acoustic Devices include Seal "bombs" and Scarers. Seal bombs are underwater firecrackers and are utilised intermittently when it is thought that particular seals are persistently returning to the same farm/pen. Only Scarers will be discussed further, as bombs have been in use within the Tasmanian aquaculture industry for some 10 years and their worth is only on individual seals, and with occasional usage. Bombs are not a long term approach to preventing predation.

5.14.1 Seal Scarers

Seal Scarers can simply be described as consisting of a control unit and one or several transducers. The control unit contains a pulse generator and an amplifier and transmits either random or continuous audio frequency signals to the transducer, where they are converted into intense sound. The sound is on a frequency and loudness degree(dB) which is "hopefully" extremely unpleasant for seals. Fish, however, will not react to it at all. Some people may find the sound intolerable, whereas others may not hear it at all. This is because the sound is transmitted in the upper limit of what the human ear can perceive.

The information collected below has been written based on personal correspondence with all four Seal Scarer manufacturers, JN Taylor Marine, and other references as noted.

General
Both the salmon and tuna industry have trialled several different types of Seal Scarers. Anecdotal evidence, both positive and negative, as to the effectiveness of the seal scarers is commonplace.

All manufacturers' don't guarantee their products and generally state that acoustic scaring should be part of an overall predator control strategy. This is understandable considering that it is likely that with all the available ADDs there will be some habituation and selection for seals that are deaf, at least in the frequency band within which they operate.

Manufacturers claim that a general lack of attention to batteries and charging systems is the single biggest reason for ambiguous reports on the efficiency of the system. Most scarers are now 24V systems and would require solar panels or wind generators to save swapping batteries every day.

Environmental
The environmental impacts of Seal Scarers is being reviewed worldwide and at least one manufacturer(Hopkins, personal correspondence, August 2000 in-house company issued document "Controlling Seal Predation On Fish Farms") is seeking to "redress the environmental arguments in favour of acoustic control with a working solution available by the end of year 2000". Ferranti-Thomson scrammers were to have this principle electronically built-in a decade ago, but the net sensor was never successfully developed, hence they operate on a random time basis. The ultimate startle device would only make a sound when a seal is in the act of attacking a fish. It is therefore reasonable to conclude that a device operating solely by a sensor triggering device will have maximum startling effect on the seal and minimal impact to the environment.

The hearing capability and range of seals has only been performed based on 2 species of seals, Harbour Harp and Californian seal lion, and then compared to a human ear characteristics. It was calculated that 184db is generally considered to be the "threshold level of pain" for most seals.

Another point that can be made with respect to Seal Scarers is that they are less likely to damage a seal's hearing than a seal bomb/cracker.

Acoustic Scarers can be divided into two main types: Barrier and Psychological method units. Acoustic Barrier units transmit high intensity sound as an active deterrent; that is, the closer a seal approaches the source, the more discomfort they experience. Psychological method units sweep through frequency ranges and transmit random transmission patterns; their main intention is to startle, though they do typically offer "unpleasant" sounds also. There are arguments in favour of both types of units.

Whilst preventing the habituation of seals within farm leases is the objective of Seal Scarers, permanent hearing damage is not. The Airmar dBII plus incorporates a "soft start" system where power to the transducers is increased gradually over a 70sec time period, enough time to enable a seal to move away.

Devices available are tabled on the following page:

Specification/Model	Airmar dB plus II	Ferranti-Thomson Mk2 4X	Lofitech	Neptune Sonar T88 & T110
Power source	24V	12/24V	12V	
Power consumption	1.7A 100%power(>22V) 0.5A 50%(power save/default setting,<22V)	1A averaged (1 battery every 36 hours) (up to 23A on scram)	approx 0.4A/12V	
Number of transducers	4	1	1	
Trans cable length	60m std, can be customized to 150m.		25m	
Number of scrams per hour	continuous circuit of 4 hydrophones	6 scrams each of 20 seconds duration	17 pings(random) in 2 minutes	
Frequency	10kHz	8 – 30 kHz	Between 10-20kHz	
Sounds	Single fixed tone	Randomised collection of frequencies	random bursts of audio frequency	
Source Level	194dB RMS re 1uPa@1m	199 dB re 1uPa@1m (26kHz)	185 dB re 1µPa@1m	
Directivity Index	Approx. omni-directional	0dB (omni-directional)	omni-directional. 60degree being developed.	
Effective scaring range	184dB re 1uPa at 40m	50m	300m radius.Note1	
Effective coverage	1 per 200m pen group 3000m2	1 per 100m pen group	280000m2.Note1	
Method of installation	Centrally placed unit with one hydrophone at each corner of the group	Centrally placed unit with single hydrophone directly beneath		
Other	"Soft start" feature			
Cost(FOB)	8100USD	circa £3k	2750USD	
Contact	Steve Christensen	John Hopkins	Dag Hansen	Alex Wood
Email/web	sales@airmar.com http://www.airmar.com/	john@aceaquatec.com www.aceaquatec.com	dhansa@Poseidon.no http://www.lofitech.no	info@neptune-sonar.co.uk http://www.neptune-sonar.co.uk
fax	+1 603 673 4624			+44 (0)1262 490 485

Table 22 : Seal Scarers and basic parameters

Notes
1. "Based on experience"

5.14.2 Future Acoustic Scarer Design

It is hoped, that within the near future, Acoustic Scarers will include automatic seal detection and activation systems. Psychologically speaking, this would be the penultimate method of conditioning seals that fish farm leases are “off limits”. Such scarers would also have reduced power consumption and the pollution debate could be negated. Note: In 1989 Parks & Wildlife and Tassal investigated the use of electrical fields generated by agitated fish as a possible indicator of the presence of stressful factors, ie seals. Cost precluded any further development.

5.15 Electric Fences

Electrified wire, as used on terrestrial farms for livestock, running the circumference of the pen at the surface has greatly aided at resisting the attempts of seals claiming the pens as haul-out sites, though some seals seem not to feel the shock and/or short the fence out. The disadvantages of the electric fences however are similar to those of the Acoustic Scarers; that is relatively high maintenance and, regularly shorting out(dropped ropes, sea state etc). Farm leases that are relatively exposed to wave action, such as Tassal Nubeena, have found that the use of electric fences is not a viable option due to the issues described above.

The use of electric fences on the System Farm however has proved very effective in deterring the hauling out of seals onto the structure.

5.16 Net Specification & Management

The below has been written due to the large amount of time and effort it has taken to extract information from various farms and net makers. In summary, quality assurance and control systems should be in place such that farms can track & improve upon their current understanding of predation through net design.

Due to the number of flexible pen manufacturers, together with their company specifications in pen manufacture, it is imperative that the farms record the exact details of the pens and upon tendering for nets, correctly specify their exact requirements. By example, although pens are commonly called by their circumference, what circumference is this ?. Through researching what pens and net systems are in use this became very apparent, and once the pipes that make the pens are welded together and floated to form a circular pen it is extremely difficult to ever get an exact measurement of the diameter or circumference.

The onus on reducing seal predation is on the farming industry. The industry should familiarise itself with the available net designs and be capable of specifying all items on the tender. Once the tender is released for quotation, tenderers have the option of specifying different materials, but should substantiate them, whether this be by design or evidence elsewhere.

As a minimum, a pro-forma table as per below should provide the basis of the tender document. The tenderer should be required to complete the table and return it together with a schematic design of the net to prove full understanding. The italized values are by example only.

Tender	*001 Revision A dated 1/10/00*	
Pen type	120/xxx	
Manufacturer		
	Required values	**Tenderer values**
Grow-out net dimensional particulars:		
Inner pipe ring inner circumference	*(120/π+0.315)*π =120.990m*	
Allowance for shrinkage	*3%*	
Circumference on top rope	*120.990*(1.03)=124.619m*	
Circumference on bottom rope	*110.000m*	
Design Taper	*(124.619/110-1)*100=13.3%*	
Jump fence	*2.200m*	
Side depth	*6.500m*	
Base depth	*Require flat base*	
No of panels	*24*	
Net material	*210/168 34mmID bar knotless, UV stabilised, black, tarred with hot resin. Minimum wet breaking strain of _________*	
Grow-out net other:		
Top Rope	*~14mm PP*	
Waterline rope	*~20mm PP* *~cringles every 2.596m(124.619/48)*	
Bottom rope	*~20mm PP*	
Side ropes	*~20mm PP continuous spliced into waterline and base rope* *~soft eyes at each rope bottom end under base rope.*	
Netting	*~To be bound using double nylon twine of xxx/xx , minimum breaking strength of xxx.* *~all ropes to be on outside of holding volume.*	
Base	*~All ropes 20mm PP* *~Design from 8 distinct netting panels, 24off ropes joining 24off side ropes.* *~Reinforcement panel of 400mm x 400mm to be centred on side rope/base rope junction. Material as per grow-out netting.*	
Gate	*~1off* *~2.5m wide, 5.5m deep, opening to 4.8m* *~16mm PP rope to surround door and door opening.* *~0.5kg lead core rope along top edge of door*	
Identification tagging		
Predator Net dimensional particulars:		
Inner pipe ring inner circumference	*(120/π+2*750+0.315)*π =125.702m*	
Allowance for shrinkage	*1%*	
Circumference on top rope	*125.702*(1.01)=126.959m*	
Circumference on bottom rope	*120.000m*	
Design Taper	*(126.959/120-1)*100=5.80%*	
Jump fence		
Side depth	*12.000m*	
Base depth	*Require flat base*	
No of panels	*24*	
Net material	*210/19x16 100mmID bar knotted, UV stabilised, black, tarred with hot resin. Minimum wet breaking strength of xxx .*	
Predator net other:		
Top Rope		
Waterline rope	*~18mm PP* *~cringles every 2.645m*	
Bottom rope	*~18mm PP*	
Side ropes	*~18mm PP continuous spliced into waterline and base rope* *~soft eyes at each rope bottom end under base rope.*	
Netting	*~To be bound using double nylon twine of xxx/xx.* *~all ropes to be on outside of holding volume.*	
Base	*~All ropes 18mm PP* *~Design from 8 distinct netting panels, 24off ropes joining 24off side ropes.* *~Reinforcement panel of 400mm x 400mm to be centred on side rope/base rope junction. Material as per grow-out netting*	
Identification tagging		

Table 23 : Example net design specification proforma & manufacturers' tender evaluation table

5.16.1 Net Receipt & Disposal

Upon receipt of a new net, and prior to use, the farm should check the netting against the order and record any discrepancies. Details regarding each and every net and FCPEP pen should be stored for future reference.

