Aqua Group

The environmental effects of salmon farming in Big Glory Bay, Stewart Island

A discussion paper on sustainable management

DISCUSSION DRAFT

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1 INTRODUCTION

This report is a discussion document aimed at those who are interested in the sustainable management of salmon farming in Big Glory Bay. The impetus for this report was three-fold: a need to bring together various studies that have been done, confusion over how the statutory management regime applies, and the need to develop a framework for sustainable management of the area. In addition it is hoped that the approach taken will be able to be used as a case study for establishing such frameworks elsewhere in the country.

The report begins by reviewing the legislative framework applying to existing salmon farming operations under the Resource Management Act 1991 (RMA) and other legislation. It then discusses future management options and opportunities available under this framework, especially with regard to the Regional Coastal Plan (RCP) which the Southland Regional Council (SRC) is currently preparing.

The environmental effects of salmon farming are discussed, based on a review of scientific papers and unpublished material. This report does not deal with individual cages and licences (there is a need to collate details of all the current approvals) but rather it looks at generic effects of cages and potentially wider effects throughout Big Glory Bay. This not only provides a basis for subsequent discussion of sustainable management but allows research priorities to be more thoroughly debated.

The chapters on legislation and effects are designed to feed into the discussion of the roles and responsibilities of the various agencies, and ideas on how sustainable management could be implemented in Big Glory Bay. A systems approach to sustainable management is proposed based on various scales of impact. A series of recommendations are included which it is hoped will stimulate industry, management agencies, iwi and other interested parties to debate issues more fully, ultimately leading to improvements in resource management.

2 BACKGROUND

A salmon farm industry has been operating in Big Glory Bay (BGB) Stewart Island since 1981. Projected production for 1993/94 is estimated to be 2350 tonnes greenweight total for the bay (Anthony Brett, MAF Fisheries Dunedin, pers. comm.). Intensive cage rearing culture is practised. Dried fish food, manufactured from waste fish material is fed, mainly from automatic feeders and by hand. This results in a loading of waste food, faeces and metabolic products into the environment. There is a large scale infrastructure associated with the farming operations: floating cage units of varying sizes and shapes which are moored to blocks on the seabed, feed hoppers, rafts, sheds, accommodation barges and boats, and cleaning units.

The farms have contributed significantly to the local island economy. There are also a number of downstream industries in the region that are to some extent reliant on the farming operations: charter boats, fish processing factories, engineering workshops for example.

At present two companies are operating, farming on seven licensed sites. An eighth site is also licensed to farm salmon although it has not been used for this to date. The licensed sites are shown on Figure 1; these are three or four hectares each (except MFL 149 which is 5.6 ha.). Mussels are also farmed commercially within the bay, principally on 3 sites on the south side.

Big Glory Bay is a semi-enclosed arm in the south-east of Paterson Inlet, a deep rock walled inlet on the east coast of Stewart Island. It covers 11.9 sq. km. of the 100 sq. km. of Paterson Inlet. Average depth in the centre of Big Glory Bay is 14 metres.

In January 1989 a dense bloom of the dinoflagellate alga *Heterosigma* resulted in the death of around 600 tonnes of salmon. Cages were moved out of Big Glory Bay onto a refuge site near the entrance of Paterson Inlet. Between late November 1992 and mid January 1993 this site was again used during a period of sustained easterly weather and high algae counts predominately of the flagellate *Emiliania huxleyi*. After the 1989 bloom the number of companies farming in the bay decreased from five to three. In 1992 one of these remaining companies bought out the third.

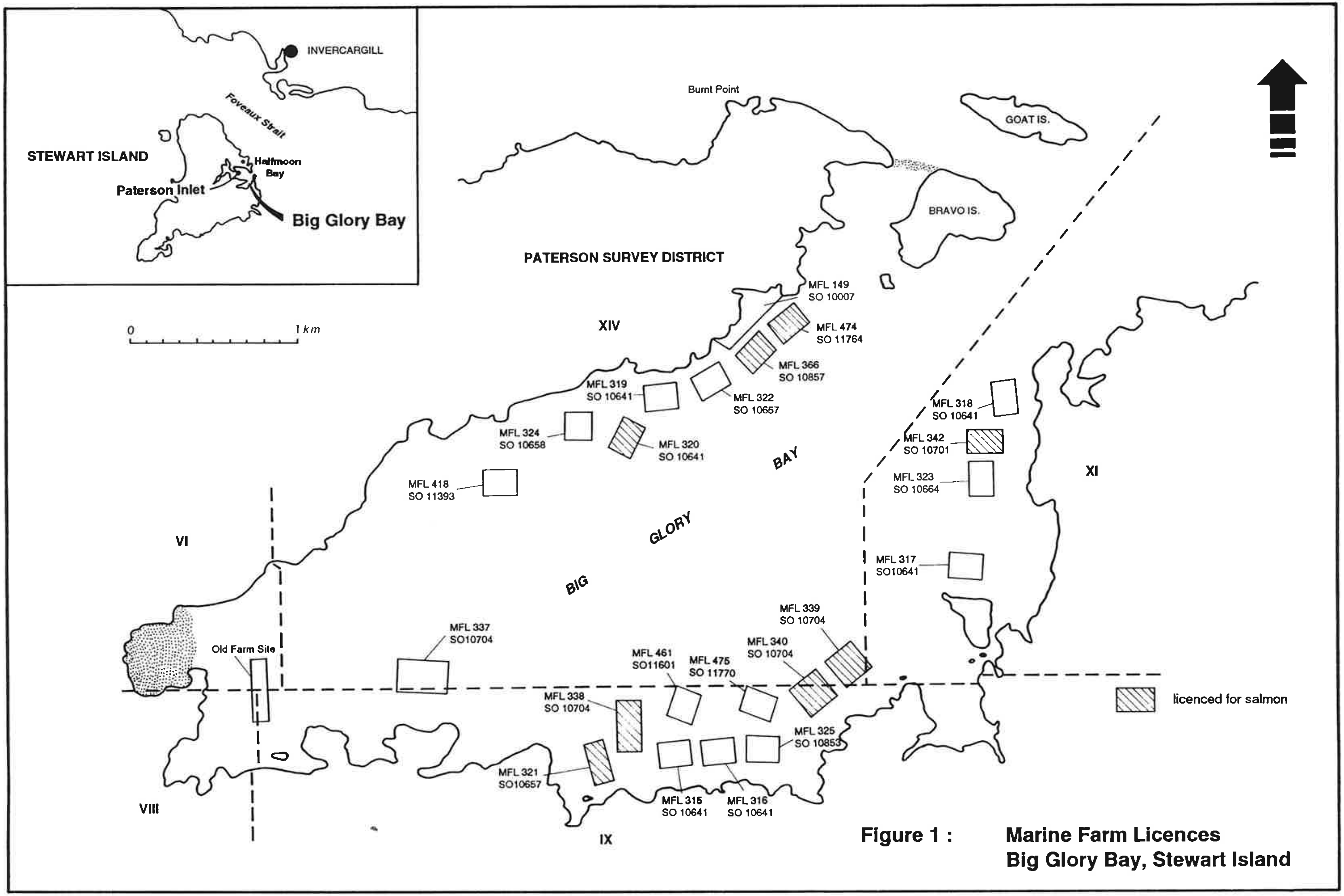

Figure 1 : Marine Farm Licences Big Glory Bay, Stewart Island

3 THE LEGISLATION

3.1 LEGISLATIVE BACKGROUND

This discussion of the legislative framework should not be construed as legal advice. The interpretation of the law is ultimately up to the Courts. If people have any specific concerns it is suggested that they should seek their own legal advice.

Before the RMA enactment, all the Big Glory Bay salmon farms:

* were operating on licences to farm mussels (and other shellfish in some instances)
* had special permits under S14A of Marine Farming Act (MFA) to farm salmon (and had been operating under this system for several years)
* had applied for S13 variations to the licences to add salmon as species able to be farmed.

These variations were granted (by signing memorandum of variation to the licences) after RMA enactment.

Other legal considerations, prior to RMA, were;

* whether they had S178(1) (b) Harbours Act plan approval as required by S30 and S31 of MFA
* whether the farms required water rights to discharge waste (uneaten food, fish faeces, cleaning agents, antibiotics) into the waters of the bay, which were classified.

3.2 EXISTING LICENCES

Existing leases and licences are saved by s426(1) of RMA which effectively maintains the MFA as a distinct code for all existing marine farming licences. This section provides for the continuance of leases and licences granted under s8 of MFA and any subsequently granted under s397(1) of RMA. S397 relates to applications made under MFA just prior to RMA enactment which were required to be determined under MFA. All these leases and licences are to:

> *"continue in force after the commencement of the Act on the same conditions and with the same effect as if the Act had not been enacted; and all provisions of that Act relating to any such lease or licence or conferring or imposing any right, power, privilege, function, duty or liability on any party to any such lease or licence shall continue to apply in respect of that lease or licence accordingly".*

Because Big Glory Bay was not subject to any maritime or district plan section s418(6) does not apply. If Big Glory Bay had been subject to existing use provisions of a maritime or district plan then a licence could continue without other permits until a rule in a RCP was made requiring a consent to be obtained.

Leases and licences under the MFA grant rights to occupy an area of the sea for the purposes of farming fish. The RMA allocates access to the bed of the coastal marine area and controls the adverse effects of activities on the environment (eg: water quality). Specific activities such as the discharge of contaminants are not authorised as such by the MFA, therefore other permissions may be required under separate legislation (eg: previously under the Harbours Act for structures). A High Court decision in *Minister of Works and Development v Tauranga County Council (1987) 12 NZPTA 385, per Davison J.*, stated in relation to a district scheme that "the council therefore has, in my view, power in effect to prohibit commercial fishing or marine farming even though a lease or licence to do so may have been granted from the appropriate authority". A similar relationship exists between the RMA requirements for coastal permits and licences under the residual MFA.

Prior to the RMA coming into force on 1 October 1991, most of the existing marine farming licences in Big Glory Bay had the necessary approvals under the Harbours Act 1950 for structures but none had been granted water rights under the Water and Soil Conservation Act 1967 for discharges of waste into water. To the extent that any unauthorised activities contravene s12, 14 and 15 of RMA they remain unlawful until a coastal permit is granted. That is, there is no basis for any existing use rights to apply.

Existing s178 plan approvals under the Harbours Act are deemed to be coastal permits by the RMA (s384(1)(b)), and so are now administered by SRC. Such approvals do not usually have any expiry dates, and this situation can continue indefinitely unless a variation or new consent is applied for.

It should be noted the applications for water rights made prior to 1 October 1991 are deemed to be applications for coastal permits (and unless withdrawn they are still valid applications until decided by SRC). Licences granted under MFA are not deemed to be coastal permits so any coastal permits not applied for prior 1 October must be treated as new applications (ie: s384 and s389(1) do not apply, but s396 will apply).

The RMA has also altered the rights of renewal previously contained in the MFA (s22). Under s426(5) of RMA the statutory right of renewal is removed and licences only have renewal rights if they are stipulated in the licence conditions. The licence holder can apply under s13 of MFA to the Minister of Fisheries for a variation to the term (and any other conditions) for up to 14 years. When granting an extension of the term under MFA (s13(4)) the Minister may extend the term on the same conditions, or with varied conditions which are not inconsistent with the requirements of the MFA. There is no limit to the number of extensions that may be so granted. The existing licences in Big Glory Bay do not have renewal conditions, thus they will expire at the end of the 14 year term (at which time a coastal permit will be required and s124 applies) unless a variation is granted.

Any such variation will of course require the concurrence of the Minister of Conservation and the Minister of Transport.

3.3 NEW MARINE FARM APPROVALS

Any proposals for further development of marine farms in Big Glory Bay will require a coastal permit which will deal with all resource management issues (eg: access, pollution and visual effects). Approvals will also be required under the residual MFA for stock and disease management issues and possibly under the Harbours Act approval for navigation and safety issues.

Until a Regional Coastal Plan becomes operative the Regional Council must notify the Minister of Fisheries upon receipt of an application in respect of marine farming (s396). Any report by the Minister must be considered by the Council.

Where an existing MFA licence did not gain the all the necessary approvals under the previous legal regime (eg: s178 of Harbours Act) the RMA provisions will apply as though it were a new application. This is also the situation where alterations or extensions to the marine farm are proposed in the future.