The salmon and tuna industry should have a procedure in place that recognizes the date of manufacture and storage times for each net against the Net Specification sheet such that the life of each & every net can be tracked. It is typical to discard nets once they have a history of 3 to 4 seasons usage.

5.17 Sinker Tubes

Comments in “Experimental Predator Control Measures on Marine Salmon Farms in Shetland” by Holly Arnold, Greenpeace UK state that Sinker Tubes or Pipe Frames were in widespread use. Early designs ranged from 50mm diameter steel pipe with mating ends, to designs which used short lengths of chain to couple the pipe lengths.

Sinker rings are in use in Tasmania, but only on smaller pens, typically 60m smolt pens, refer Figure below.

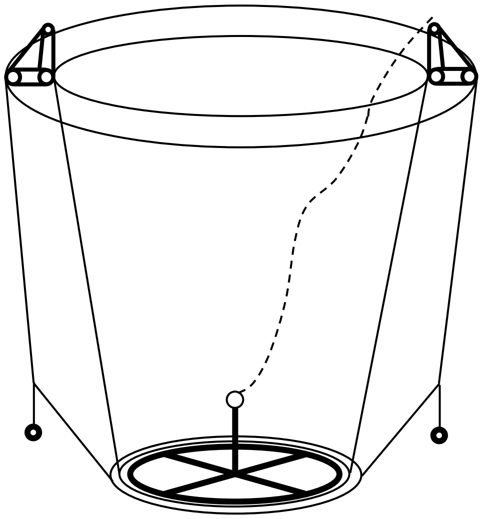


Figure 23 : Typical sinker ring in small(smolt) pen

“Lightweight sinker” tubes were trialled at Nortas in 1992-93 and at HAC on 80m pens in 1997. The HAC tubes trialled consisted of rolled 2” pipe with mating ends, and also a 16 sided polygon from RHS sections with flanged ends. As per the Shetland experiences, the pipe mating design and the RHS flanges failed.

Figure 24 : Corner section of trialed lightweight sinker ring

They were however considered successful in reducing seal predation, but the nets were found to lift in any current. It is likely that insufficient weight was inherently provided in these sinker tubes to hold the netting down from the lift forces during current flow. The advantage of Sinker Tubes, over point bomb masses is twofold:

1. More evenly distributed load, thus should a seal attempt to push a section of netting, then it is more likely that more mass is attached to that netting; and
2. Inherent degree of rigidity to their circular shape, thus the flexible base seen when using point masses is now not so apparent.

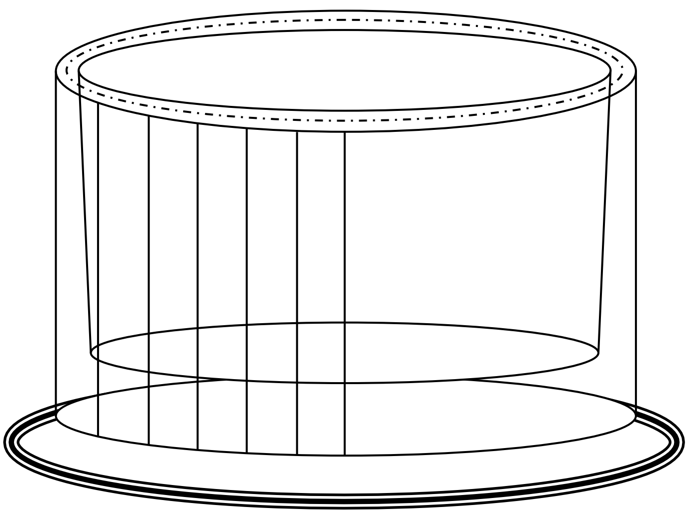


Figure 25 : Depiction of sinker ring on outside of outer pipe ring

Buoyancy calculations for a 120m pen show that a steel sinker ring is possible, albeit it would be heavy to lift with limited personnel once dropped into position(described further below). A cost comparison against manufactured “bomb” weights(24off 100kgIW equals approx $2000) indicate that a steel Sinker Ring is a relatively expensive capital investment.

Ring Circum m	Pipe mm	Grout density Kg/m3	Weight IW no grout Te	Weight IW with grout Te	$ Supply + Fabricate + Galv + Construction on-site	$ Grouting pump/ cement	$ total estimated
128	88.9OD 11.1WT	2400	1.9	2.5	15000	1200/ 250	16450
128	114OD 8.6WT	2400	1.5	2.8	15580	1200/ 530	17310
128	168.3OD 7.1WT	2400	0.7	4.0	18100	1200/ 1400	20700

Table 24 : Cost sheet for steel Sinker Rings to suit 120m pen, locally fabricated

Less expensive methods of obtaining a more evenly distributed load than that of a steel Sinker Ring include a PE pipe ring with steel wire ballast, as per Froyaringen, or a plastic pipe ring with sand fill, as typically in use in New Brunswick.

5.17.1 Froyaringen

Froyaringen, of Norway(http://www.havbruk.no/froyaringen/index.html), provide sinker rings commercially to the European salmon industry. The rings are made from PE pipe and filled with steel wire to provide the required weight.

The company's first sinker-ring was on a 90m pen and weighted with approx 6 kg/mIA and placed in a locality with 1 knots current. The system was not very successful. The weight was then increased to 12kg/mIA with more success. Typically the company provides sinker rings for 90m & 70m pens. The weighting for a 90m pen being 17-20kg/mIA, for a 70m pen 12-14kg/mIA, the variation in weighting being for 250-315mmOD FCPEPs respectively. The Sinker Ring weighting being dependent upon the available pen buoyancy. The largest ring the company has provided to date is 96m for Hydro Seafood in Norway; 120m rings are currently being planned(2off 400OD pipe).

Probably the biggest disadvantage of sinker Rings such as the Froya Ring is the awkwardness in handling. On "smaller" pens davits are fitted to lift the sinker-ring. On "larger" pens cranes on support boats must be employed. Chains are typically used to support the weight of the ring when not hung off the netting.

5.18 Computational Modelling of Aquaculture Pens

In collaboration with an undergraduate project at the AMC Maritime College at Newnham, the 20:1 physical scale model was modelled on Anysys, a proprietary FEA program. The use of FEA computer programs give the designer the benefit of making alterations in a step by step process to achieve the optimal design, thus FEA is a powerful tool for predicting the performance of equipment before it is built, and for refining equipment performance once in operation. No wave forces were input, only a current force was modelled. An input program was written in VisualBasic, where the main parameters were entered and the output text file is read by Ansys. To reduce computing time the grouping of the meshes is performed, in a manner as described by H. Gignoux & R. Messier, 1999.

The confirmation of the FEA computer model was by first matching deflections, and general shape, against the physical model, then by the modelling of the full size pen deflections at Aquatas-Sheppards. Results for both cases were encouragingly positive.

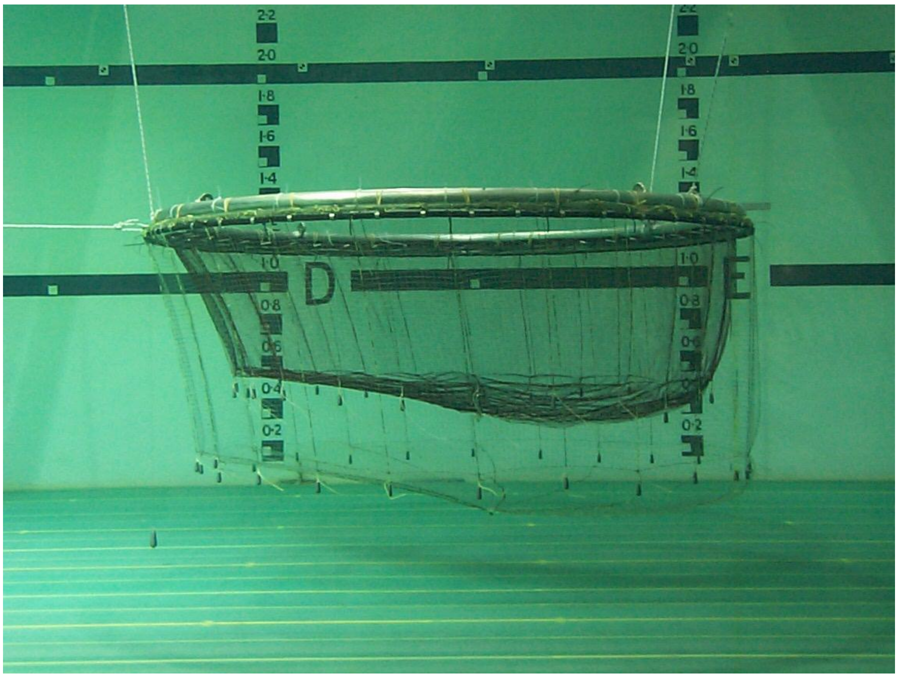


Figure 26 : Physical model at 0.06m/s

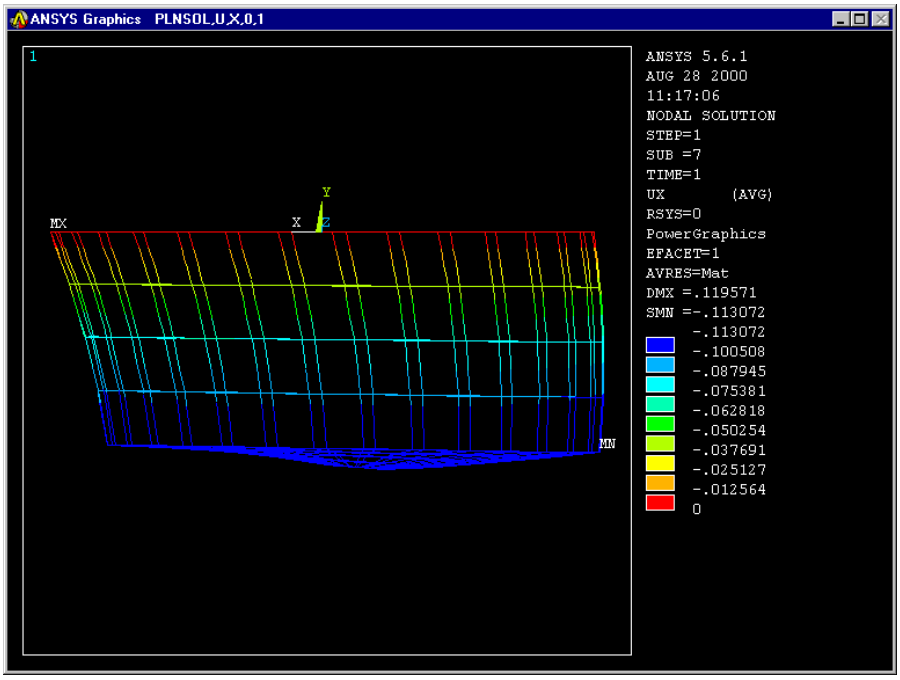


Figure 27 : FEA computer model at 0.06m/s

Further work with the computer model is progressing. It is hoped that in the near future that confidence in an accurate computer model will be available and both the impact from a seal on a predator net, and a sinker ring can be modelled. Results to date are provided in Appendix 3.

5.19 Tuna Farms

5.19.1 General

Tuna farms typically utilise flexible PE pipe pens, but typically with only one pipe ring. This is because the pens are towed to the fishing grounds and thus must be able to fulfil the two functions of towing and grow-out. The pipe diameter is typically 400OD. As the nets are towed, typically a 1m deep section of heavier ply netting is hung on the diamond at the water surface to provide elasticity during the tow operations. Steel stanchions are typically employed and clamped hard onto the pipe.

Seals gain access to tuna pens by jumping over the jump fence; alternatively seals will access holes left in the netting by sharks. Anecdotal evidence suggests that seals will “work away” at holes in the netting until there is a large enough hole to gain access to the grow-out net, and that seals can “chew through” both the grow-out and predator netting. Once inside, seals can barrel the tuna up against the walls of the grow-out net. White coloured netting, and 3-4 weeks of marine fouling is preferred before stocking the pen as this ensures good visibility of the netting to the tuna.

Sharks penetrate through the grow-out net or, if a predator net is fitted, both nets. In an effort to reduce seal predation, Bronze Whaler sharks have been left in the pens; once inside though it is largely thought that this stresses the tuna.

5.19.2 Tuna netting

A typical sample piece of grow-out netting was made available from Quin Marine in Port Lincoln. From the table below it can be seen that the solidity ratio for typical Tuna grow-out netting is in the order of 0.054. That is, the ratio is less than that typical of salmon farm netting. Therefore, if tuna netting where weighted identically to the typical salmon farm arrangement(24off 100kgIW), then significantly less net deflection and volume loss would occur. However, as noted in the previous section, Tuna farms typically utilise only one pipe ring and thus such weighting is not viable. This is discussed further below. Typical predator netting values are also provided for information.

Target scale factor		**20**	**20**	**1**
Details	**Mesh size, a mm**	**-**	**Avg Twine thickness, d mm**	**Solidity**
Tuna Grow-out KL	80		*4.355*	0.0544
Tuna Predator K	4½" / 6"		4.5	0.039 / 0.029

Table 25 : Typical tuna Netting Details

Two farms intend trialling netting with a filament of stainless steel twine in the forthcoming season.

Predation nets are not employed unless specific problems persist with predators. Then a weighted polyethylene "shark netting" is hung from outside wall of the single pipe ring as a curtain net; that is to the seabed. Predator nets however are not favoured as the netting tends to "bounce" on the seabed and create suspended sand particles which affect the tuna's health.

Antifouling is not a critical issue for the tuna industry as the farm grow-out period is relatively short(6 months), and the mesh size is considerably larger than that on salmon nets.

5.19.3 Jump Fences

Jump fences are an extension of the grow-out netting. Jump fences have evolved from a standard working height of approximately 1m to now 3m. This is a result of seals in the past jumping over the jump fence into the pen and/or rolling onto the pen pipe and using their self weight to bend the handrail down into the water, and then rolling into the grow-out net with the tuna. Typically one 3m pole is found on every second stanchion.

5.19.4 Net Tensioning

Tuna farmers typically weight their netting less than salmon farmers. However as tuna grow-out netting is typically heavier(approx 0.54kg/m2), the difference in weight to typical salmon grow-out netting is circa 120%(based on a grow-out net of similar design). However the requirement for less weight is most likely a function of the solidity ratio as for typical tuna netting it is much lower than that used for typical salmon netting(0.054 versus 0.087). Unless the tuna farmer employs a typical salmon pen of 2 rings there is an obvious limitation to the maximum amount of tensioning weight that can be hung on a tuna pen.

Net design is typically of 16 panels, with 3kg/m lead line on the bottom circumference. Weighting is typically by bomb weights, identical to those in use by the salmon aquaculturlists. The method of weighting is typically by the Free Hanging Method, although Kalis have 6kg/m lead line inbuilt in the base circumference and utilise no bomb weights.

5.19.5 Electric Fences

Farms also typically employ electric fences around the pen; electric fences are considered an effective deterrent but require regular maintenance due to shorting out(ropes falling on live wire, waves coming over live wire) and battery drainage.

5.19.6 ADD usage

Seal Scarers have been trialled in the past with mixed success. On the whole tuna farmers are very sceptical of their use, believing at the very least that seals "work around" the scarer. Airmar Scarers have been trialled in the past by both Australian Bluefin and by Kalis with success, though Bluefin believe they lost their effectiveness after 1 year as they were acting like a "dinner bell".

5.19.7 Bird Netting

No bird netting is utilised across the industry.

5.19.8 Shark Pod Usage

A commercial version of the diver shark pod is used by several tuna farmers when transporting tuna caught in the Great Australian Bight into the Port Lincoln aquaculture lease area. Anecdotal evidence suggests that the majority of shark interactions occur during the tow-in period, and up until marine growth has formed; this can be a 2 to 3 months period.

5.20 Overseas Experiences/Techniques

Correspondence and dialogue with salmon farmers in Europe is given below. Anecdotal evidence suggests that the seal problem in Europe is not as great as that faced by the Tasmanian salmon industry. The most reasonable explanation for this is because seals in Europe are typically smaller, of a different shape, have a different foraging behaviour and general demeanour, than seals found in Australian waters.

All information provided below is to be considered anecdotal in form.

5.20.1 Ireland

<u>Killary Salmon</u>

- No predator nets;
- Seals approx 200kg;
- AHDs not very successful, not in use anymore;
- “rogue” seals can be shot under licence;
- “heavy” weight on net because of current(1-1.5kts) , ie 12 to 14off 30kg on 70m pen approx;
- grow-out fish pens smolt 18mm mesh 210/60, “heavies” 25mm mesh, 210/90;
- Floating support to hold bird/herron netting, approx 10’high, base 6-8’, top3-4’, netting not tied to this support, spec x polar circle; and
- Oceanspar 145m circum, spectra, 250kPounds 22000m3, no seal problem.

<u>Muirgheal Teo</u>

- find it difficult to use predator nets due to “strong“ current(2 nets touching) 2.5kts peak, 1kt slack, much net deformation;
- Seals more nuisance;
- Believe seal strikes from bottom, more at night;
- Used to use concrete weights, now steel; and
- Have used Ferranti Thompson ADD, now broken, considering Airmar.

5.20.2 Shetland Isles

Conical shaped nets in the Shetland Isles are proving effective against seals. The net is sufficiently tensioned at the base to eliminate net folding in current. A false floor is added, as it is largely believed that predation is generally from the bottom. No predator nets are used. The largest drawback in the use of these nets is that relatively deep water sites are required.

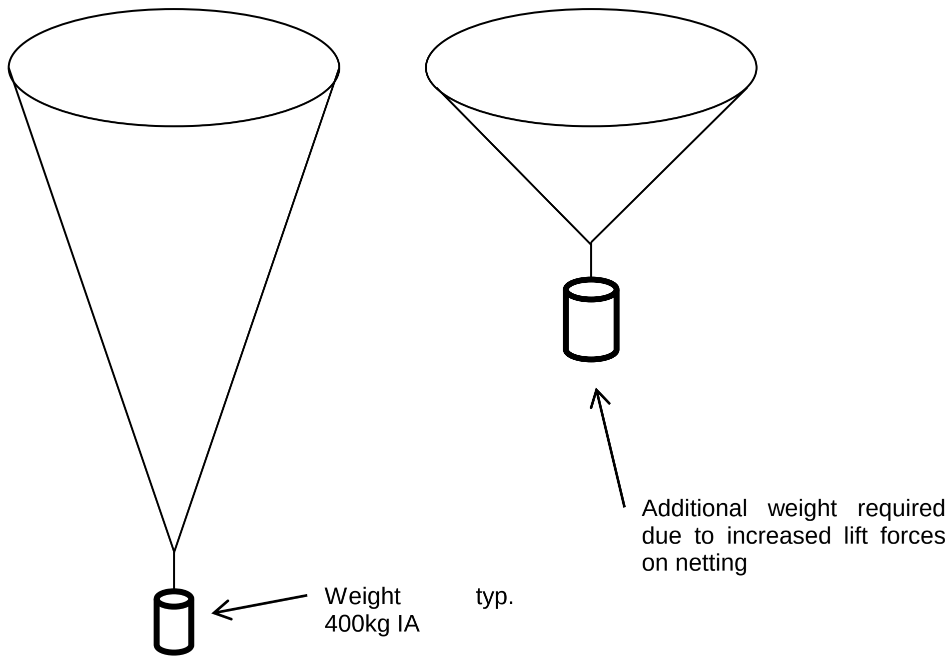


Figure 28 : Conical nets for "deep" and "shallow" water depths

Typically 33% of the pen water column depth can be utilised as volume for stocking fish. Obviously to obtain net volumes typically seen throughout the Tasmanian industry, "very" large diameter pens would be required.

Success from seal predation is most likely due to the even distribution of forces through the net.

Other farm sites are utilising flexible pens, due to water depth restrictions, together with Froya Rings. Seal predation continues with these systems as the net bases are still relatively untensioned. False floors have not been trialled to date.

5.20.3 New Brunswick(Bay of Fundy), Canada

Typically pens in the New Brunswick industry are flexible polyethylene pipe pens, similar to the pens in use in Tasmania. Pens of circumference 70m are the most common, although a few 100m pens are in use. Net weighting is predominantly by use of a sand-filled ring made of 4-inch plastic pipe, 70 meters in circumference, and suspended beneath the pen collars such that the ring hangs approximately a meter below the predator net. The ring is ultimately supported by ropes tied to the pen collars. The weight of the ring filled with sand is approximately 1.5Te. Scuba divers tie the predator net to the ring. Due to the relatively "large" currents in the Bay of Fundy, the grow-out net is typically tied to the predator net; this assists in having both nets keep the same shape(similar concept to porthole method). This is performed by divers between the grow-out net and the predator net.