3.4 TRANSITIONAL REGIONAL COASTAL PLANS

A Regional Coastal Plan (TRCP) under the transitional provisions of the RMA (s370 and s371) is deemed to include a number of existing regulations and rules from previous statutes. This includes, by virtue of s370(2)(b) of the RMA, determinations of the Minister of Fisheries under s4(2) of the Marine Farming Act notifying areas that shall not be available for marine farm leases or licences.

One such determination was in place in Southland. On 26 August 1983 the Minister determined that the foreshore, sea bed and waters surrounding Stewart Island would not be available for marine farm licensing or leasing, except for those areas identified within Big Glory Bay.

The accompanying map excluded farming within the bay from most of a coastal strip of varying width. There were three accompanying notes:

Note 1 *All marine farms will be conditioned so as to enable the farm to be moved on a temporary basis to enable anchoring of an oil rig.*

Note 2 *The effect of the plan is to close areas to marine farming. Unshaded areas of sea are those areas which* *will be closed to marine farming. Any application in the closed areas will be automatically declined. No marine farms will be granted automatically.*

The shaded area will remain as it was, that is available for application as marine farms. The applicant must still complete the normal application procedures of advertising, marking the area, calling for objections and informing certain persons after which the Minister will either grant or decline the application. No marine farms will be granted automatically because they are within the area available for application. A report is issued with this plan giving further information.

Note 3 *Any marine farms, if granted, will be licences only, which gives the licences the right to carry out marine farming within the specified area, but does not give any rights of possession. This means anyone may pass over, under or through the licensed area.*

The effect of the determination was to make all marine farming, within the meaning of the MFA, a prohibited activity on the foreshore, sea bed and waters surrounding Stewart Island except for those areas in Big Glory Bay shaded in the map (s371(2)). By virtue of s371(3) and s369(1), marine farming in those shaded areas becomes a discretionary activity.

The TRCP also includes existing water classifications developed under the Water and Soil Conservation Act 1967 (s26C) by virtue of s370(2)(c) and s368(2)(b) of RMA. Any resource consent seeking to use the waters of the region contrary to the classification will be considered a non-complying activity. The classification also includes a provision which allows for the reasonable mixing of a contaminant before a discharge must meet the minimum water quality standard.

The Southland Harbour Board Stewart Island Bylaws 1985 (under the Harbours Act 1950) apply to Big Glory Bay, and are administered by SRC. These bylaws have specific provisions controlling navigation and safety around marine farms, as well as powers in relation to the deposition and removal of material from the foreshore (royalties may be required). The Minister of Transport and Harbour Boards have powers to erect navigational aids but existing navigation routes and anchorages have no specific recognition under any legislation or bylaws. Navigation and anchoring are not recognised in the TRCP but they are given status in the policies of the now defunct Southland Regional Scheme, and as such, the SRC "shall have regard" to these policies in carrying out its functions under RMA. Navigation controls may be created under the MFA (s28), or through changes to the bylaws, and potentially some controls are also possible in a RCP, but only in consultation with the Minister of Transport.

3.5 REGIONAL COASTAL PLAN

The SRC is required by the RMA to prepare and notify a Regional Coastal Plan (RCP) for Southland by 1 October 1993, and this RCP must then be approved by the Minister of Conservation. The purpose of the RCP is to promote sustainable management of the coastal marine area (CMA). The RCP may also form part of a wider regional plan covering the CMA and related coastal environment, in which case the Minister only approves that part relating to the CMA. In preparing the RCP there must be consultation with central government (particularly MAF Fisheries, Ministry of Transport (MOT), the Department of Conservation (DOC), iwi authorities, users and the wider community.

The RCP will establish the objectives, policies and rules for the allocation of coastal space and the management of adverse effects of activities in the CMA. This may include the control of;

* use of seabed and associated natural and physical resources
* extraction of sand and other materials
* taking and use of water
* discharges of contaminants
* storage, use, disposal or transportation of hazardous substances
* emission of noise
* activities in relation to the surface of water.

The scope of RCPs is circumscribed by s30(2) in that it cannot "apply to the control of the harvesting or enhancement of populations of aquatic organisms, where the purpose of that control is to conserve, enhance, protect, allocate or manage any fishery controlled by the Fisheries Act 1983". This presumably encompasses aspects of marine farming controlled under the MFA. There is no clear statement in the MFA of its scope and jurisdiction, but it clearly relates to the allocation of exclusive rights to farm fish and the management of issues such as disease control. The potential for conflict in relation to the carrying out of these functions is covered in Chapter 5.

Generally existing uses are not affected by the RCP until their coastal permit expires and, as noted above, the RCP also cannot not affect the rights and entitlements of existing MFA licences until they expire. The only exception is that a RCP may influence the conditions of an existing coastal permit, including those currently associated with marine farming, where a rule setting minimum water quality standards is established in the RCP (s128).

The RCP provides all those with an interest in the management of

Big Glory Bay with a number of opportunities;

* to review the existing transitional plan;

* to determine what sustainable management means in the context of Big Glory Bay and establish clear objectives or goals for future management;

* to establish environmental bottomlines, including sustainable fishing stock limits, in the form of clear rules and guidelines;

* to identify and protect conservation values;

* to address the conflicts between marine farmers, and between marine farmers and other users (eg: recreation);

* to define the roles of the various management agencies and the marine farmers; to establish the baseline environmental monitoring requirements;

* to streamline management processes.

* to provide for suitable refuge sites

Subsequent chapters of this report discuss the concept of sustainable management, environmental bottomlines and the roles of agencies. In terms of streamlining management procedures the RMA provides a range of tools which may be applicable to Big Glory Bay, including;

* permitted or controlled activities - the RCP can establish criteria whereby certain activities are either permitted as of right or do not require full public scrutiny. These types of permission can be used where an activity only has a minor effect or where the adverse effects are known and can be acceptably controlled by standard conditions;

* prohibited activities - certain types of activity can be prohibited from an area where it is not possible to mitigate the adverse effects to an acceptable level. This may be appropriate for very sensitive areas and means applications cannot be considered for such activities within these areas.

* market or psuedo-market mechanisms - for new applications this could include such mechanisms as coastal tendering (Part VII), bonds and other economic instruments environmental compensation. It is thus possible to include rules in a RCP that promote competition between users and the internalisation of environmental costs. It is not possible to transfer coastal permits from one site to another (they may be transferred from one owner to another), but it is possible have permitting system that allows for movement from one area to another within a coastal permit. The RCP can establish guidelines or rules

for such systems.

* transfer or delegation of functions - the RMA can allow a range of functions to be carried out by other parties where this is deemed to be more effective and efficient. For example, it may be easier for monitoring to be done by DOC or MAF Fisheries rather than SRC. It is also possible to transfer certain management responsibilities to iwi if this appropriate.

* environmental effects assessment - the requirements for effects assessment are set out in the Fourth Schedule of RMA but additional or alternative requirements can be prescribed in the RCP.

The use of these types of mechanisms within a RCP framework can increase certainty for all parties, as well as introduce flexibility to deal with marine farming industry requirements. The RCP can thus establish areas suitable for marine farming and develop procedures to deal with special issues, such as refuge areas.

3.6 REFUGE SITE

Following the *Heterosigma* bloom in 1989, discussions were initiated about suitable refuge sites to use in the event of further blooms. After consultation with industry, iwi, and DOC two sites in Paterson Inlet were chosen, including the site used during the 1989 bloom. MAF Fisheries subsequently issued a special permit under MFA allowing these sites to be used in appropriate circumstances. This permit is valid until 31 September 1994 or until the Southland RCP is operational, whichever occurs soonest. Whilst the MFA special permit granted the right to occupy the refuge sites in certain conditions, it is the RMA that controls the use of the seabed and the adverse effects of farming on the environment. These means a coastal permit would be needed to legally occupy and farm on these refuge sites. However the Minister of Fisheries' declaration restricting marine farming in Stewart Island waters to Big Glory Bay, now part of the TRCP, means marine farming is a prohibited activity in Paterson Inlet. SRC is not able to accept an application for a coastal permit for marine farming in these waters. A change to the RCP would be needed to allow a permit to be issued. In the transitional period, up to when a new RCP is notified, a request to change the plan can only be made by the Minister of Conservation or the adjoining territorial authority or initiated by SRC itself. The refuge sites were occupied during the 1992/93 bloom.

3.7 ENFORCEMENT

Generally each statute has separate enforcement codes and enforcing agencies. Conditions on existing marine farming licences can only be enforced under the MFA by MAF Fisheries.

Similarly, bylaws under the Harbours Act relating to navigation can only be enforced by the Harbour Board, in this case the SRC. Where marine farming is authorised by a coastal permit or controlled by rules in a plan then the SRC, or any other person, may enforce the permit conditions under RMA.

In addition, the RMA contains wide powers for the SRC, or any person, to apply for an enforcement order where an activity or action "is or is likely to be noxious, dangerous, offensive or objectionable to such an extent that it has or is likely to have an adverse effect on the environment" (s314(1)(a)(ii)). This power is independent and irrespective of any consent or licence that may authorise that activity and is designed to control adverse effects which are the result of unauthorised activities or where such effects were unforeseen when authorised.

4 ENVIRONMENTAL EFFECTS: A REVIEW

4.1 INTRODUCTION

Table 1 summarises the known environmental effects resulting from salmon farming in Big Glory Bay. These effects can be divided into those resulting from the following:

* The feeding of fish and consequent production of effluent and solid waste, with local effects on both the water column and the seafloor

* The use of chemicals and medical treatments and their input into the water column

* Discharge of other contaminants e.g. rubbish, polystyrene beads from uncased flotation, sewage

* The use of structures and their effect on the landscape and on other users

* The effect of farming practices on wildlife, marine mammals and other native species.

In sections 4.2 - 4.6 the nature of these environmental effects, their magnitude and significance are discussed, and the current state of knowledge assessed. These sections expand upon the summary in Table 1 and reference the relevant sources of information.

The combined farming activity in Big Glory Bay results in an accumulation of impacts on the bay. These cumulative impacts are greater in intensity and possibly longer lasting, than if individual farm units were placed in separate localities outside the bay. This arises partly because of the nature of Big Glory Bay, a semi-enclosed bay, having limited water exchange with Paterson Inlet. In order to identify and predict cumulative impacts a relatively greater amount of data is needed than for the assessment of individual activities. Cumulative effects may be synergistic, more uncertainty about these effects is likely to exist, and there is a potential that the impacts will spread beyond the bay. Cumulative effects are discussed in section 4.7.

An assessment of the likely environmental effects arising from two proposed farming methods, cage rotation and the use of larger zone areas, is presented in section 4.8.

Table 1: SUMMARY OF ENVIRONMENTAL EFFECTS OF SALMON FARMS IN BIG GLORY BAY STEWART ISLAND

Activity	*Results*	*Effects*	*Text Reference*
1. Production of effluent & solid waste	increase in organic matter in the ecosystem	potential changes in ecology of micro-organisms	4.3.2.2
from feeding fish food	**On water column**		
	soluble wastes in the water column	change in water clarity	4.3, 4.3.6
	nutrient enrichment of water body, esp. N	organic loading and local DO deficit, possible toxicity may affect benthos	4.3.2
		fish may be stressed or killed by algae	
	stimulation of algal blooms through hypernutrification	potential for eutrophication	4.3.2
	localised elevated levels of ammonia	possible toxicity problems	4.3.3
	fluctuations in dissolved oxygen of water column		4.3.5
	low dissolved oxygen levels near seafloor		
	release of gases from sediments: H2S, methane	change in taste and odour of water body	4.3.6
		can cause gill damage and mortality in farmed stock	4.3.7
		bubbles can act as vectors for pathogens	4.3.8
	leaching of vitamins, pigments from food	poorly understood (may affect plankton)	4.3.2.2
	On sea floor		
	deposition of solids on the seafloor	smothering under cages	4.3.1
	organic enrichment of sediments		
		change in benthic community structure	
	increase in mercury levels	uncertain, but seems to be causing measurable toxicity in sediments	4.3.4
2. Chemicals and medical treatments	presence of chemicals and drugs in water body		4.4.1
use of antibiotics		unknown	
use of cleaning agents		unknown	
use of antifoulants	effects of types currently used is unstudied		
3. Other contaminants			4.4.2
dumping dead fish and offal		unknown	
greywater from boats and barges			
toilet discharges	faecal coliforms, viruses etc	potential effect on human health	
accidental fuel spills			
rubbish		plastics can affect wildlife eg strangling, accumulation in gut	
		unsightly on beaches	
degrading polystyrene		beads can kill seabirds if accumulated	
4. Effect on landscape and other users			4.5
	physical obstruction	not properly assessed	
	effect on Maori cultural values	not assessed	
	degrading of landscape	various, see Petrie report	
5. Effect on wildlife etc.			4.6
physical presence	noise, activity	pied shag colony near NZ Salmon now abandoned	
shooting of seals and gulls		number killed unknown	
entanglement in nets	dolphin drownings		

4.2 A SUMMARY OF PAST RESEARCH AND MONITORING

In 1982 the Cawthron Institute was commissioned by BP Chemicals NZ to assess the impact of sedimentation on the benthic habitat within the environs of the company's experimental licence area at the head of the bay. Gillespie and McKenzie[1] reported on smothering of benthic flora and fauna beneath the cages, anoxic conditions in the surface sediments, the production of methane and hydrogen sulphide gases, and elevated levels of inorganic nutrients in the water column. BP's farm, the first in the bay, was located in 9 to 12 metres depth; biomass of fish on site is not given (although it was originally set up to produce 50 tonnes per annum). In 1985 this site was swapped for a deeper site (MFL 338), with more current flow, on the south side of the bay.

In the 1980s an Otago University student studied the impact of this original farm on the benthos[2].

Between 1988 and 1990 Water Quality Centre staff at Hamilton (now National Institute of Water and Atmospheric Research (NIWAR)) carried out salmon farming studies in Big Glory Bay under partial contract to MAF Fisheries, Southland Catchment Board and Department of Conservation; industry funding was also provided. Field data was collected initially between 11-27 February 1988. Four reports have subsequently been produced[3,4,5,6].

Roper et al.[3] summarise information pertinent to the formulation of appropriate water right conditions; impact on benthic life and on water clarity are the primary considerations.

Rutherford et al.[4] consider factors which could limit the long-term sustainable production of salmon in Big Glory Bay. Two factors are considered in detail; the potential for eutrophication and for dissolved oxygen depletion. A model is developed to allow a prediction of maximum sustainable salmon production to be made.

Pridmore and Rutherford[6] use the same model to predict values of nutrient and chlorophyll concentrations to compare with field measurements taken during a bloom of *Heterosigma* cf. *akashiwo* in Big Glory Bay in February 1989. Estimates of sustainable production levels are not discussed in this third report.

In this latter report (which was funded by MAF Fisheries and WQC), estimates of nutrient input into Big Glory Bay were refined, and the input values for nitrogen and chlorophyll levels in Paterson Inlet were amended to those measured during the 1989 bloom (which represented known worst case conditions). The estimate of sustainable salmon production was reworked in April 1992 by Pridmore on request of Big Glory Bay Working Group, using these amended values[7,8] (see 4.3.2.1, Appendix 1).

A plankton watch (monitoring) programme is run by Big Glory Seafoods staff for the benefit of the salmon farms in Big Glory Bay. The programme is carried out to alert farms to any danger of algal bloom. It was initiated in 1989. Samples are taken at least weekly in Big Glory Bay; from spring to autumn this is extended to include Paterson Inlet sampling. Levels of each species are identified, either on site or by an external laboratory; results are sent to each company.

Although information has arisen from the plankton watch programme and through the above research initiatives, the effect of the farms on the Big Glory Bay environment has not been systematically monitored since the industry's inception. In April 1992 a group was established to develop an initial monitoring programme. It was set up under the auspices of the Big Glory Bay Salmon Farm Working Group which comprises representatives from the salmon farming industry and the various agencies with administrative responsibilities for the farms. At time of publication of this document the monitoring proposals, designed to detect eutrophication of the water column and sediments of the bay, had not yet been implemented.

4.3 EFFECTS FROM PRODUCTION OF WASTE FOOD, FAECES AND METABOLIC PRODUCTS

The wastes from the salmon farms which enter the water body in the form of two major fractions: solid and soluble. Solid wastes may be in the form of either suspended solids in the water column or solids that accumulate on the sediment. Soluble wastes are dissolved in the water column, either directly as metabolic products of the fish or indirectly through leaching from the solids[9]. The major component of solid waste material is organic carbon; the nutrients phosphorus and nitrogen are the most important constituents of the soluble wastes. The absolute and relative output of the various forms of effluent are determined by the form of the food, feeding techniques, stocking densities, general husbandry and processing methods[9]. The capacity of the local environment to cope with the wastes determines their fate.

In a review of the effects of finfish farming on the environment Woodward[9] thought the most important effects to be the increase in particulate matter entering the sediment system and the increase in nitrogen and phosphorus entering the water column. The principal factors determining and affecting fish farm effluents are represented diagrammatically in Woodward[9]; (Figure 2).

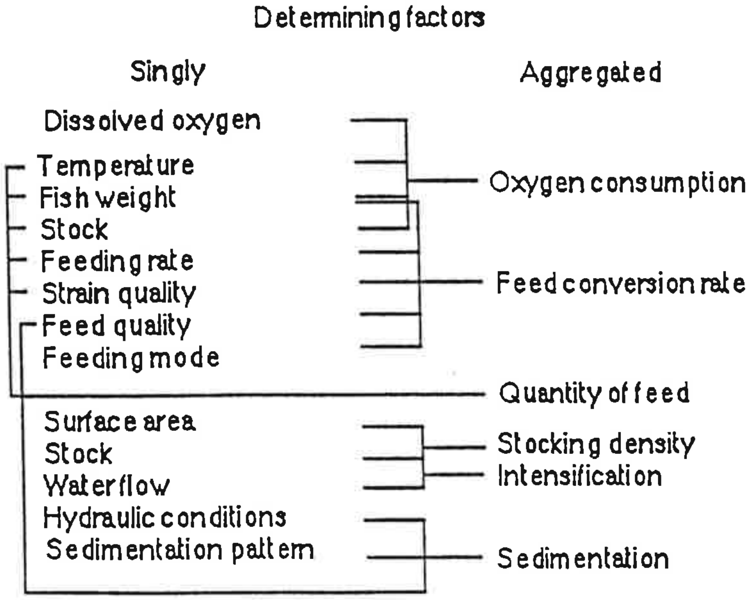

Figure 2. Summary of principal factors determining and affecting fish farm effluents.

Source: Woodward 1989[9]; after Querellou J., Faure A. and Faure C. *EIFAC Tech. Pap.* (1982) 41: 166p.

4.3.1 Effect on the seafloor

Natural recycling processes in the bay can be modified by the accumulation of particulate organic matter on the seafloor. Decomposition of the organic matter occurs mainly in the sediments where it is catalysed by microbes. The initial reactions are aerobic but as oxygen is depleted alternative compounds are reduced through a sequence of anaerobic degradation pathways: nitrate reduction, sulphate reduction, fermentation and methanogenisis. This anaerobic sequence is found through time and with depth in the sediment. Sulphate reduction is the norm; methane is produced only under conditions of very high organic enrichment[9].

The layer in which oxidising processes become displaced by reducing processes is definable by a redox-potential-discontinuity (RDP). The location of the RDP with respect to the depth in the sediment basically depends on the equilibrium food:oxygen flow into the interstices of the sediment. Both factors are reflected by the organic content and grain size composition (mean size, sorting, clay fraction)[9].

The presence of *Beggiatoa*, a sulphide oxidising bacterium, which lives on the surface of the sediment in white filamentous mats, indicates that free sulphide is reaching the sediment water interface; it is an indicator of the transition between aerobic and anaerobic reactions. However it does not indicate the total zone of influence of a fish farm.

The amount of solid waste depends on the efficiency with which fish are able to convert food into growth; this is commonly expressed as the food conversion rate (FCR). Pridmore and Rutherford[6] diagrammatically estimate the fate of nitrogen through the salmon farms during 1988 when annual production was approximately 1000 tonnes. Only 25% of the nitrogen inputted via food is retained as fish flesh (Figure 3).

The extent to which this solid waste affects the seafloor surrounding a cage or farm depends on the rate of dispersion of the excess particulate matter.

Roper et al.[3] examined two sites, IN52 (now called MFL 474) and MFL 338. Sediment concentrations were found to be elevated above background only within 25-50 metres of the edge of the farms studied. The examination of sediment composition may underestimate the distances that wastes spread, firstly because waste breakdown probably occurs fairly rapidly on the edge of the waste patch and could make it difficult to precisely define the edge of the patch and secondly because there may be periodic resuspension and redistribution of wastes during storms[3]. Although physico-chemical effects could only be detected out to 50 metres biological effects extended well beyond this[3]. Responses of benthic animals were typical of those caused by an organic gradient, and are likely to have resulted from intense organic enrichment and the smothering effects of matter falling to the bottom[3].

These waste accumulations had built up during 2-3 years of operations on the sites studied. It appeared that solid wastes were not being continually scoured away from under the farms by currents but that a large fraction of the solid flux to the seabed accumulates under the cages. The zone of impact immediately under the farms and for several metres away was severely polluted; few species survived and only pollution tolerant ones were abundant. Further away, a transition zone occurred where numbers of species and individual abundances increased, reaching peaks at about 100 metres from the edge of the farm. The species present were not just pollution-tolerant ones but representative of a enriched community. This suggests that organic material is an abundant food source for fauna leading to increased numbers of tolerant species. This enriched community merged into what was probably normal community structure at about 200 metres away[3].

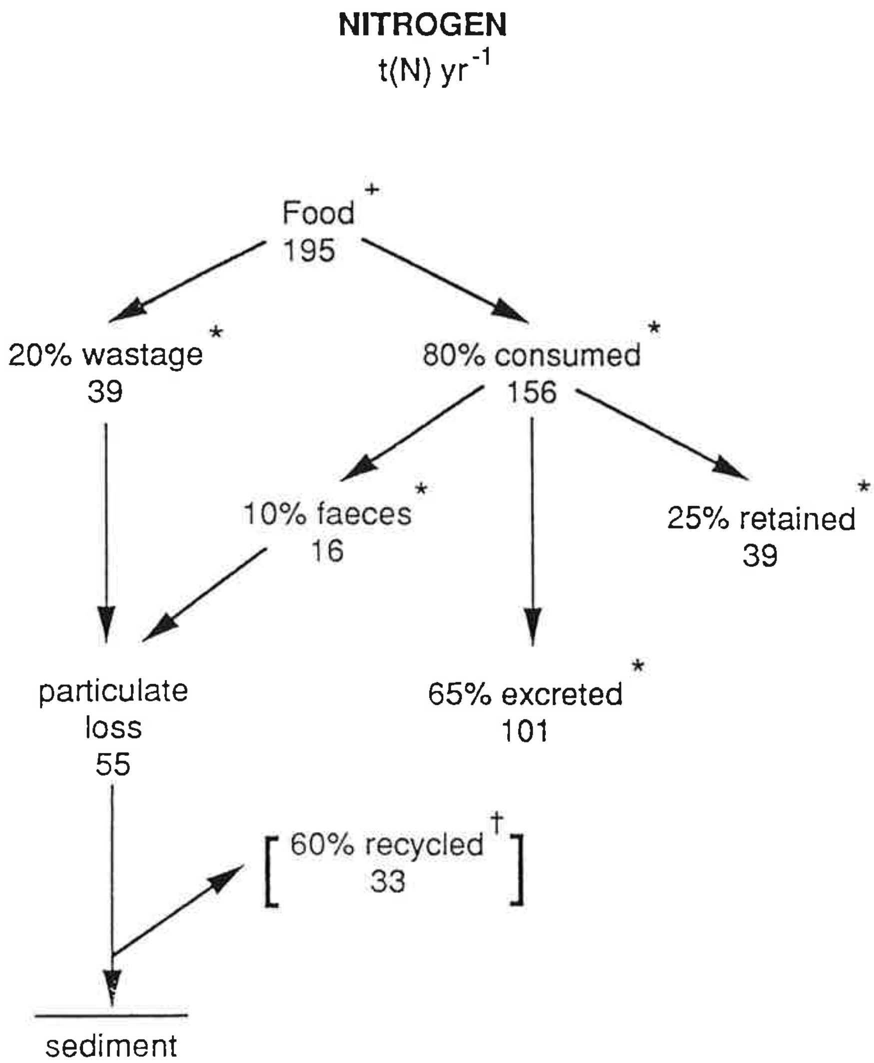

Figure 3. Quantitative estimates of the fate of nitrogen (N) through salmon farms in Big Glory Bay during 1988 when annual production was 783 tonnes.