5.21 Novel Anti-Predation Method Discussion

Novel methods of reducing predation were discussed at the commencement of the project. These included:

- use of electricity as a behavioural deterrent(shark pods/electric above water fencing/electric underwater fencing); and
- use of variable buoyancy talking killer whale model as a deterrent.

These and other novel methods considered during the course of the project are described below.

5.21.1 Submerged Electrified Fence

A shark pod has been purchased by Tassal and will be worn by divers at Tassal Nubena. Anecdotal evidence suggests that shark pods are effective against seals at a very close range. Further testing is required to determine why.

Use of a submerged electrified fence system, either over the whole net or in purpose made holes where seals could be negatively conditioned not to make contact with holed areas of the net. This could easily be performed by use of a commercial Shark Pod unit, identical to that which tuna farmers' use during tows of tuna pens.

A brief literature search was performed into the use of electric current in a saltwater environment. One reference was found that described electricity as having been trialed to reducing marine growth. The article(KS. Kjelleberg & P. Steinberg, 1994) stated that such a system has been trialled in the past 40 years, and described three mechanisms upon which it was based:

a. Secondary chemo-toxic effect;
b. Inhibits enzyme or protein processes; and
c. Exfoliates surface.

No other literature was found.

5.21.2 Non-Physical Fence System

During the initial literature search, an article titled “The Development of a Non-Physical Fish Fence System” using combined infrasonic and electric fields was sourced. This project was of 2 years duration, beginning in late 1992 and drew conclusions that previous research has shown that although electric fields can induce muscle spasms in fish, the fish do not possess senses which allow them to determine the direction of the field source. It has frequently been observed that fish finding themselves subjected to an electric field, will swim into a region of stronger field and be killed. In contrast fish can easily detect the location of sound sources. Research described in the report showed that it was possible to construct a non-physical fish fence based on combined infrasonic and electric fields which is capable of confining fish in a chosen area. The non-physical fence described in the report has been successfully tested on both 1C(2-4kg) and 2C(5-7kg) salmon. Although this is a novel concept, it could only be recommended if suitable methods were also used for the exclusion of predators.

Other similar novel, non-physical fence methods include air bubble curtains and electric screens.

5.21.3 Variable Buoyancy Talking Killer Whale Model

Killer whales are natural predators of seals and it is hypothesised that a killer whale “scarecrow” could be locally constructed to use in deterring seals form entering farm leases. Killer Whale models have been constructed in the past in Ireland, and on the west coast of America. Local construction cost estimation is $10000; more should the whale require to be talking. The use of the whale could promote the predation problem to the general public, and the efforts that salmon industry is pursuing. The general public could even be involved in naming the whale. However the employ of a Killer Whale model is not seen as a long term solution!

5.21.4 Crittercam

Crittercam is an animal-bourne integrated video, audio and TDR data logging system designed for studying the behaviour and ecology of large marine vertebrates at sea where systematic human observation is impossible (G. J. Marshall, National Geographic TV, 2000). As the method of predation by seals is largely based on anecdotal evidence, objective evidence of the predation method would assist greatly in the determination of where the current best designs have weaknesses.

A seal that has a proven repeat predation behaviour on a considered “best” design farm net could be chosen to carry a crittercam to obtain objective information on seal predation. Targeting specific behaviour of predation by the chosen seal could be by data acquisition over continuous time intervals when the chosen seal is within a determined range of the farm. This is possible through the integration of either an ultrasonic or VHF transmitter within the crittercam unit, and/or a satellite transmitter.

5.22 Final Discussion / Recommendations

5.22.1 General

An article by Gary Loverich of OceanSpar describes the inadequacies of Gravity Type Structures(flexible pens) in some detail at http://www.oceanspar.com/CAMRIVER.html The article is titled “A Summary Of The Case Against The Use Of Gravity Pens In The Sea Farming Industry” 1997, and states also that “Predation of Atlantics is also encouraged by their own behaviour in the net. Higher currents cause them to shelter in the wake of the pen sides, centimetres away from marine mammals”. If this is simply the case, seals are exploiting the natural behaviour of the fish.

Seals, consciously or unconsciously, judge the reward of food against the effort of predation. Successful anti-predation measures require the fish farmer to tip the balance in favour of preventing the seal the opportunity to predate efficiently. The point of balance however varies within different individuals(weight, effort etc) and depending on the availability of other wild fish. The balance can also be manipulated through educating the seal that farms are not favourable areas in which to hunt.

The most recent article on seal predation(D. Morris, 2000), based on predation in Maine, concludes that there is no silver bullet that will solve the seal problem once and for all. This is true for the Tasmanian salmon industry also.

The generalised “first pass” recommendations for all salmon farms is firstly to adopt the maximum possible weighting on their predator nets. Previous discussions have detailed a recommended 20% tension weighting(2.4Te for typical pen structure); this however is dependent upon the integrity and mooring arrangement of the pen, and other factors such as marine growth etc. Needless to say, the predator nets must be of a high-quality design with a base designed to be flat (ie. without removing tension from the side panels). If the farm fulfils the above gross recommendation and predation above their adopted KPI continues, or it is felt that this is not feasible, then the farm must investigate available options for increasing the buffer distance.

Detailed recommendations are provided below. They can be adopted as a whole or individually.

5.22.2 Additional Tensioning & Pen Arrangement

As 20% of the available buoyancy has been adopted as the recommended allowable for tensioning the typical pen structures, to provide more tensioning additional buoyancy must firstly be provided. There are basically three options:

1. Upgrade by fitting an additional pipe ring of 315OD and 48off additional typical stanchions, turning these stanchions to face the outside.;
2. Purchase of a new design stanchion which includes an allowance for an additional third pipe ring; and
3. Purchase of a new design stanchion with increased separation between pipe rings designed for 2 off “larger” than typical diameter(315OD) pipe rings.

As the interactions between seals and farm personnel is increasing, and is unwanted, the design of the outer handrail is also important in consideration of any new stanchion design. Bird pole support is another consideration.

Tassal Nubeena are experiencing good results with GRP bird poles and are considering a rota-moulded PE outer stanchion that includes a hollow sleeve for the fixing of the bird pole. The GRP poles are proven in that they have been used in short lengths of plastic pipe sleeves that were made fast with rope to the current stanchion design. The unknown with PE outer stanchions is any impact load that may be imparted to the stanchion upon the bringing of a vessel alongside.

Stanchions manufactured from marine grade aluminium would have a much larger strength per cross-sectional area in deference to PE stanchions, but would not be able to sustain as high a bending moment as a PE stanchion if the PE stanchion design were made to be elastic. If the outer stanchion design is of a relatively large section at the junction to the pipe connecting brace, and includes a hollow section for the purpose of sleeving a birdpole, then the design is seen to be rigid and an aluminium stanchion would be the design choice. It is thus recommended that any stanchion that employs a PE outer stanchion undergo FEA analysis, with an point impact load at a typical vessel rail height, and/or a destructive test of a stanchion by a drop load.

Although further consideration to the use of aluminium as a pen stanchion is required(corrosion estimation, friction coefficient on PE, fixing distance between stanchions using rope, etc) since the design loads are unknown and PE outer stanchions are unproven, it is recommended that any new stanchion design be fabricated from marine grade aluminium material sections with the outer stanchion braced back to the inner stanchion. Additionally, it is recommended that a length of impact absorption rubber be fitted to the outer stanchion The brace height on the outer stanchion is fixed at approximately 0.8m height from the seawater surface as this is considered the rail height of most service vessels. To allow for personnel movement within the pen structure then, additional height is required.

Calculations show that if a stanchion was manufactured to contain three pipe rings of 315OD 19WT, then total available buoyancy is circa 19500kg. Adopting 20% of the allowable buoyancy for net tensioning, 3900kg is available. To avoid concerns regarding any twisting in the connecting braces of the stanchions in a sea state due to the distance between stanchions, increase the number of stanchions to 60off. This allows for continued use of the current 100kgIW bomb weights, but more thereof are possible; this increases the total tensioning weight that can be hung. Now a number of tensioning systems can be employed. By example, adopting the porthole method on the predator net, with 30off 100kgIW bomb weights, there remains 900kg for the tensioning of the grow-out net if required at a later date.

A cheaper alternative for the porthole method would be the use of three pipe rings of 280OD 16WT, the total available buoyancy is then circa 15500kg. Adopting 20% of the allowable buoyancy for net tensioning then 3100kg is available. Again, adopting 60off stanchions and 30off100kgIW bomb weights, there remains some 100kg of the allowable buoyancy.

Calculations show that should the stanchion be manufactured to contain three pipe rings of 355OD 21WT, then total available buoyancy is circa 25500kg. Adopting 20% of the allowable buoyancy for net tensioning, then 5100kg is available. Adopting the sock method on the predator net, with 30off 100kgIW bomb weights, there remains 2100kg for the tensioning of the grow-out net. This can be with 30off 100kgIW bomb weights hung in a pendulum method.

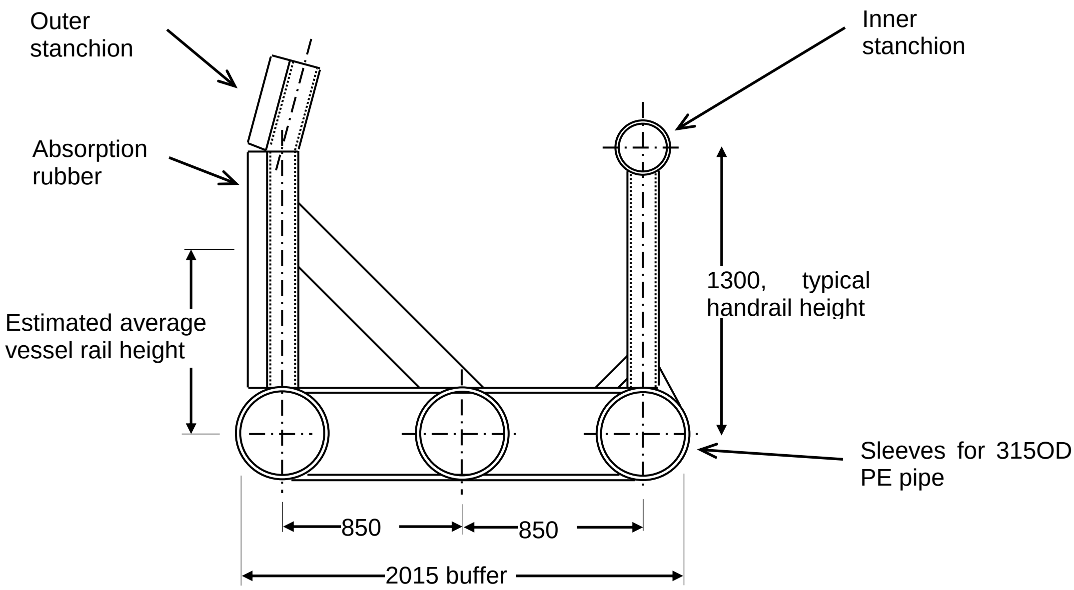


Figure 30:Schematic of recommended three pipe brace with outer stanchion using 315OD PE pipe

5.22.3 Predator Nets

The weighting and maintenance of predator nets all contribute to the protection of the farmer's stock. The use of predator nets will continue should the current pen design continue. This is due to the flexible nature of the pen and net design. These inadequacies are also the benefits of the pens in that they provide flexibility and affordability, compared to "rigid" pen structure alternatives, which typically have a "higher" capital cost.