+ estimate based on data presented in Pridmore and Rutherford 1990[6].
* estimate based on information in Gowen and Badbury *Oceanogr. Mar. Biol. Ann. Rev.* 25 (1987): 563-575.

(Source: Pridmore and Rutherford 1990[6])

Their observation that impacts occur within about 200 metres (of the farms) is probably typical of all farms in the bay, according to Roper et al.[3]. Subsequent quantification of the extent of impact of the farms, as a result of longer occupation of these sites has not been carried out. It is anticipated that sediment chemistry, with specific reference to the rate of recovery of these patches, will be examined as part of a postgraduate study at Marine Sciences, Otago University, partially funded by Department of Conservation (DOC).

4.3.2 Nutrient levels

4.3.2.1 Hypernutrification

Sea-cage salmon rearing results in the liberation of nutrients (in the form of soluble excretion products, faeces and uneaten food) which have the potential to increase nutrient concentrations in the waters of the bay and to stimulate the growth of phytoplankton[4]. Any substantial and measurable increase in the concentration of a nutrient has been called hypernutrification[10]. Hypernutrification does not necessarily lead to eutrophication which is an increase in primary productivity over the natural level, which in turn can result in an increase in secondary (zooplankton) production which could influence inshore fish production[10].

In some eutrophic coastal regions this enhanced productivity can be in the form of algal blooms (short periodic bursts of algal growth). In extreme cases blooms can be dense and extensive causing large fluctuations in dissolved oxygen, as a result of algal respiration at night and during the senescence of the bloom[10].

Blooms of phytoplankton affect water colour and clarity. If toxic algae are present they can kill fish. It has been suggested that small, non-toxic blooms can stress farmed fish, which could enhance their susceptibility to disease and/or ability to respond to treatment[10].

Nutrient concentrations in Big Glory Bay and in Paterson Inlet were measured by the Water Quality Centre (WQC) in February 1988 and January 1989, at the latter time during the *Heterosigma* bloom[4,6]. Based on the average ratio of particulate nitrogen to particulate phosphorus measured during January 1988 it was assumed the nitrogen and not phosphorus was likely to limit phytoplankton growth[4].

A model was developed to predict spatially-averaged nitrogen and chlorophyll concentrations in Big Glory Bay. This was combined with a phytoplankton growth model to examine the effects of nitrogen availability and hydraulic flushing on phytoplankton yields. An estimate of the maximum yield of salmon production in the bay that would be unlikely to result in repeated blooms, was calculated from the model (see Appendix 1).

A dense bloom of *Heterosigma* cf. *akashiwo* which occurred in early January 1989 resulted in the death of about 600 tonnes of caged salmon[11].

> *"It appears that the early January bloom in Big Glory Bay was initiated and promoted by a combination of factors: circulation/topography of the bay, the regional meterological and hydrological conditions, high nutrient input from several sources, and the vertical migratory behaviour of Heterosigma which together act to form the dense bloom at the surface"[11].*

During the two years of study (88/89), the salmon farms appeared to have increased nitrogen concentrations in Big Glory Bay by amount 30%[6]. The marginal effect of the salmon farms during January 1989 was to increase the mean chlorophyll concentration of Big Glory Bay by 3 mg m^{-3} (ie 33%)[6].

4.3.2.2 Effect on plankton ecology

The release of dissolved inorganic and organic nutrients and particulate material from fish farms can induce changes in the ecology of micro-organisms (e.g. phytoplankton, bacteria and protozoa)[10]. Blooms may arise from the release of certain vitamins contained in uneaten foodstuffs e.g. Vitamin B12 is a growth requirement for the toxic microflagellate *Prymnesium parvum*[12]. The formation of anoxic sediments beneath cages can prevent excystment of dinoflagellate cysts and dispersal of sediments could result in the release of cysts into the water column and, under suitable conditions, the development of an algal bloom[13].

A study conducted in a Scottish loch concluded that exchange of water between a sea-loch and its adjacent sea area has an important bearing on phytoplankton and could restrict the accumulation of biomass resulting from hypernutrification. Hypernutrification may therefore occur without a change in the standing crop of phytoplankton[14]. If enhanced primary productivity and phytoplankton biomass does result, changes in the oxygen budget of a water body are likely[14]. Any longterm change in nutrient status of the water could influence the species composition of phytoplankton and form the growth of flagellates if silicate becomes the limiting nutrient as a result of the excess of nitrogen[14].

In Big Glory Bay there is potential for *in situ* growth and for phytoplankton biomass to accumulate. The rate of flushing is likely to have important bearing on whether this is sustained.

The salmon industry has carried out a plankton watch programme since the 1989 *Heterosigma* bloom (4.2)[14A]. There has not been any explicit study of the relationship between the micro-organisms in the bay and the effluent produced by the farms.

The programme has recorded several blooms of **Mesodidium** since January 1989.

4.3.3 Ammonia

WQC assessed the likelihood of ammonia toxicity in 1989 and derived recommended maximum acceptable concentrations of non-ionised ammonia that would safeguard against long-term toxicity to marine life[15].

Invertebrates are generally less sensitive to ammonia than fish. WQC[15] calculate the levels of ammonia that might exist, given a production of 3,000 tonnes yr^{-1} of salmon in the bay. The level calculated was lower than but comparable with, maximum levels suggested as guarding against toxicity. Given this the WQC[15] considered it unlikely that salmon farming will stimulate ammonia toxicity, and considered it likely that water appearance and eutrophication problems would be evident before ammonia toxicity became of concern. However with increased salmon production, there was considered to be some potential; hence the recommendation that there is a need to monitor nutrient levels in Big Glory Bay.

The calculations were based on the parameters used in the first version of the phytoplankton/nitrogen model ie before it was reworked in Pridmore and Pridmore[6] (1990) or by Pridmore in April 1992. It would be worth recalculating the amount of ammonia that may be present at 3000 tonnes yr^{-1} production, and measuring levels which currently exist, before accepting any recommendation about the levels of ammonia in the bay.

4.3.4 Mercury

Excreted and unused salmon food is resulting in accumulations of mercury beneath the farms. The amount of mercury, from fish food, is of the same order as that deposited through the whole bay by natural processes[15].

Sediment samples from beneath farms collected in February 1988 contained mercury at a level of 0.5 mg kg^{-1}, a likely five-fold increase above background. This reflects the use, over several years, of food containing close to 0.5 mg kg^{-1} mercury. The WQC authors contend: "A continuation of the present situation is probably not satisfactory.....This situation is avoidable"[15]. At times the farmers have been using imported feed, with lower mercury levels, to try and reduce total mercury input, and mercury level in fish flesh.

Continued use of food containing 0.4-0.5 mg kg^{-1} of mercury would lead to a product difficult to market if product specifications are enforced[15].

WQC did not see a problem with mercury levels in the water column, as estimated levels were much lower than USEPA guidelines to guard against acute and chronic toxicity in seawater[15].

There was a difficulty in locating information, appropriate to Big Glory Bay, about the likely effect of the mercury levels on waste patch recovery. WQC noted the retired patches were not demonstrating rapid recovery, on superficial inspection, but did not link this specifically to mercury. The effect on marine benthic organisms was noted; although showing a general tolerance to elevated levels of mercury in the water column, marine invertebrates will accumulate mercury from the sediments and the local food chain would be anomalously elevated in mercury[15].

Whilst WQC did not find any firm evidence of environmental damage, and argued against a direct impact on benthic invertebrates and microbial communities, "it should be remembered that laboratory tests on the sediments in question demonstrated a toxic response proportional to sediment mercury content[15].

Pridmore has suggested that feed contents could be defined, to reduce contamination by prescribing mercury levels[7].

There may also be concerns about mercury levels in invertebrates collected from the bay for consumption, e.g. scallops.

4.3.5 Dissolved oxygen levels

Dissolved oxygen levels in the bay were studied by Rutherford et al.[4]. The authors concluded oxygen consumption by waste accumulations on the sea-bed under the farms is unlikely to cause serious oxygen depletion in mid-water if the farms are at least 250 metres apart (including distance from old farm sites). They recommended that cages should be no closer to the bed than 5 metres and that there be a 500m separation between farms to ensure that dissolved oxygen depletion from one farm does not affect another. This recommendation is based on fish respiration rates within cages and its likely effect on downstream cages under worst case assumptions (no reaeration or vertical mixing). There should be a greater separation between large cages. If farms were separated by a minimum of 500 metres, the dissolved oxygen deficit from upstream farms should be no larger than 1 gm^{-3} unless cages were 100 metres or more in diameter[16].

Pridmore[16] also recommends that if a licence area contains several small cages that are widely separated, the total area of all cages should be calculated and used as the effective diameter of a single cage, located near the edge of the licence area closest to the adjacent licence area.

At present these guidelines are not being applied, and the siting of cages/farms has not been assessed to determine if any problem areas exist, given present siting arrangements.

4.3.6 Water clarity

Roper et al.[3] stated that a level of salmon production which would not conspicuously affect water clarity in the bay was 3000*t* yr-1 (total biomass produced) A large safety margin of 2000*t*y-1 was incorporated because of uncertainties about the nitrogen and chlorophyll levels likely in Paterson Inlet and nitrogen inputs per unit of salmon production.

The model needs to be reworked (as the nitrogen/phytoplankton model was), with the known worst case flushing conditions (values for nitrogen and chlorophyll concentrations in Paterson Inlet) and refined nitrogen input values (as used in Pridmore and Rutherford 1990). Until this is done it is not possible to predict at what level of production there is likely to be a conspicuous effect on water clarity in the bay. "If production approaches 3000 t yr^{-1}, or if farming begins in Paterson Inlet, then further study should be undertaken...."[3].

Other aspects of effects on water quality that have not been assessed are possible production of an offensive taste and odour e.g. from methane and the practice of using high pressure jets of water and underwater vacuum cleaners to remove algal growth off nets.

4.3.7 Hydrogen sulphide

During methanogenisis, bacterial interaction results in spontaneous gassing of nitrogen, carbon dioxide and methane and a small amount of hydrogen sulphide production from the waste patches on the seafloor. Methane can bubble up carrying H_2S trapped in the bubbles. The WQC modelling in 1988[4] suggested that the evolution of toxic hydrogen sulphide from the waste patches was a potential problem at all licence sites in the bay, under worst-case mixing conditions (calm conditions, low currents and large accumulations of wastes). At the time no direct evidence was found of toxicity at the farms. The authors predicted hydrogen sulphide problems could extend 250 metres down-current from the farms and 7.5 metres above the bed[4].

The production of hydrogen sulphide in marine waters may be of several orders of magnitude greater than in freshwater due to the abundance of sulphate in seawater. H_2S is very soluble in seawater but stable only in the presence of oxygen and is oxidised relatively quickly to the non-toxic sulphate in oxygenated water[10]. Measurements of H_2S in seawater are difficult to make reliably.

Woodward[9] reports that farmers in some long established farm areas are finding that H_2S trapped in methane bubbles leaving the bottom sediments may be causing gill damage and mortality, in areas where there is a long term accumulation of fish solids. Hydrogen sulphide is very toxic to fish at low levels. Rutherford et al.[4] 1988 recommended that further work on this problem was required. In the meantime there have not been toxicity problems reported by the farming companies. More recently (1992) Pridmore does not consider hydrogen sulphide a problem to the farms in their present locations but could be a problem if a farm was located at the head of the bay[6].

Woodward[9] likens fish held in cages to the canaries used in coal mines to detect noxious gases; "Salmonids, in particular, are extremely sensitive to any degradation of water quality. The first indication of a significant deterioration in conditions will come through the responses of the fish".

4.3.8 Pathogens

The microbiological content of the water column and sediments, at or near the farm sites, has not been studied.

Rutherford et al.[4] noted that gas bubbling from the sediments provide a potential vector for transporting pathogens from the waste patches back into the pens of fish, a problem reiterated in 1992 by Pridmore[7].

Concern is often expressed that fish farms may act as a disease reservoir for pathogenic infections that could pass onto wild fish stocks (Rosenthal[12], *in* Woodward[9]).

Diseases have been recorded as transferring from farmed to wild fish but there is little clinical sign that diseases have appeared in wild stocks (Phillips and Beveridge[19], *in* Woodward[9]).