On the typical, nominal 1065mm buffered pens, the recommended net tensioning weight of 2.4Te(24x100kgIW) applied on the predator net is recommended. Tassal's experience at Nubeena with this arrangement(Porthole System) is proving itself effective with approximately 1.6 seal strikes/day/pen with a 4" stretched mesh predator net against 3 seal strikes/day/pen with a 6" stretched mesh predator net; both systems utilising full weighting on the predator net, that is 24x100kgIW on the predator net.

In summary, predator net recommendations on the typical pens include:

- Increasing the buffer distance between the grow-out and predator nets (inadequacies in design due to ill-taut netting generally, at gate, and allowance for oversize netting because of PA shrinkage). Recommend a minimum 2m buffer distance;
- Increasing the net side taper such that more force is transferred through to the base of the net. Recommend 12% minimum on grow-out & predator netting; and
- Recommend minimum 2.4Te directly hung-off the predator net. To achieve this for the typical pen, if 20% of the available buoyancy is accepted as the maximum for tensioning, the porthole method must be adopted. Alternatively a third pipe ring can be retrofitted by reversing the current typical stanchion; this has the effect of increasing the buffer distance and allows for over 20% of the available buoyancy to be hung.

5.22.4 Salmon Behaviour

An investigation, whether by an individual, by employ of several underwater cameras, or through a survey of divers is recommended to objectively determine the daily(& possible seasonal) behavioural patterns in schooling of farmed salmon. Factors that are considered to influence schooling and possibly predation include current flow, light, feeding times, water salinity etc. A basic insight could be objectively drawn from the Aquatas bagged fish. Presently there is only anecdotal evidence to suggest that salmon move into the upper 2 meters of water at night-time, whereas during the day the population is evenly distributed, and they tend to swim up into any current flow.

5.22.5 Predation Methods

As discussed in preceding sections, predation methods are largely based on anecdotal evidence. The mode of attack is fundamental to the understanding and therefore improvement of any protection system. Employ of a Critercam unit would undoubtedly determine predation methods of a particular seal at a particular time. Acquisition of sound during this period may also prove highly valuable in the determination of a typical seal's hearing range and thus may make the specification of Seal Scarers for Australian seals more exact. A project that pursues this is currently under development through D. Pemberton, P. Warner and N. Gales(CALM WA).

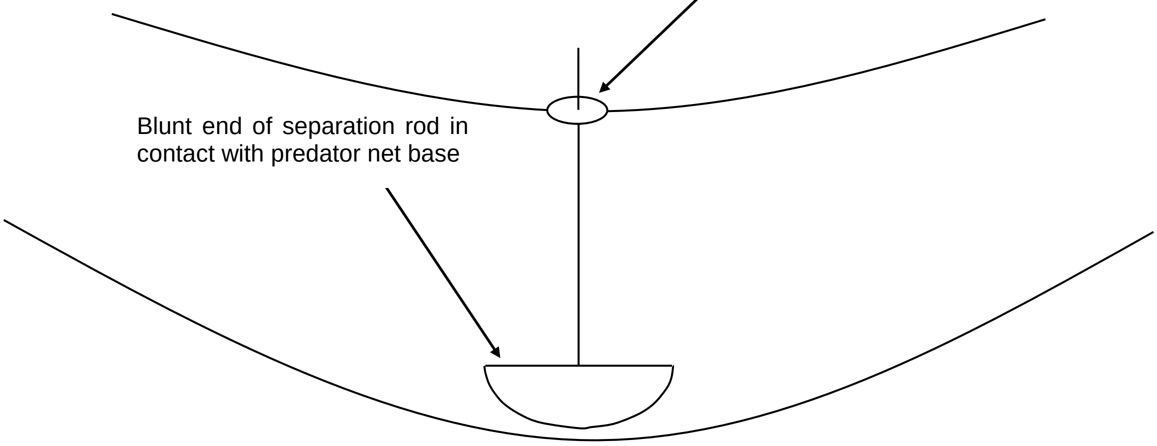
Another approach would be for industry to arrange for farm and contract divers to report personally observed predation by seals. This could be done as part of the divers log. In addition to reporting seal predation observations, divers would be free to give advice as to their personal thoughts on the inadequacies of the net system, albeit this information would be largely subjective. It is believed industry could easily support such an arrangement.

5.22.6 Separation Stick

An observation from salmon morts due to seals is that seals typically remove the underbelly only. An easy conclusion to draw is that at periods the salmon move to the bottom of the pen and it is these fish that the seal attacks. This concurs with the experience in the physical model construction in that it proved difficult to gain any tension through the base; this was described in section 5.8. When seals attack from the base of the predator net they push the predator net up to make contact with the grow-out net.

It is recommended that a separation stick be employed between the grow-out netting & predator netting. A separation stick of neutrally buoyant steel pipe would be manageable underwater. The length of the required stick would vary from pen to pen dependent upon the farm's installed nets on each pen. The depth of the predator net base from the grow-out net base varies widely between salmon farms. It is a function of the net design(minimum separation distance specified as required for net changes), the tensioning method employed, and net making inadequacies. As such, measurement of the required separation stick length would be required on an individual case by case basis. It could be performed by threading a rope through a pulley block on the surface at the pen center, then attaching this rope to the centre of the grow-out net. A nominal tension could then be applied, thus pulling the grow-out net centre up. Note, excessive upward tension to the grow-out net centre would result in the unwanted situation of lost tension to the side panels. A diver could then measure the distance between the grow-out and predator net centres with a tape, and a separation stick could be manufactured to suit.

Figure 29 : Separation Stick schematic



5.22.7 Aquatas Full Size Pen recommendations at Sheppards

Predator nets can be rendered ineffective by large currents as they are prone to come in contact with the grow-out net, or vice versa, dependent upon the weighting method and the total mass employed on each net. A specific current problem regarding tensioning and current flow was observed from the on-site measurements taken. The current flow is under 1knot, but even at this relatively modest flow, the predator net comes in contact with the grow-out net.

There are several methods of approach to solving this problem:

1. Change existing fouled net/s with clean net/s therefore reducing drag;
2. Replace existing concrete weights with denser point masses, such as steel, to reduce drag effects;
3. Change weighting arrangement to porthole system;
4. Adopt in excess of the recommended 20% available buoyancy on the existing pen to reduce net deflections;
5. Change pen out with pen of additional buoyancy, then hang more tensioning mass to reduce net deflections; and
6. Change pen to a new/modified pen with greater buffer distance with extra buoyancy, and hang more tensioning mass.

5.22.8 False Bottom Floor

A further relatively inexpensive recommendation is to provide all future grow-out nets with a false floor. A false floor, fitted at least 1m from the grow-out net base, is recommended. The material used is recommended to be PP or PE(both float IW) of a ply and denier that are chosen only in as much as they will prevent the salmon swimming through. By example, 210/60 stretched mesh size 80mm. It is recommended that knotless netting be used to reduce drag and lift effects.

As above, a recommended enhancement to the false floor would be a separation stick located centrally between the false bottom floor and the grow-out net. It would provide another level of protective barrier.

5.22.9 Bird Netting

As the current use of bird netting relies on designs similar to those of the grow-out or predator bases, together with bird poles through which tension is applied, it is recommended that a simpler system where the bird netting is free hung over a floating support structure and tied back to either the inner or outer handrail is adopted. Refer figure below.

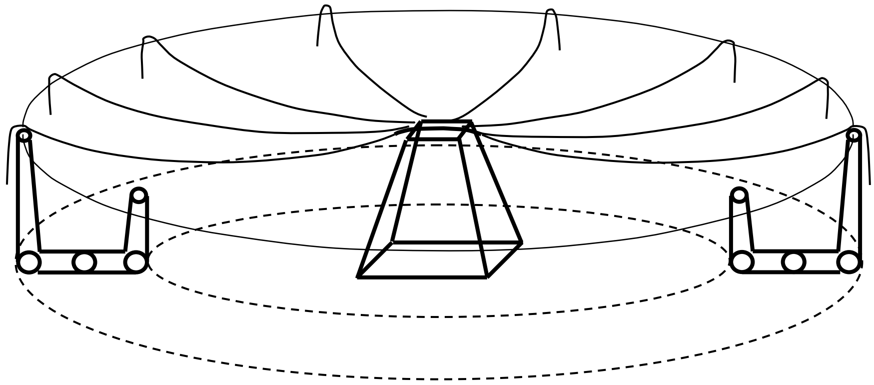


Figure 31 : Recommended alternate bird netting arrangement

The advantages of such an arrangement are that it is very simple and would require virtually no maintenance, and that the designs of the current bird netting could be simplified. The main concern with such an arrangement is in the determination of the height of the support structure such that there is sufficient slackness in the hanging catenary when a wave crest passes through the pen.

5.22.10 ADDs

It appears that in the past ADDs have been purchased in exasperation, and choice has been dependent largely on cost. D. Pemberton, 1989, wrote in “The Interaction between Seals and Fish Farms in Tasmania”, that he performed local testing of two available ADDs and reviewed all available literature. It was found then that acoustic scarers do not prevent all seal attacks. This statement, from available anecdotal evidence today on ADDs purchased and trialled over the past years, is still true. However, ADD designs have altered significantly in recent years and the trialling of ADDs under specific conditions should begin again. Any testing should be performed under strict guidelines such that qualitative measurement of an ADDs effectiveness can be concluded.

It was also stated within the aforementioned report that if acoustic devices are to be used, they should be used within the behavioural conditioning model only. Any other use of them will promote the “dinner bell” effect; this then would exclude the use of the Airmar ADD.