4.4 EFFECTS OF CONTAMINANT USE

4.4.1 Chemicals and Medical Treatments

Chemicals used in the Big Glory Bay industry fall into three main categories: drugs used as therapeutic agents, anaesthetics, and disinfectants. The range of chemicals and medical treatments used in Big Glory Bay to control disease outbreaks is undocumented.

Antibiotics to control disease outbreaks are normally administered through medicated food. Antibiotics will escape to the environment in uneaten food and also in faeces if not metabolised by the fish. Only one antibiotic has been used in Big Glory Bay to date: Terramycin (oxytetracycline) which was used to treat vibriosis, a stress related disease. Outbreaks of this disease has subsequently been overcome by reducing stress at the time of smolt entry into seawater (Kevin O'Sullivan, Big Glory Seafoods, Invercargill, pers. comm.). (The major concern likely to arise from indiscriminate use of antibiotics is not so much the concentration in the effluents, but its undesirable effects and its real effectiveness in preventing infections[20]. Bacteria are known to develop resistance to antibiotics rapidly. There is a risk of transference of antibiotic resistance to normal bacteria found within the human gut if numbers of antibiotic -resistant bacteria are ingested. Chemotherapeutic products used in the treatment of bacterial, fungal and parasitic diseases remain in fish for varying periods and can become a public health hazard.)

Anaesthetising agents are been used during grading of fish; the two used are Benzocaine and Phenoxyethanol. Overseas anaesthetics have also been used to prevent product damage during harvest. Disinfectants are used to clean boats and rafts.

There are few disease problems in Big Glory Bay and fungicides and pesticides are not used (Kevin O'Sullivan, Big Glory Seafoods, pers. comm.). Compared to Europe farmed stocks here are relatively disease free. However it may be inevitable that disease and the requirement for medication will become a greater problem as the industry develops.

So far studies of steroids, including specific hormones used for inducing maturation and spawning indicate there is no potential human health hazard[20]. It is uncertain whether these are used in the Big Glory Bay operations.

Effect of leaching of vitamins, etc. from food is unknown.

The potential effect of chemicals derived from farm construction materials and antifoulants used on nets has not been assessed. Tri-butylin (TBT) based compounds were used in the first years of the Big Glory Bay industry but are now banned. Big Glory Seafoods use a copper based antifoulant instead (Kevin O'Sullivan., Big Glory Seafoods, pers. comm.).

The effects of such chemicals and medications on wild stocks is unknown but it is probably minimal in comparison with other impacts (Phillips et al.[21], *in* Woodward). Different chemicals will have different lifetimes once exposed to the environment[9].

The full range type of therapuetants, anaesthetics and disinfectants used in the bay need to be ascertained and an assessment of their likely impact on the environment made.

4.4.2 Other Contaminants

Other contaminants discharged into the bay as a result of farming activities include:

* plastics; discarded rubbish
* polystyrene used for flotation breaking down, when these are uncased
* toilet discharges
* grey water discharges from houseboats and barges.

An example of the potential for contamination was provided by the operation on a previous farm: cages were constructed from aeroplane tyres glued together and filled with polystyrene beads. when part of an unassembled cage was left on a beach, the structure broke and beads escaped. In early rafts uncased polystyrene was used for floatation. During construction, which has occurred on beaches the polystyrene blocks are cut to size; again beads and fragments result. In a recent incident used polystyrene was burnt on a beach in the bay (Greg Lind, DOC Stewart Island, pers. comm). It was a condition on later Harbours Act plan approvals and on the memorandum of variations and MFL 474 licence issued in 1991 that all polystyrene used must be cased. The impacts from polystyrene occur when ingested by marine animals e.g. seabirds. The beads pack the crop or gut and eventually can lead to starvation.

Rubbish from the salmon farms, which washes up in beaches in Big Glory Bay and Glory Cove is unsightly. It can also be a hazard to marine life and seabirds e.g. plastic bags which may be ingested. Regular beach cleanups are undertaken by some farm staff.

At times damaged and unused cages stored on beaches and in intertidal eelgrass flats in small coves, for lengthy periods.

There is the potential for pathogen contamination from sewage and greywater discharges from boats and barges on site.

Recently lithium chloride has been used as a deterrent to seals.

4.5 EFFECT ON LANDSCAPE AND OTHER USERS

Fish farms introduce artificial structures into a landscape which, in the New Zealand context, is natural in character and of high scenic quality.

Petrie[22] recognises three issues of special concern that have too be addressed in Paterson Inlet if consideration is to be given to landscape conservation:

* the acceptability of major fishfarm developments in open landscapes

* the cumulative landscape effects of numerous fish farm developments

* the loss of wilderness character in areas of undeveloped landscape

In Big Glory Bay the visual effect of the salmon farms is considered to be a negative element in the landscape particularly because of the prominent siting and the high reflectivity of the superstructure on the salmon farms. "The impact of these structures can be lessened by the application of a sympathetic blue-grey colour range of the coastline"[22]. This is illustrated by video image editing.

Experience with fish farms in Scotland's Highland region has shown that care in location and design of cages is needed to protect visual amenity and to safeguard the integrity of areas of natural beauty. Considerations should include the overall mass, grouping, alignment and distance from shore of cages. The colours and textures of surface gear have to be taken into account and how the structures are likely to be viewed[23]. The location and design of shore bases is a further consideration in the protection of visual amenity.

A number of guidelines have been recommended in Scotland[9].

Surfaces of high reflectivity include shiny metal feed hoppers and the white silos on the barge Kiwa.

There has been no assessment of the manner in which adverse visual effects from the Big Glory Bay structure could be ameliorated, other than Petrie's observations. Plan approval has not been used to assess the likely impact of cage design, grouping etc., or to try and ameliorate adverse impact.

The siting of salmon farms has the potential to affect recreational activities in Big Glory Bay and the tourist industry. These effects have not been quantified. On 1988/89 the Southland United Council called for submissions on the future of marine farming in Southland. 117 submissions were received. 12 of these concerned the impact of marine farms on recreation, and 18 its impact on tourism[24]. Actual impacts have not been assessed. Industry representatives contend that the presence of the farms is a drawcard tourists; local charter boat owners offer trips to the farms often in conjunction with a fishing trip (eg, Brian Powers, Regal Salmon, Invercargill, pers. comm.).

There are several tauranga waka (canoe landing sites) within Big Glory Bay (Paddy Gilroy, Kaupapa Atawhai Manager Department of Conservation, Invercargill, pers. comm.); it is not known if other waahi tapu or taonga (treasures) are present. The effect of the farms on Maori cultural values needs to be assessed.

4.6 EFFECT ON WILDLIFE, MARINE MAMMALS AND OTHER NATIVE SPECIES

The presence of a dense aggregation of fish can be an attraction to predators e.g. seals, dolphins, fish and birds. Predation damage can occur either through direct attack or secondary infections caused by large numbers of fish damaged or injured.

Problems with wildlife and marine mammals which have been experienced by farmers in Big Glory Bay are:

* nuisance of gulls attracted by feed
* need to use nets on smolt cages to prevent seabirds predating the young fish
* seal attacks on fish, damage to fish, nets, consequent loss of fish

* visits by bottlenose dolphins, which swim around and under the cage nets, and panic the fish, damaging them.

To date the industry has dealt with such problems using their own initiative. A number of concerns have been passed on to the Department of Conservation about shooting of seals, gulls and shags and about dolphins being droned through entanglement in nets.

In January/March 1990, weekly seal counts were carried out in Paterson Inlet for eight weeks. An average of 3 seals were seen on Tamihau Island; the most observed at one time was eight. During counts in 1971-73, up to 35 seals were seen, at different times of year on Tamihau Island. Seals were also seen on rocks at the western end of Ulva Island during these earlier counts. Over the same period, seals on islands in eastern Foveaux Strait, increased significantly, over 100% in several cases[25]. However no link between the decline of seals in Paterson Inlet and salmon farming activities has been shown.

There is the possibility of the naturalisation of species and breeding of salmon in rivers; escapes of farmed salmon appear inevitable. The practice of throwing reject fish over the side at time of grading, may contribute to this. In 1990 a salmon parr was found by a researcher in the upper reaches of the Rakeahua river which enters the head of Paterson Inlet. Salmon have been observed trying to enter the small stream at the head of Big Glory Bay (Richard Hare, Invercargill, pers. comm.). Suitable spawning habitat probably exists in the Freshwater River, the second major river entering the Inlet (Lindsay Chadderton, DOC Stewart Island, pers. comm.). Introduced fish such as trout have not been recorded in Stewart Island rivers; the catchments are essentially pristine, with a low number of native fish species present. In the late 1980s, one salmon farm company netted considerable numbers of salmon in various parts of Paterson Inlet; these were being target fished as the result of a large escape incident. The effect of a naturalised salmon population around Stewart Island, on native marine communities, has not been studied.

The fertilisation of the water body and excess food available may enhance resident fish species[9]. Fish may be attracted to the physical structure of the cages and or mooring blocks and this may lead to congregations of fish around these.

4.7 CUMULATIVE EFFECTS

The siting of several farm units in Big Glory Bay creates a cumulative impact on the ecosystem. The individual components of salmon farming activity at a site within the bay interact to create a further type of cumulative impact on that site. In addition the effects from the various salmon farms within the bay have a cumulative effect on the Big Glory Bay ecosystem. Various factors determine the fate of the farm wastes and affect the capacity of the bay environment to cope with farming impacts: the siting of farms, their proximity to each other, the amount of food input and its nutrient and mercury levels, the flux between the patches and the water column.

When determining whether the farming activity in Big Glory Bay can be sustained by the ecosystem without severe degradation occurring, significant factors are likely to be the total amount of food inputted into the bay, the extent of modification of the seafloor and its rate of recovery, the effect on phytoplankton and potential for repeated blooms. The manner in which these impacts are interrelated is relevant when developing any guidelines to limit environmental impact to an acceptable level.

Little is known about the likely effect of relocating the farms on the proposed refuge sites in Paterson Inlet; whether the impact on the benthos there is likely to be significantly different to the impact in Big Glory Bay. The effect of the farms in Big Glory Bay on the main body of Paterson Inlet is also largely unstudied.

4.8 ASSESSMENT OF THE LIKELY ENVIRONMENTAL EFFECTS OF PROPOSED FARMING METHODS

Both individual cages and larger farm units have occasionally been moved within licensed sites (and also around the outside of sites); this practice was more common at the head of the bay were the first farm operated in shallower more sheltered water. Overseas, cage rotation and fallowing of areas to allow recovery and reuse is practised in places. It has been suggested as a suitable management tool for Big Glory Bay particularly if the licensed sites (now 3-4 hectares) were replaced by larger zones.

Appendix 2 contains a brief review of pertinent information about the effects of cage rotation and the use of site fallowing.

4.8.1 Likely impacts of cage rotation

If fallowing was to be developed as a management practice, guidelines should be developed which consider the relationship between the time that a site was to be occupied and the time it is to be fallowed before reoccupation. Both the hydrographic characteristics and stocking densities on site would have to be taken into account when considering these. It may be necessary to impose limits on stocking density to guard against longterm souring of a site.

The principle of limiting benthic effects to a licence site, a permit area or an approved mixing zone is a basis on which guidelines can be developed. The recovery rate of Big Glory Bay farms appears to be slower than that documented for Scottish[10] and Tasmanian[26] studies. Also mercury may be implicated as a factor in the recovery of the Big Glory Bay sites (and possibly not in the Tasmanian and Scottish farms).

4.8.2 Likely impacts of the suggested zone system

The zones requested by industry were considerably larger than the current licence areas. Big Glory Seafoods sought 57 ha, Regal Salmon 90 ha and NZ Salmon 22 ha. Although these applications have been outdated by recent events (e.g., changes of farm ownership and large scale cage replacements) the current operators are still seeking to expand into larger zones.

Moving cages around, even whilst retaining a level of production comparable to a non-fallowing system, would result in greater areas of seabed being modified. It would be reasonable to assume that all areas within an approved zone would be modified.

Two predominant habitat types in Big Glory Bay are recognised both in Roper et al.[3] and in Hare[27]. *Lenormandia chauvinii* meadows, beds of red algae dominated by this species, grow over most of the shelf area at the upper end of the bay and at places along the northern and southern shores at depths down to 20 metres. In deeper areas of the bay a largely infaunal mud community is present. A dense assemblage of brachiopods, living predominately below 18 metres depth, on the soft sediment seafloor, extends from the main body of Paterson Inlet into the baymouth. Both the brachiopod community and the *Lenormandia* meadows are likely to be more susceptible to longterm change from salmon farm impacts if farms are located above them.

Roper et al.[3] suggest that the meadows probably play an important role in stabilising the muddy bottom and provide a refuge for animals. Rainer's findings in Otago Harbour showed that the presence of macroscopic algae principally *Lenormandia* favoured the deposition of silt and organic detritus[28].

Brachiopods, as a phylum are sensitive to increases in sedimentation (Ken Grange, NIWAR Wellington, pers. comm.). Their sensitivity to smothering was demonstrated when one farm was relocated near Groper Island in Paterson Inlet at the time of the 1989 *Heterosigma* bloom. Within three weeks all the brachiopods under the seacages were covered by a thin layer of sediment and many were buried and had died. Brachiopods on the seafloor immediately adjacent to the area beneath the cages appeared unaffected[27].

Any zone system set up may need to be sited so that *Lenormandia* meadows and dense brachiopod assemblages on the seafloor are not affected by the salmon farms.

5 ADMINISTRATION AND ENVIRONMENTAL MANAGEMENT RESPONSIBILITIES

5.1 INTRODUCTION

In this chapter the administrative and environmental management roles of various agencies are summarised. The legal basis for various roles is explained only where this has not been covered in Section 3. The situation which existed before commencement of the RMA, that which exist in the transition period, and that which is likely to exist after the transition is described. (If the existing marine farm licences (MFLs) are renewed *ad infinitum* the transition will never end). Legislative problems (e.g. overlapping responsibilities which result in inefficiencies) or provisions that need clarification, are highlighted.

Marine farming occurs in coastal areas which are included in the Crown's jurisdiction, therefore the Crown is required to have a system of administration to handle its interests. Roles associated with marine farm administration and environmental responsibilities can be divided into the following components:

1 Allocation of coastal space and rights of tenure, including ancillary facilities not located on the farm site.

2 Controlling environmental effects, including:

   * setting standards (e.g. for structures)
   * compliance with these standards
   * state of the environment baseline monitoring
   * monitoring of the effect of marine farms on the environment including cumulative effect of multiple farms
   * consideration of farming species that do not naturally occur in an area; genetic manipulation of species.

   Effects can occur both below mean high water springs (the coastal marine area) and on land e.g. from ancillary facilities.

3 Mitigating the impact of marine farming on species protected under the Marine Mammals Protection Act 1971 and the Wildlife Act 1953. Enforcement when protected species are killed.

4 Resolving user conflicts such as activities that interfere with farming.

5 Safety including navigation: responsibility for marking farm areas, navigational safety, safety standards for structures.

6 Building Act 1992: safety of people, sanitation and fire control in buildings under the Building Act 1992.

7 Assignment of rights to harvest farmed stock and to hold stock that would be illegal under the Fisheries Act including compliance to ensure the wild fisheries regime is not being compromised (e.g. through laundering of illegal fish product).

8 Stock health standards, disease control, control of movement of contaminated stock.

9 Maintaining public health including export standards

10 Registration of marine farming entitlements (lawful record of licences, leases, permits etc.).

11 Undertaking research

* on environmental effects
* on stock health, disease
* on other production related matters.

Allocation of production limits to control cumulative effects of several farms operating in one bay would come under roles under 1, 2 and 4 above.

Table 2 summarises the roles undertaken by various agencies in respect of the Big Glory Bay salmon farms. Where the authors believe these roles do not appropriately sit with an agency, this is shown.

TABLE 2 : **Roles of various agencies in the administration and environmental management of the Big Glory Bay salmon farms**

AGENCY	ADVOCACY	SPACE ALLOCATION	EFFECTS	USER CONFLICTS	SAFETY & NAVIGATION	BUILDING ACT	SPECIES PROTECTION	FISH STOCK & HEALTH	PUBLIC HEALTH & EXPORT	REGISTRATION OF RIGHTS	RESEARCH
MAF	X	(X)	(X)	X	(X)			X	X	X	X
SRC	(X)	X	X	X	X	X					X
DOC	X	X	X	X	X		X				X
SDC			X			X					
MOT					X	(X)					
SAHB			(X)						X		

<u>KEY</u>

X = roles that agencies are currently doing or appear to think they should be doing.
(X) = those roles for which, in the author's opinion, agencies do not have a statutory function and/or should not be doing.

MAF MAF Fisheries
SRC Southland Regional Council
DOC Department of Conservation
SDC Southland District Council
MOT Ministry of Transport
SAHB Southland Area Health Board

5.1 ALLOCATION OF COASTAL SPACE; RIGHTS OF TENURE

Prior to RMA

Marine farm licenses are a covenant between licensee and licensor. The licensor agrees to grant the licence subject to certain terms and conditions, for the use of the area as a marine farm pursuant to the provisions of the MFA.

Any occupation of space not covered by the MFA (and not on a MFL site) required a Harbours Act approval (e.g. a foreshore occupation licence for a storage shed/raft).

Town and Country Planning Act 1977 (T&CPA) provisions applied to any land-based facilities sited above MHW; these were the District Council responsibility.

During the transition

Existing marine farm licences are saved by the RMA (and remain MAF Fisheries responsibility (3.2).

Although they were previously exempt from Harbours Act approval houseboats and barges now require RMA approval because they are restricted under sections 12(1))b) and 12(4) of that Act.

After the transition:

The allocation of space will be part of the RMA coastal consent process.

5.2 CONTROL OF ENVIRONMENTAL EFFECTS

The salmon farms affect a number of different components of the environment:

* water quality and marine fish

* the seabed and benthic species

* landscape of marine farm structures

* marine life due to farming introduced species and from genetic manipulation of species

* wildlife, marine mammals, and native freshwater fish

The current knowledge about the nature of these effects was reviewed in Chapter 4.

5.2.1 Effect on water quality and on the seabed

Although the effects on water quality and on the seabed arise predominantly from the same activity - the feeding of food to salmon - responsibility for the control of generated impacts has been, and continues during the transition, to be split.

Before RMA

Water quality was the direct responsibility of the Southland Regional Council (previously as the Catchment Board) under the Water and Soil Conservation Act 1967. The water classifications in the bay (SA and SB) both include a requirement that "There shall be no destruction of natural aquatic life by reason of a concentration of toxic substances nor shall the waters emit objectionable odours". As natural aquatic life includes species of the sea-floor, SRC had a role in controlling environmental effects on the seabed.

The effect of farming on water quality was never explicitly a consideration under MFA and was not explicitly recognised in that Act as grounds for upholding an objection unless it related to undue interference with recreational or scientific use, which resulted in the proposal being contrary to the public interest. The MFLs require that farmers keep a record of all chemicals used on the licence site.

The effect of marine farming on the seabed should (theoretically) be considered as part of the marine farm application assessment process. MAF Fisheries's sea cage salmon policy provides guidance about suitable/ unsuitable sites: "Conditions on the licence limiting production may be imposed where the site is judged unsuitable for larger production or where the cumulative impact of farms may require a limit on production imposed."

During the transition

The dual responsibility of MAF Fisheries and SRC remains. The control of environmental effects is a responsibility of SRC under RMA. The RCP can cover matters relating to the use of water and discharge of contaminants (3.5).

During the transition the MFL conditions continue to apply and administration of these is MAF Fisheries's responsibility. The MFL's contain a number of provisions that appear to be aimed at least partly at controlling environmental effects (e.g., requirement as to the minimum depth in which farms must operate, keeping of a production log, provisions for instituting "sea-bottom" and "bio-physical" monitoring programmes, prohibition on the use of tri-butyl tin (TBT) as an antifoulant, requirement to encase polystyrene if used for flotation, and provision for requiring the licensee to mitigate the cause or effects of waste material on the seabed of the licensed area). There is a condition requiring licensees to keep a record of all disinfectants, antibiotics, antifoulants or other chemicals used.

A further condition on the MFLs is that the licensee is not to deposit dead salmon or offal within Big Glory Bay without written approval from the Regional manager, MAF Fisheries South. Dumping of waste could also be controlled by MFA regulations and is covered by the Harbour Board bylaws. The conditions discussed in the previous two paragraphs are all included in the memoranda of variation not the original licences (except for MFL 474 executed in 1991) The memoranda were signed after the RMA commencement which indicates control of environmental effects was only implemented post-RMA.

MAF Fisheries also has an interest in the effect of salmon farms on the environment because of its fisheries responsibilities - pollution from farms could affect wild fisheries.

The RMA requires state of the environment monitoring and monitoring of consents issued (s35). At the moment the Big Glory Bay Salmon Farm Working Group (4.2) is trying to develop a monitoring programme. This is not specifically linked to any statutory requirement though MAF Fisheries may adopt it (or part of it) under the licence conditions that provide for biophysical and sea-bottom monitoring. DOC and SRC members of the group envisage that it will also provide information needed for the s14 and 15 RMA resource consents, if these proceed. MAF Fisheries have agreed that an effective monitoring programme has to be agreed prior to allowing a production increase from the present understanding of 2400 tonnes of salmon per annum to 3000 tonnes per annum (letter from D Brown MAF Fisheries Dunedin to K Mawhinney DOC Invercargill, 14 August 1992). MAF Fisheries is currently developing mechanisms by which to constrain production.

Although MAF Fisheries's sea-cage salmon policy recognises the need to control various operational aspects, mechanisms available are limited to creating regulations (s48 - the specified subjects do not include the control of environmental effects); inclusion as a licence condition. In the latter case matters other than those specified in s9(a) to (h) can only be included, subject to the requirements of MFA, "as may be agreed on between the parties...or as may be necessary for the operation of a marine farm" (s9(i)). S9(a) to (h) does not specify that control of environmental effects can be included in a licence so this would fall in the other matters basket.

<u>After the transition</u>

The effect of salmon farming on the environment will be controlled through RMA mechanisms.

5.2.2 Effect of marine farming structures

<u>Before the RMA</u>

DOC administered the s178 Harbours Act plan approval for marine farms; MOT approval was incorporated in this process. The criteria against which the plan approval application was judged was the effect on the public interest; the likely effect on the environment was one factor in this consideration. There was no mechanism for controlling the effects of houseboats and barges on the landscape.

There are not any mechanisms in the MFA specifically aimed at mitigating of the effects structures might have on the landscape although controls may be included in a MFL with the agreement of the licence holder e.g. the Big Glory Bay licences include a condition about encasing polystyrene used for flotation.

During the transition

All approvals for marine farm structures are the responsibility of SRC under the RMA. Control of environmental effects from ancillary facilities on land is the responsibility of the District Council, and through the Regional Policy Statement, the SRC. The landowner has a role (e.g. DOC for occupation licence for a house at the head of the bay). Ancillary structures in the water (in the CMA) are the responsibility of SRC if they are not on a MFL site.

After the transition

RMA mechanisms will apply: structures fixed to the seabed will require a coastal permit unless they are expressly allowed in a RCP.

5.2.3 Farming new species

Before RMA

This was MAF Fisheries responsibility under the MFA: MFLs specify the species that may be farmed on that licence area: presumably this is relevant consideration as to whether the licence was granted or not, although both the MFA and MAF Fisheries's sea-cage salmon policy are silent on species choice and the effect of this (and subsequent escapes) on the environment.

During the transition

The MFA is silent on what criteria, if any, should be used to decide whether s13(3) variations to farm new species should be granted. Choice of species for new ventures falls within the scope of the RMA.

After the transition

For any new ventures, the environmental effects of introducing new species are relevant considerations during the coastal consent process.

In future it is anticipated that the introduction of exotic species into New Zealand will come under the Environmental Risk Management Authority (ERMA) and the Hazardous Substances and New

Organisms Bill. Regional coastal plans could potentially restrict the movement of exotic fauna into a region and control the farming of species that are exotic or do not naturally occur in the area, because such introductions could affect the natural character of the area and because of the general powers of regional councils in the Second Schedule to the RMA (recognition of opportunities for aquaculture) and their role in regional pest control. Introductions of exotic plants can be restricted (s12 RMA).

5.2.4 Genetic manipulation of farmed species

Before the RMA

The MFA is silent on this issue; there were no instances in Big Glory Bay.

During the transition

For new ventures, the environmental effects should be part of the consideration of the coastal permit application.

For existing ventures, this is a matter that the RCP could address.

After the transition

The effects of genetically manipulating species would come within the scope of the RMA processes and the Biosecurities legislation, if passed.