5.22.11 Sinker-Ring

Use of a correctly weighted sinker ring would make a substantial difference to predation, as it would reduce the overall deformation of the bottom area of the grow-out and/or predator net, and it would provide a more evenly distributed load.

It is recommended that physical model testing be performed in the first instance to determine the basic sinker ring design parameters. FEA analysis of a sinker ring in a full size pen is also recommended.

5.22.12 Record Keeping

Comments in “Experimental Predator Control Measures On Marine Salmon Farms In Shetland”(Holly Arnold, Greenpeace UK) state that “It is very difficult to evaluate the efficiency of pen net tensioning in reducing seal predation…” and mortality as there are no 'before and after' figures available for entanglement and direct kills”. This is typically the case also with the Tasmanian Salmonid industry; proven by the difficulty with which to gain information throughout this project.

Conclusions from the analysis of logbook data taken in 1988-89(D Pemberton 1989) described the need for a more comprehensive “logbook”. From salmon farm visitations, only now are farms developing KPI predation data, rather than relying on pure anecdotal evidence of changes in net materials, tensioning methods etc. The use of KPIs needs to be extended to obtain a degree of quality throughout the farms operation. Should even just one farm implement such a system, then over the duration of 2 to 3 years major conclusions could be drawn on various techniques.

It is recommended that a database be initiated, of seal mortalities against:

- Choice of and number of fish attacked;
- Tensioning methods;
- Stocking density; and
- Net design(reference to particular net).

This is easily accomplished by available software, such as Microsoft® Access. A computer studies undergraduate could be employed in a term break to develop a pro-forma that could be utilised across the salmonid industry. Part of the undergraduate’s work scope would be to train at least one employee from each farm to input data and use the program. It is recommended that the chosen employee be an appointed seal-netting “champion” to be responsible for the record keeping of seal morts against net design and tensioning methodology.

6.0 BENEFITS AND FURTHER DEVELOPMENT

Prior to this project, there appeared to be no multidisciplinary strategic approach to the reduction of predation by seals. This report, at the very least, provides a basic reference point in describing methods and techniques currently in use in the Tasmanian salmon and South Australian tuna industries. It describes net design parameters and failings, and provides basic recommendations to reducing predation using the existing pens and net designs.

Generalised beneficiaries of this project include the farming sector and supporting industries, fisheries research and conservation groups, as well as the predatory population of seals.

If the recommendations are recognised and implemented then the specific benefits will be:

- Improved productivity from farms(lower stress level in fish, fewer mortalities);
- Reduced seal monitoring and relocation costs;
- Compliance with animal conservation acts;
- Improved public acceptance of aquaculture through industry adoption of passive deterrent systems; and
- Technology transfer between industry and the research community, and visa-versa.

It is difficult, if not impossible, to quantify benefits as a result of this project as only estimate figures of $1.5million and $1.2million for the salmonid and tuna industries respectively were initially provided. No individual farm mortality figures were ever provided or sighted. Implementation of the recommendations provided, it is hoped, are ongoing. Once the salmon and tuna industries implement quality systems that record and assess changes, and make such information available to other Association members, then the true benefits of this project, and any further developments, can be analysed.

As the use of flexible PE pipe pens is likely to continue, further multi-disciplinary research is required to investigate available options and make objective conclusions. Refer to the Table below.

Further computer modelling, of both full size pens and physical models, is required to gain confidence in the FEA analysis and results. Due to the inaccuracies involved in the current model, a simpler model may prove a worthwhile alternative in gaining such confidence in the FEA analysis. Ultimately, the development of a computer model to an extent where the determination of the effects of wave motion on flexible pens, and thus stress and strain data, can be performed. This involves testing in the AMC wave tank where the development of an optical measurement system is required. The construction of a simple model, in order to focus on basic parameters, may be required in the first instance to confirm the FEA program, then the use of the 1:20 flexible frame physical model.

At the final draft of this report discussions where ongoing with an ADD manufacturer for the objective testing within Tasmanian waters.

Recommendation	Action/Admin/Funding	Result	Benefit
Further investigation into salmon behaviour during predation by underwater cameras and diver survey.	• TSGA • Tassal • FRDC • Salmon subprogram • Research Assistant	Accurate knowledge of daily behaviour, possibly seasonal behaviour.	Tasmanian salmonid industry, possibly the world salmonid industry.
Further investigation into the mode of attack on salmon underwater Permanent underwater cameras Crittercam.	• TSGA • FRDC • Salmon subprogram • Research Assistant	Accurate knowledge of mode of attack.	• Tasmanian salmonid industry, possibly the world salmonid industry; • General public awareness into industry problem.
Objective testing of ADDs Preferably automatically operated ADDs Note: Aceaquatec trialling new automatic model as at Feb 2001	• TSGA • FRDC • Salmon subprogram • Research Assistant	Objective assessment of ADDs	Global aquaculture industry
Specific to typical 120m salmon pens and netting • increase buffer distance between grow-out and predator; • employ separation stick; • add false bottom floor; • Increase side net taper on predator & grow-out nets; and • hang minimum recommended weights (dependent on available buoyancy & pen geometry)	Individual salmon farms	• Reduced morts • Reduced conditioning of seals that farmed salmon is “easy” prey.	Individual salmon farms
Additional tensioning on salmon netting increase pen buoyancy(additional pipe ring/ additional stanchions/new stanchions)	Individual salmon farms	• Reduced morts • Reduced conditioning of seals that farmed salmon is “easy” prey.	Individual salmon farms
Employ of Sinker Rink on salmon pens	Individual salmon farms	• Reduced morts • Reduced conditioning of seals that farmed salmon is “easy” prey.	Individual salmon farms
Appoint “Seal Champions” Charge with responsibility of Quality Control / Keeping of accurate records	• TSGA • TBOA (for annual record keeping & reporting) • Individual salmon & tuna farms	Central point for all objective information on farm pertaining to predation. Ability to make step by step modifications based on “hard” evidence to increase net & pen performance. • Reduced morts • Reduced conditioning of seals that farmed salmon is “easy” prey	Individual salmon & tuna farms
Create common database Accurate quality records, KPIs etc across farms	• TSGA • TBOA • FRDC • Computing student	Commonality & control across industry • Reduced morts • Reduced conditioning of seals that farmed salmon is “easy” prey	Individual salmon & tuna farms
Adopt minimum of 2m high jump fences on tuna farms netting on the diamond for flexibility	Individual tuna farms	• Reduced morts • Reduced conditioning of seals that farmed tuna is “easy” prey.	Individual tuna farms
Adopt exotic(spectra/dyneema) high strength netting on tuna farms Increased protection from sharks, & so seals.	Individual tuna farms	• Reduced morts • Reduced conditioning of seals that farmed tuna is “easy” prey.	Individual tuna farms
Objective assessment of BHP Marinemesh(currently on trial). Investigation into adoption of mesh on typical 120m pens, against all associated costs of current synthetic netting, seal relocation etc.	• TSGA • FRDC (funding for industry lifting frame etc) • AMC(engineer: under/post grad)	• Reduced morts • Reduced conditioning of seals that farmed tuna is “easy” prey.	Global aquaculture industry

<u>Further FEA computer modelling</u> Determine minimum buffer distance for a range of flow speeds(inshore & offshore conditions) and tension weights. Investigate seal impact to design out weak points (requires input from mode of attack investigation)	• TSGA • FRDC • AMC(engineer: under/post grad) • Salmon subprogram	Provision of accurate model such that full scale changes and assessment not required. • Reduced morts • Reduced conditioning of seals that farmed tuna is “easy” prey.	Global aquaculture industry
<u>Further physical scale modelling</u> Performed at the AMC Flume Tank & Wave Tanks “new” model. Investigate use of false bottom.	• TSGA • FRDC • AMC(engineer: under/post grad) • Salmon subprogram	Provision of accurate model such that full scale changes and assessment not required. • Reduced morts • Reduced conditioning of seals that farmed tuna is “easy” prey.	Global aquaculture industry
<u>Further investigation as to deterrence by use of Shark Pod</u>	• TSGA • Tassal(as one unit in use) • FRDC • Salmon subprogram • Research Assistant	• Reduced morts • Reduced conditioning of seals that farmed tuna is “easy” prey.	Global aquaculture industry

Table 26 : Précis “way forward”

7.0 CONCLUSION

Australian & NZ salmon farmers' differ markedly from other salmon farmers' around the world in that seals in Australian waters are protected. Farmers' of salmon in Norway, the UK, Ireland, Chile and Canada can all shoot seals should they pose a threat to the farmers' stock. Australian farmers then must continue to consider the threat of predation with all activities related to the rearing of salmon, including budgetary expenditure, net design, tensioning, site selection, and gain market recognition for being seal friendly to recoup lost proportion of fish via out competing foreign imports.

The majority of the base objectives of the project have been reached in that:

- A passive anti-predator model was made, based on industry experience, anti-predator expertise and operational/mechanical suitability;
- The model was evaluated under various flow conditions; and
- Recommendations have been made for the production of a commercial scale anti-predator system for testing under Tasmanian conditions.

Meeting of the objectives of the project was difficult because of:

- No factual engineering detail on farming equipment & techniques, tensioning methods, etc at the project commencement;
- Information regarding exact method of seal strikes being largely anecdotal and/or varied across both the salmon & tuna industries;
- Confidentiality between farm companies, net makers, pen manufacturers
- Confidentiality between all the above noted entities and the Research Assistant; and
- Frustration of salmon & tuna farmers' in that predation cannot be solved in an easy manner.

The drawing of conclusions is difficult as:

- Limited funding is available to most fish farmers to pursue anti-predation measures;
- Accuracy was not attained through 20:1 scale model to enable conclusions to be made; and
- There is a large variance in farming equipment & techniques, tensioning methods, etc.

The easiest conclusion to make is that a rigid netting system would prevent any predation. At the lower end of the cost scale this is represented by Onesteel Marinemesh, on the upper end it is represented by engineered structures, eg spar buoys, or flexible bag systems. However, such conclusions do not address the existing pen problem.

The physical barrier method of excluding predators by the use of predator netting has evolved since the beginning of the Tasmanian salmonid industry to where it is now almost 100% effective against seals. Seals are capable predators and will exploit any weaknesses in any physical barrier to eat farmed fish if less effort than hunting wild fish is required.