5.2.5 Responsibility for previously used sites

Before the MFA

There is at least one site in Big Glory Bay previously licensed used but no longer licensed. There have also been sites used which have never been licensed e.g. a smolt farm which was incorrectly located. There is no condition on the MFLs assigning responsibility to the license holders should the licence expire, or be cancelled. Presumably MAF Fisheries is responsible for keeping track of which areas have actually been used. Under RMA a responsibility for monitoring the condition of these sites is not explicitly conferred on anyone.

The MFA is silent on the question of responsibility for sites once the licence expires or is cancelled; it only has provisions relating to the removal of structures on licence expiry.

During the transition

There is a provision in the current licences requiring the licensee to take any reasonable steps as specified to mitigate the cause or effects of any waste material on the seabed of the licensed are, if required by the Minister. This is consistent with MAF Fisheries's sea-cage salmon policy.

If the farms are granted coastal permits covering sections 14 and 15 RMA SRC is able to require a bond, to cover the contingency of farms going bankrupt and abandoning sites which require clean-up.

After the transition

RMA mechanisms would apply.

5.3 EFFECT OF THE FARMS ON PROTECTED SPECIES: WILDLIFE, MARINE MAMMALS AND NATIVE FRESHWATER FISH.

Before RMA

Wildlife, marine mammals and freshwater fish are protected under separate legislation, all administered by the DOC. The relationship between the MFA and these other statutes is unclear.

When the farms in the bay were granted variations to their existing licences, to farm salmon, there were several existing detrimental effects on wildlife which were known to DOC. These were not considered a sufficient basis to decline concurrence because of the size and significance of the industry. However mechanisms to limit damage (mitigate or reduce adverse effects) do not exist under the MFA.

During the transition

The Wildlife Act, Marine Mammals Protection Act and Conservation Acts are separate codes; the RMA does not deal specifically with protection of these animals, only their habitat. However the RCP could address the issue of cage design to deter seals from attacking and so lessen the threat they pose to the caged fish.

The role of the protection legislation in controlling incidental effects on protected species, as a result of marine farming, needs to be clarified (a parallel was recognised by the Fisheries Legislation Taskforce with respect to by-catch in commercial fishing activity).

After the transition

The relationship between these statutes and the RMA needs to be clarified. These Acts should be strengthened to enable effects to be mitigated.

5.4 OTHER USER CONFLICTS

Before the RMA

These were MAF Fisheries responsibility: s34 of MFA deals with wilful injury or damage to marine farms, and s35 with obstructing the lessee or licensee from farming or lawfully taking stock from the leased or licensed area.

During the transition

There is now a dual responsibility. These provisions of the MFA continue to apply to existing MFLs and operations. The RCP could potentially deal with such matters because of the general powers of regional councils given in the Second Schedule. The draft New Zealand Coastal Policy Statement also has pertinent policies.

After the transition

These parts of the MFA, which are in the offences section were not repealed. They may be included in the new Fisheries legislation. RMA provisions also apply.

5.5 SAFETY

There is considerable overlap in responsibilities relating to safety and navigation and to the control of environmental effects pertaining to the use of structures.

Before the RMA

MOT, DOC and MAF Fisheries all had roles in the administration of safety requirements for marine farming. The concurrence of the Minister of Transport was required for all marine farm licences. MAF Fisheries sea-cage salmon policy provides that, in areas where there is no plan gazetted under the Town and Country Planning Act 1977 (T&CPA), salmon farming will only be allowed in areas that MAF Fisheries considers suitable based on guidelines for siting and approved by the MOT as not interfering with the safety of navigation, and generally acceptable to Maori values. Areas suitable for farm placement were delineated by MOT in the early 1980s, to leave adequate navigational and anchorage areas; all licence applications have fallen within these areas, although they have never been gazetted.

There is a large degree of duplication in the MFA and Harbours Act provisions relating to structures. The MFA (sections 30 and 31) provides for the licensee to ensure all structures and rafts are maintained in good order and repair, with day beacons, lights and fog signals life-saving and distress equipment as required by the controlling authority. It also requires the structures and rafts to have S178 Harbours Act approval. There is provision for construction to a standard to withstand the action of tides, stress of weather, storms etc. and for removal of non-complying structures. All structures and rafts are to be removed on expiration of the licence; and the Act provides for a bond as a part of the licence to cover this circumstance (s9(c)) although MAF Fisheries have refused to implement this provision, to date. There is power to remove structures in the event of non-compliance.

The Big Glory Bay salmon licences also contain provisions:

* relating to approval of structures, rafts, buoys and buoyed longlines by the Ministry of Transport and requirements for beacons, lights, buoys and fog signals as required by MOT.

* removal of structures when licence expires.

* maintaining these in good order so that they don't deteriorate through want of repair and so become a hazard to navigation.

Conditions required by MOT were also incorporated in the S178 approval granted by DOC (another duplication).

The Southland Regional Planning Scheme, prepared under the T&CPA by the Southland United Council adopted as policies 10 criteria for placement of marine farms, which were developed from MOT criteria designed to minimise navigational danger and interference with other coastal users.

The Director General of MAF may require an applicant to supply survey information about an area intended to be leased or licensed (s43 MFA). When notice in writing is given of the intention to grant a lease or licence the applicant may be required to have the area surveyed and a plan prepared by a surveyor. There is also a requirement in the MFA to mark and keep marked the boundaries of leased areas (s27) but not licensed areas. It is not current practice to retain marks of the site boundaries on the water.

<u>During the transition</u>

SRC is responsible for administering the safety matters included in coastal permits (by virtue of the s178 plan approvals). The RCP can potentially include safety and navigation matters that can be covered in a plan. The conditions in the MFLs, relating to the three matters outlined above, continue to apply.

Compliance with the MFL siting requirements is the responsibility of both SRC and MAF Fisheries. It is an offence under s4A MFA to farm any area that is not a leased or licensed area. It would also be an offence under the RMA, because of restrictions in S12 of that Act.

<u>After the transition</u>

The RMA would control the matters that could be included in a plan (e.g. requirements for lights etc., marking of sites, provision of navigation channels, removal of unused structures). Other matters remain MOT responsibility.

5.6 APPROVAL FOR STRUCTURES UNDER THE BUILDING ACT

This Act was passed subsequent to the RMA. In the CMA it is SRC's responsibility to administer it, and above MHWS the District Council's. During the RMA transition there are potential overlaps with the other safety matters described above.

5.7 RIGHTS TO HARVEST FARMED STOCK AND TO HOLD STOCK THAT WOULD OTHERWISE BE ILLEGAL UNDER THE FISHERIES ACT

Before the RMA

This is covered by s49 MFA which states nothing in the Fisheries Act or regulations made under that Act shall apply in respect to the taking, possession, acquisition, disposal or disturbance of fish or marine vegetation being farmed by lessee or licensee.

During the transition

S49 MFA continues to apply to the existing MFLs. MAF Fisheries recognise the need for new farms, which operate under the RMA system only, and which are farming species that are controlled by the Fisheries Act, to have authority to hold and harvest these species, under that Act. This is partly to prevent the laundering of illegally caught fish through a marine farm. An amendment to the Fisheries Act has been included in the Resource Management Act Amendment Bill (now before Parliament) to rectify this matter.

After the transition

This aspect would be controlled by MAF Fisheries under fisheries legislation. Presumably permission to farm some species in specific localities could be refused under the Fisheries legislation.

5.8 STOCK HEALTH AND DISEASE CONTROL

Before the RMA

This is a MAF Fisheries responsibility under MFA (ie sections 33, 41, 42 and 42A). There is also the ability to make regulations to keep areas free from disease, infection, and contamination.

During the transition

Responsibility remains with MAF Fisheries. These sections of the MFA including the power to make regulations, were not repealed.

After the transition

Presumably similar provisions will be included in new legislation; responsibility remains with MAF Fisheries.

5.9 MAINTAINING PUBLIC HEALTH INCLUDING EXPORT STANDARDS

This is the responsibility of MAF Fisheries and of the Southland Area Health Board (SAHB). These agencies have signed a memorandum of understanding about their respective roles (Kevin Campbell, SAHB Invercargill, pers comm). A shellfish sanitation programme covering Big Glory Bay is run by SAHB to ensure harvested shellfish meets human consumption requirements. The results are externally audited by the USFDA. The survey is reviewed every three years; it looks at impacts on the bay, including the presence of biotoxins.

5.10 REGISTRATION OF MARINE FARMING ENTITLEMENTS

Before the RMA

Leases and licences are registered by MAF Fisheries (under s15-20 of MFA). The Big Glory Bay MFLs include a condition requiring approval to be given before any of the licence is assigned, sublet or parted with.

During the transition

Under the RMA there is no explicit requirement for the registration of coastal permits whether for structures/water rights or for new farming ventures, other than the duty to keep records (s35). In the meantime MAF Fisheries maintains the register; these parts of the MFA were not repealed.

After the transition

It is unclear whether there is an intention to continue the register beyond the expiry of all MFLs. It is debateable whether s122 RMA provides sufficient registration of interest for security purposes (i.e. as security for borrowing money). The Fisheries Legislation Review Taskforce recommended an independent security registration system be legislatively established on a user-pays cost recovery basis for all fisheries rights. This may be a suitable solution for aquaculture rights as well.

5.11 RESEARCH AND MONITORING

The responsibility to carry out research depends on its purpose for which it is being undertaken. There is no explicit responsibility under the MFA for any research in marine farming or the effects of farms on the environment. Any requirement for monitoring relates to the relevant administration roles, rather than constituting a role in itself. For instance s35 RMA confers on local authorities the duty to gather such information and undertake or commission such research and to monitor the environment as is necessary to carry out their functions under the Act.

6 DISCUSSION OF SUSTAINABLE MANAGEMENT

6.1 INTRODUCTION

The purpose of the RMA is to "promote the sustainable management of natural and physical resources". In the Act sustainable management means;

> *"managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while -*
>
> *(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations: and*
>
> *(b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *(c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment."*

This report is not the place for a full discussion of the implications of sustainable management. This has been done elsewhere[30,31,32] but there are a few key concepts which need to be outlined in order to put the subsequent discussion in context.

Firstly, it is important to view the RMA not as a prescription, but rather as a framework and a process for sustainable management to be defined. Thus the above definition is necessarily very broad and must be applied in this context to Big Glory Bay, before it becomes really meaningful.

Secondly, the Act approaches resource management from the position of managing the adverse effects of activities on the environment; it is not about directing development or social and economic planning *per se*, as did some previous planning laws.

Thirdly, RMA refers to the "promotion of sustainable management" which implies that sustainable management is not necessarily achieved overnight, but rather is a goal to which we must strive over time.

Lastly, there are three inter-related concepts involved in sustainable management which are especially relevant in Big Glory Bay:

* renewability - the use of resources at a rate (or in a way) which sustains those resources for the use of future generations.

* reversibility - the depletion or use of resources should be reversible by means of natural restocking or ecological restoration. Irreversible loss of species or ecosystems should be avoided.

* environmental bottom lines - combines the above concepts and says that there should be limits established which ensure renewability and reversibility. Such bottomlines are often not self evident and definition involves judgements about risk and uncertainty.

In a natural system such as Big Glory Bay the application of these concepts can change dramatically with the geographic and time scale over which they are considered. For example the loss of a benthic organism under a cage can be seen at a very localised level to be irreversible but in the context of the whole bay, and over many years, it can be viewed as sustainable, because of recruitment back into the area if cages where to be shifted.

In order to explore these dimensions a systems approach is proposed, involving three scales:

* salmon cage

* Big Glory Bay

* Stewart Island.

The aim is to briefly consider the environment at each scale as an open system and look at the interconnections between scales. Priorities and bottomlines are proposed at each scale for further discussion.

6.2 SCALE 1 - SALMON CAGE

6.2.1 Discussion

Addressing the effects of cages in isolation has obvious shortcomings but it is interesting to postulate what issues would arise if there was only one salmon cage in Big Glory Bay.

Given what we know about the effects, the primary issue in terms of sustainable management appears to be the recovery of the detritus patches that accumulate under the cages. In particular, are the effects irreversible or what is the rate of recovery? This highlights issues such as, what are the impacts of mercury and other contaminants on the natural recovery processes? It should be possible to establish a performance standard for the depth and extent of patches and the rate of recovery and then determine discharge limits to meet this. For some contaminants it may be simpler to establish input controls (e.g., limits on mercury in feed).