There is no easy method for controlling seal predation on the current flexible pen structures. The pen design is successful in that it is relatively cheap, and is flexible. In the static situation, if the net design, amount of tension and the tensioning method prevent seal predation, then, with respect to predation, the flexibility will be its undoing under any environmental condition, as ill-taut netting(due to deflection and deformation) will result. To compensate for these periods it is recommended that the starting point for success in reducing predation will require the integration of more than one method. In summary these are given below and described briefly in the following paragraphs.

1. Adopting best net materials and designs;
2. Providing maximum tension in the predator net;
3. Increasing the buffer distance between the grow-out and predator nets; and
4. Preventing collection of weak or dead fish from the grow-out net bases by addition of a false bottom or separation stick.

It is recommended that tapers of at least 10% be adopted for both the grow-out and predator nets. The greater the taper the more tension through the base. Due to their elastic characteristics, the preferred frameline material is spectra or dyneema, followed by braided line, then the current materials of PP or PE. Likewise, the preferred netting material is spectra or dyneema. Anecdotal evidence is that seals have been corkscrewing through predator netting of 5" stretched mesh; therefore 4" stretched mesh for predator netting is recommended.

In the long term it is envisaged that the predator net will become the main net of farming the stock and the grow-out net will return to being a “holding” net. That is the denier and ply of the grow-out net can be reduced if maximum weighting of the predator net proves successful.

Maximum tension to the predator net for a typical pen is recommended at 20% of the available buoyancy, that is circa 2.4Te. For the current typical pens, this implies no weighting on the grow-out net(porthole method).100kg weights can be hung directly by divers, by adopting the Concertina method, by having predator nets fitted with socks or portholes. However, when the buffer distance is increased by the addition of a third pipe ring, the recommended 20% can be hung and additional weighting can be hung on the grow-out net.

Increasing the buffer distance can be via two options. The preferred option is a new stanchion design which incorporates three pipes. Three pipes satisfies the safety issues when farm personnel are working on the pen and would result in lower stresses in the connecting brace between pipes should the same buffer distance be designed with two pipes. The alternative, a cheaper option, is to add a third pipe ring to the current design, utilising the current stanchion facing outwards. It is thought that the dynamics of this option, analogous to an articulated three joint vehicle, would survive the inshore wave loads typically seen in the current lease sites.

The design of a false bottom could further complicate, and possibly impede, the net design. Such a false bottom should be designed such that it offers no resistance to the tension in the side panels and be from PP or PE material, with a small section of lead line centrally such that it is fractionally negatively buoyant. A buffer distance of at least 0.5m in the water would be recommended.

A simple option to preventing the collection of fish from the base is to add a separation stick. Fitted through the grow-out net centre and fixed to the centre such that when a seal pushes up the predation net, the grow-out net is also pushed upwards. A sleeve in the predator net to which the stick could be fitted would be ideal, alternatively a blunt stick weighted at the blunt end and of a low profile so as to not be excessively affected by drag, could be trialled initially.

Further objective research is required on the latest models of Seal Scarers in determining their effectiveness. It may be that the current net design and tensioning methods are sufficient when Seal Scarers are employed

Scope exists for combining improved netting techniques, ADDs and proven seal-proof farming methods, such as the System Farm, to improve seal protection of farmed fish

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APPENDIX A : INTELLECTUAL PROPERTY

The physical model constructed, consisting of the rigid and dynamic model pen, and the grow-out and predator netting are owned by the TSGA, FRDC and the TMAG. No use of the models shall be made without prior approval of the TSGA.

APPENDIX B : STAFF

R. Schotte	TSGA
D. Pemberton	TMAG
D. O'Brian	Huon Atlantic Salmon(HAC)
John Wakeford	AMC Fisheries
S Tiedemann	Tassal
P. Warner	Tassal
M. Finn	Tassal
J. Smith	Pivot NT
Chris Lambert	AMC Fisheries
T. Smithies	TSGA
D. Shields	Aquanel
R. Mawby	Aquanel
Darryl Boothy	Huon Atlantic Salmon(HAC)
Peter Heard	Aquatas
Tim Reid	DPIWE(Marine)

APPENDIX C : FEA RESULTS TO DATE

The following results are representative of analysis to date of FEA modelling of the 120m pen at Aquatas-Sheppards.

The base has been removed from the analysis for these examples as the base grouping algorithm requires further refinement.

APPENDIX C1 : Base case

GENERAL				
Flow velocity cm/s	37.5			
Element Type	Cable elements(for no bending stiffness)			
Young's Modulus N/m2	1.8E8			
Density kg/m3	1.14E3			
PREDATOR NET				
Model mesh size	3.75			
Top diameter m	40.012			
Bottom diameter m	35.2			
Mesh mm	152.5			
Twine mm	3.1			
Depth m	15			
Tension Weights kgIW	24x100(70kg+30kg pendulum by divers)			
Drag Coefficients	Normal, Cdn	3.0	Tangential, Cdt	1.2
Resultant Displacement	Dx	4.9	Dy	1.9, at leading edge node 11.25m depth.
GROW-OUT NET				
Model mesh size	2.5			
Top diameter m	37.8			
Bottom diameter m	36.0			
Mesh mm	43.4			
Twine mm	3.4			
Depth m	10			
Tension Weights kgIW	24x35(70/2 shared)			
Drag Coefficients	Normal, Cdn	0.65	Tangential, Cdt	0.25
Resultant Displacement m	Dx	4.38	Dy	1.69

Table C1 : Inputs & outputs from FEA program

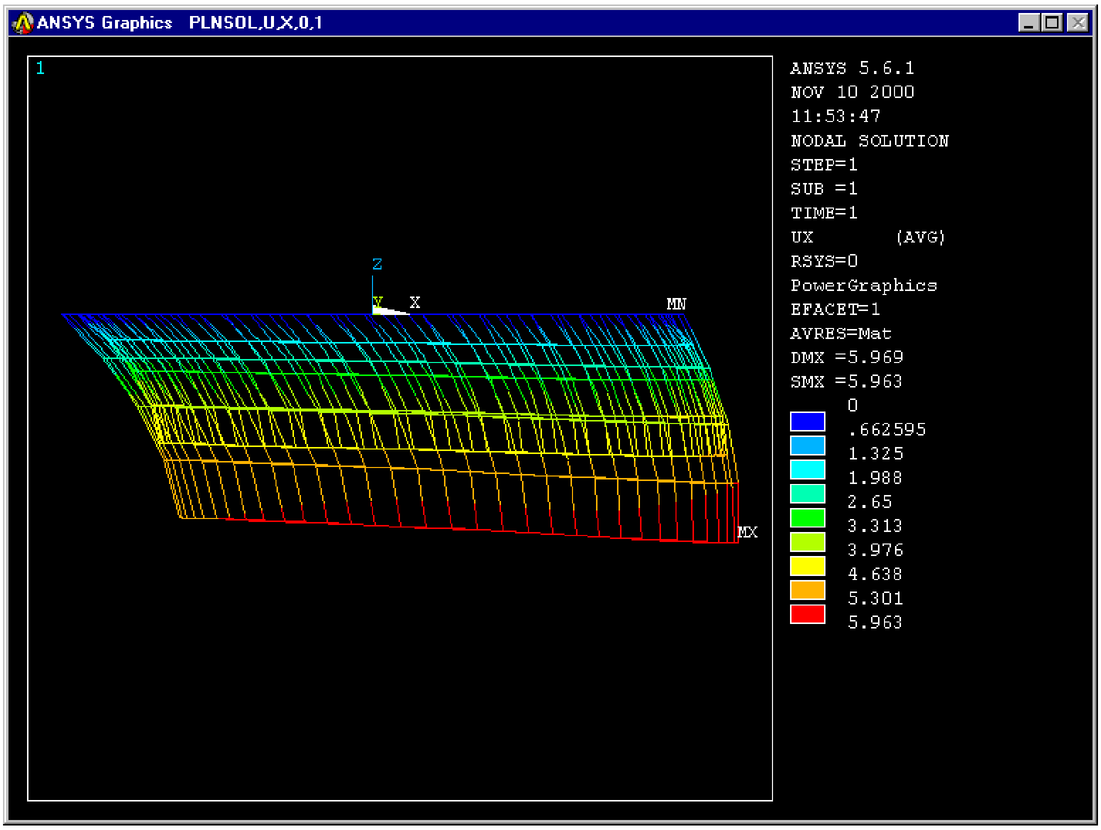

Figure C1 : FEA computer model at conditions given in Table C1

APPENDIX C2 : Effect of increased weights on base case

GENERAL				
Flow velocity cm/s	37.5			
Element Type	Cable elements(for no bending stiffness)			
Young's Modulus N/m2	1.8E8			
Density kg/m3	1.14E3			
PREDATOR NET				
Model mesh size	3.75			
Top diameter m	40.012			
Bottom diameter m	35.2			
Mesh mm	152.5			
Twine mm	3.1			
Depth m	15			
Tension Weights kgIW	24x150			
Drag Coefficients	Normal, Cdn	3.0	Tangential, Cdt	1.2
GROW-OUT NET				
Model mesh size	2.5			
Top diameter m	37.8			
Bottom diameter m	36.0			
Mesh mm	43.4			
Twine mm	3.4			
Depth m	10			
Tension Weights kgIW	24x35(70/2 shared)			
Drag Coefficients	Normal, Cdn	0.65	Tangential, Cdt	0.25

Table C2 : Inputs & outputs from FEA program

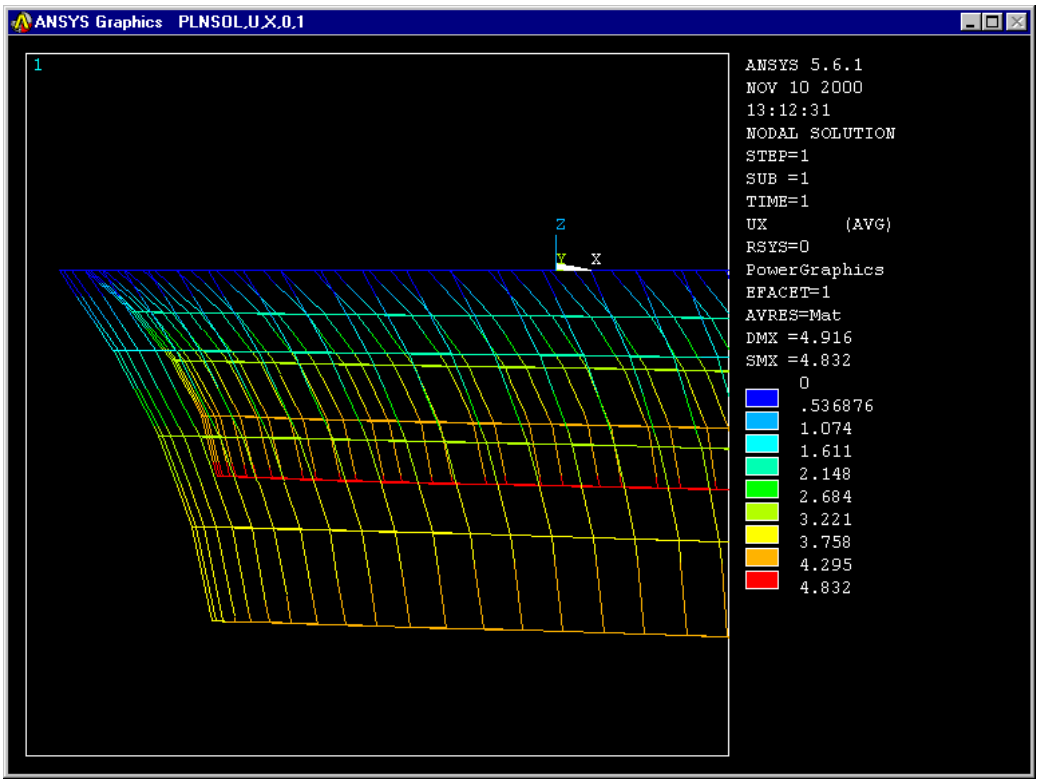

Figure C2 : FEA computer model at conditions given in Table C2, identical to that of Table C1 except 24x150kgIW tension weights on predator net. Note reduced displacement on predator net in the x direction, thus increased separation between Predator & grow-out net.

APPENDIX C3 : Static condition displacement in the z direction(vertical).

GENERAL		
Flow velocity cm/s	0	
Element Type	Cable elements(for no bending stiffness)	
Young's Modulus N/m2	1.8E8	
Density kg/m3	1.14E3	
PREDATOR NET		
Model mesh size	3.75	
Top diameter m	40.012	
Bottom diameter m	35.2	
Mesh mm	152.5	
Twine mm	3.1	
Depth	15	
Tension Weights kgIW	24x100(70kg+30kg pendulum by divers)	
Resultant Displacement m	Dz	0.185

Table C3 : Inputs & outputs from FEA program

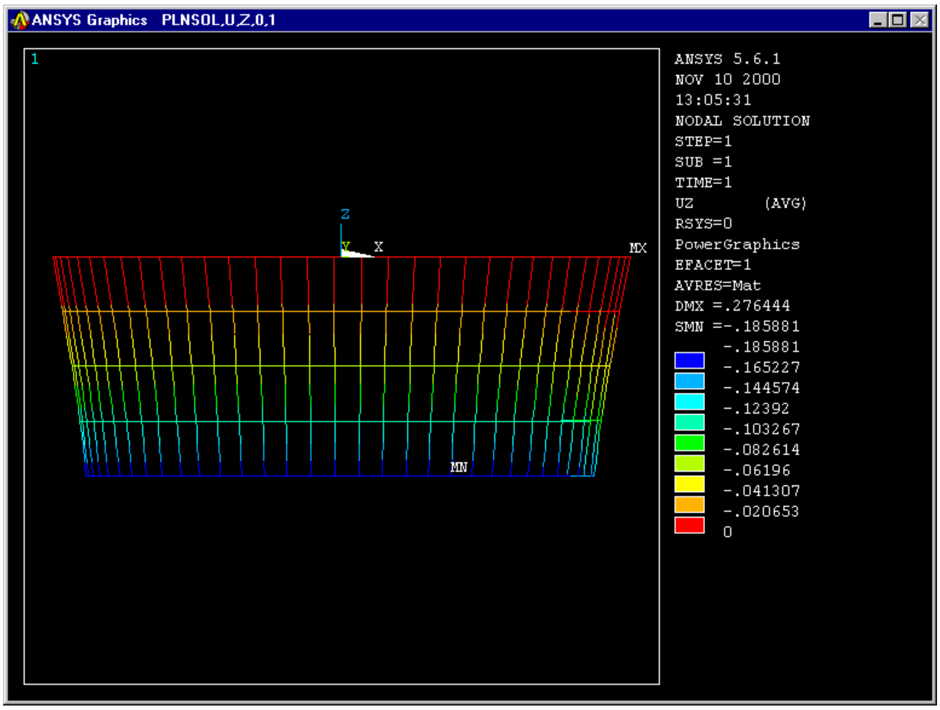

Figure C3 : FEA computer model at conditions given in Table C3

APPENDIX C4 : Seal impact, static condition

GENERAL				
Flow velocity cm/s	0			
Element Type	Cable elements(for no bending stiffness)			
Young's Modulus N/m2	1.8E8			
Density kg/m3	1.14E3			
PREDATOR NET				
Model mesh size	3.75			
Top diameter m	40.012			
Bottom diameter m	35.2			
Mesh mm	152.5			
Twine mm	3.1			
Depth m	15			
Tension Weights kgIW	24x100(70kg+30kg pendulum by divers)			
Drag Coefficients	Normal, Cdn	3.0	Tangential, Cdt	1.2
GROW-OUT NET				
Model mesh size	2.5			
Top diameter m	37.8			
Bottom diameter m	36.0			
Mesh mm	43.4			
Twine mm	3.4			
Depth m	10			
Tension Weights kgIW	24x35(70/2 shared)			
Drag Coefficients	Normal, Cdn	0.65	Tangential, Cdt	0.25

Table C4 : Inputs & outputs from FEA program

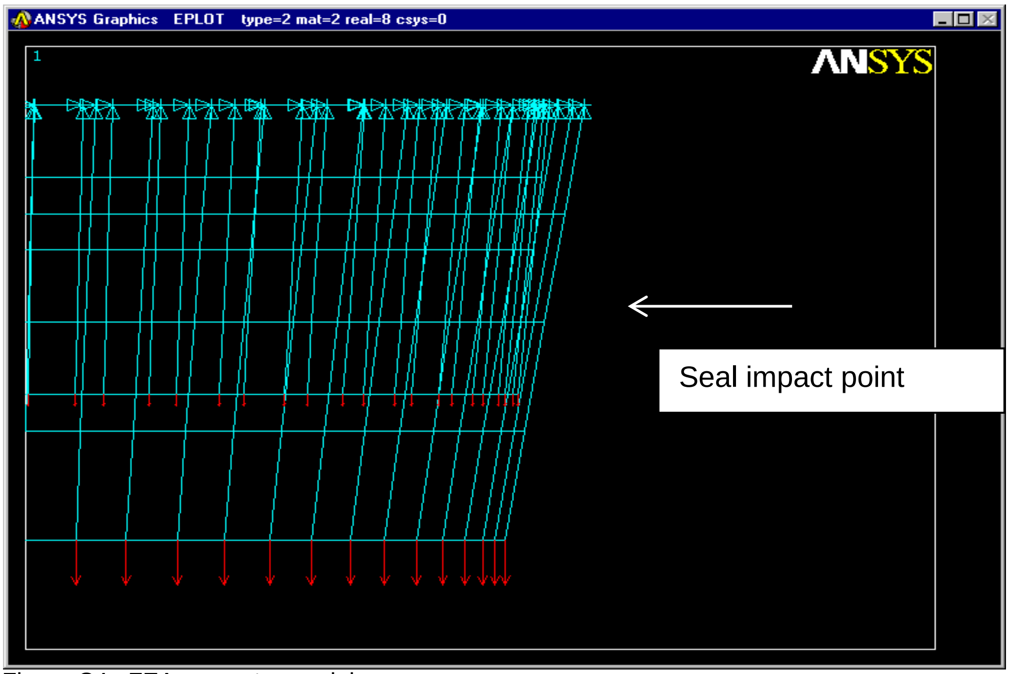

Figure C4 : FEA computer model

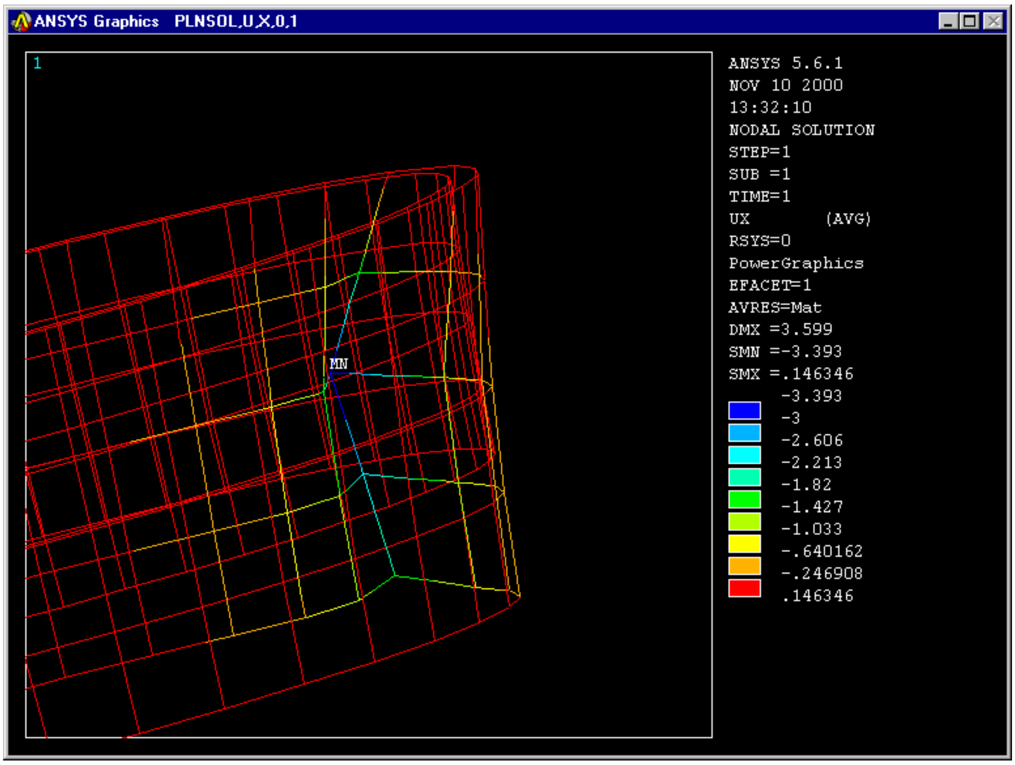

Figure C4 : FEA computer model depicting typical impact from seal