The second potentially irreversible impact relates to waahi tapu, mahinga maataitai and other taonga, such as tauranga waka sites in Big Glory Bay. Preferably these should to be identified and cages not sited in these areas. It may be possible to have development compatible with these values but iwi should have direct input to such decisions.

There are a range of other effects which are not critical to the key concepts of sustainable management but the management of their adverse effects may be desirable from the wider community perspective (see Table 3). These second order issues could be addressed in a number of ways, including conditions on consents, specifying controlled activities or performance standards in plans, establishing guidelines or best practicable options and the use of alternative means such as incentives or measures available under other Acts (e.g. Harbours Act bylaws).

Table 3 - Adverse Environmental Effects at Salmon Cage Scale

Effects	Suggested Management Options
loss benthic community	performance standards
loss of taonga	rules avoiding cages in areas
visual impacts	conditions on resource consents
navigation and safety	Harbours Act bylaws
effects of rubbish disposal	best practicable option, Fisheries regs and LGA bylaws
water quality effects (eg: DO, H_2S)	no action or controls on cage spacing

(LGA = Local Government Act)

Visual impact is always a very subjective issue and one in which cumulative impact is important (thus it is more critical to addressed it at the Big Glory Bay scale). At a single cage scale unnecessary visual intrusion can be dealt with as part of the resource consent and in line with the Regional Council's more general coastal policies.

Similarly, navigation and safety issues (such as lights) at this scale are probably more simply dealt with under Harbours Act and Building Act bylaws and regulations. There are a number of issues relating to navigation lanes and anchorages that are appropriately dealt with at the Big Glory Bay scale.

Rubbish disposal can cause water pollution and entanglement of birds and marine mammals. At the cage scale existing controls such as fisheries regulations and Local Government Act bylaws are probably sufficient.

Deterioration of water quality due to the discharge of contaminants, either from the detritus from the cages or decomposing patches, potentially has its most significant impact at the Big Glory Bay scale. The discharge of H_2S from patches and reduced dissolved oxygen (DO) are strictly localised in their impact. The salmon in the cages are the mostly likely to be impacted by these factors thus there is every incentive on the farmers to control such adverse effects themselves, without imposing controls. Alternatively voluntary or mandatory rules on the spacing of cages may be required in the RCP.

Problems associated with toxic algae blooms have impacts at the cage scale but because the cause is external to Big Glory Bay they should be addressed at this larger scale.

6.2.2 Environmental Bottomlines

Following from the above discussion two bottomlines need to be developed to achieve

* the avoidance of irreversible effects on the benthic community

* the protection of waahi tapu, mahinga maataitai and tauranga waka.

The first objective requires specific study of the recovery rates of patches, especially the long term impact of persistent contaminants, and some judgements made about the risk of irreversible impacts. The second objective requires consultation with iwi and possibly the identification of sites, such as tauranga waka, and the development of appropriate rules for their protection.

6.3 SCALE 2 - BIG GLORY BAY ECOSYSTEM

6.3.1 Discussion

Because Big Glory Bay is both a geomorphologically and hydrologically confined feature, this scale is appropriate for addressing the most significant sustainable management issues. The resultant imperatives are to understand Big Glory Bay as an ecosystem and to identify the inputs and outputs from the system, especially the flows between Big Glory Bay and Paterson Inlet (see Table 4).

The most significant water quality issue is the potential for eutrophication of the Big Glory Bay due to the cumulative inputs of nutrients from salmon cages. Eutrophication could not only adversely effect the ecosystem, including wildlife and fisheries values, it would seriously impact the salmon farms themselves. Studies have shown that inputs from Paterson Inlet, temperature and wind patterns and the presence of certain algae are all important factors influencing the eutrophication. Essentially this is an issue of renewable use of the Big Glory Bay ecosystem, but there is also potential for eutrophication of Big Glory Bay to impact Paterson Inlet.

There is no evidence that elevated nutrient levels due to salmon farming have caused toxic algae blooms in Big Glory Bay. These blooms should be viewed as natural hazards associated with marine farming and some other fishing activities, and are addressed in section 6.4. In the future with an increase in salmon farming, elevated nutrient levels could become a trigger or an exacerbating factor for algal blooms. Non-toxic effects, such as reduction in water clarity due to algae growth, are also potential impacts of elevated nutrient levels.

As noted in Chapter 4, attempts have been made to model the effects of nutrient loadings in Big Glory Bay in order to determine the carrying capacity. Although these models are based on many assumptions the results are reasonably conservative. Given the uncertainty and the potentially significant and irreversible impacts it is important that any carrying capacity established be conservative.

Determining the carrying capacity should be complemented by performance standards for nutrient discharges from cages. In this way nutrient loadings can be limited and monitored, and excessive loadings can be avoided.

Given that it is not yet possible to predict the level of production at which there is likely to be a conspicuous effect on water clarity in the bay, until the WQC model is recalculated (4.3.6), it would be unwise to assume that any level of farming would never likely to create a problem. It may prove necessary to implement a separate carrying capacity for the bay to maintain water clarity at acceptable levels.

A further potentially significant impact on the Big Glory Bay scale is the widespread loss of benthic communities beneath cages and the effects of increased sedimentation in Big Glory Bay. If cages are regularly moved and patch recovery rates are slow then the cumulative loss of benthic community may impact the Big Glory Bay ecosystem (e.g. loss of benthic habitat types and diminished food sources for fish). At the Big Glory Bay scale this is primarily an issue of renewable use of the resource. However certain habitats or processes may not be sustained if smothered by waste from the farms e.g. *Lenormandia* meadows and their hypothesised role in sedimentation patterns, also brachiopod assemblages. In this case prohibiting farming over such areas would be a suitable precautionary approach.

Table 4 - Adverse Environmental Effects at Big Glory Bay Scale

Effects	Suggested Management Options
eutrophication	carrying capacity, performance stds
loss of benthic community	cage rotation, performance stds prohibited areas
loss of mahinga maataitai	carrying capacity
visual impacts	controlled activities, guidelines amenity carrying capacity
impaired navigation/safety	designated navigation routes and anchorages
noise, seal scaring	performance stds, guidelines
effects of rubbish disposal	see Table 1
other water quality effects (eg: DO, H_2S)	no action or controls on cage spacing

To effectively manage effects on the benthic community information is required on the rate of patch recovery and how this relates to cage rotation and carrying capacity. Rules in a plan may be required to manage cage rotation and performance standards set for sedimentation rates and patch recovery.

The protection of mahinga maataitai is very closely related to the maintenance of the ecosystem, thus the above measures relating to carrying capacities and performance standards should be sufficient to safeguard these values. Other potential impacts could occur in terms of access and spiritual issues, but given the intensity and nature of the development these should not be major. Nevertheless the iwi should be consulted.

The visual impact of salmon farming occurs primarily at the Big Glory Bay scale. Although Big Glory Bay has high natural scenic values it is not generally regarded as outstanding or unique in the Stewart Island or national context. Thus given the scale of cages, the fact that the effects are reversible and the isolation of the area the effects should be able to be managed using controlled activity criteria and/or guidelines in the RCP. Another option could be to limit the cumulative effect of all the farms within the bay on the landscape and recreational values by establishing an "amenity" carrying capacity.

The nature of salmon cage structures, their regular movement and the intensity of development in Big Glory Bay may cause navigation problems for salmon farmers, fishers and recreational users which are not adequately dealt with by normal measures under the Harbours Act (e.g. lights). These adverse effects could be avoided by way of rules in plans, or conditions on resource consents, to ensure cages are not located in designated navigation routes and anchorages.

Further issues such as noise and rubbish disposal could potentially have effects at the Big Glory Bay scale, but there is only limited evidence of this and no suggestion that the effects are irreversible. Harassing or killing marine mammals is illegal under the Marine Mammals Protection Act and the effects of farm activities on these species should dealt with under that legislation rather than the RMA.

6.3.2 Environmental Bottomlines

Two objectives are suggested based on the above discussion:

* the maintenance of the Big Glory Bay ecosystem

* the containment of impacts within the Big Glory Bay.

These should be achieved by establishing bottomlines in terms of a carrying capacity for salmon farming in Big Glory Bay, with complimentary controls on cage rotation and performance standards for nutrient load, patch recovery and sedimentation rates, and the establishment of prohibited areas within the bay. This will require information on the dynamics of Big Glory Bay ecosystem, patch recovery rates and contaminants from cages. Inherent uncertainty in these estimates of carrying capacity will require bottomlines to be conservative and their effectiveness closely monitored.

6.4 SCALE 3 - STEWART ISLAND

6.4.1 Discussion

There are three issues which are best addressed at a scale larger than Big Glory Bay:

* toxic algae blooms

* local effects of refuge sites

* effects on Paterson Inlet.

As noted above, the toxic algae blooms that have affected salmon farms in Big Glory Bay in recent years can be considered a natural hazard. Unlike some other natural hazards there appears to be no need for statutory intervention (e.g., floodplain zoning), although it is important that mechanisms be put in place to allow rapid and flexible responses to such blooms when they occur. The only other alternative would be to locate farms in other areas less prone to such blooms, but this is a commercial decision.

The response to date has been to permit the salmon cages to be towed to designated refuge areas at the entrance to Paterson Inlet. In the future this could be allowed for by rules in a plan and/or separate resource consents. Such rules or consents would require information and management responses similar to that for the cage scale. At the refuge site the salmon farms may still encounter algae blooms but here their effect is less likely to be exacerbated by this temporary occupation than in Big Glory Bay where nutrient levels have been elevated by the salmon farms. These factors may require some further study to determine the appropriate location of cages and maximum duration of stay.

The only other potentially significant impact at this scale would be due to contaminants, such as nutrients and sediments, emanating from Big Glory Bay impacting the ecosystem of Paterson Inlet. This should not be a problem if the objectives suggested for Big Glory Bay are met.

6.4.2 Environmental Bottomlines

Following from the above discussion two bottom lines need to be developed to achieve:

* the avoidance of irreversible effects on the benthic community

* the avoidance of contamination of Paterson Inlet from salmon farming activities in Big Glory Bay

The means of establishing bottomlines to achieve these objectives has been discussed in the previous sections.

6.5 ALTERNATIVE LOCATIONS

Moving the salmon farming to alternative locations has been discussed at various times since the farms were first established. Such options are not available until the moratorium is lifted by way of a change to the transitional RCP (only the Minister of Conservation, the District Council or the Regional Council can initiate such a change) or as part of the new RCP.

The broad approach to sustainable management proposed above would apply equally well to other locations, such as Paterson Inlet. Obviously, considerable site specific information would have to be collected and the issues could be different in some respects.

7 PROPOSALS FOR FURTHER ACTION

7.1 RESEARCH AND MONITORING

This section recommends the first steps in implementing the options suggested in the previous chapter to achieve sustainable management of the Big Glory Bay salmon farms. It draws on the review of environmental effects in Chapter 4. It does not aim to pre-empt any recommendations the monitoring committee of the Big Glory Bay Salmon Farm Working Group may make.

1 **Rate of recovery of the waste patches on the sea bed**

Research the recovery rate of the waste patches, including determination of factors which may be influencing it (including mercury).

2 **Establishment of a carrying capacity for Big Glory Bay**

Study of the hydrodynamics of Paterson Inlet and its exchange with coastal waters

Study of the nitrogen excretion, egestion and assimilation by salmon in Big Glory Bay

Monitoring of the impact of the farms with respect to the potential for eutrophication (hypernutrification, phytoplankton biomass and species

Ammonia: recalculate the amount that may exist in Big Glory Bay, at 3000 $t\ yr^{-1}$ salmon production; measure existing levels (and seasonal variability?)

3 **Performance standards for nutrient loading of the bay, waste patch recovery and sedimentation rates.**

High mercury levels are a problem that definitely merits further investigation; high levels may delay recovery of the waste patches and have adverse effects on the natural aquatic life of Big Glory Bay, some of which are eaten. Monitor mercury levels in the sediments; incorporate into research on recovery of the waste patches.

Monitor rate and spread of sedimentation due to salmon farming, to ascertain trends and the relationship with bay hydrodynamics.

Map vulnerable habitat types (WQC may hold sufficient raw data).

Monitor nutrient levels as in 2 above.

4 Guidelines for the control of visual impact

Landscape assessment is needed to determine methods of reducing visual impact, for inclusion in the RCP. As this is intimately linked with community values and perceptions, consultation will be needed.

5 Protection of Maori values

Consultation with iwi needed

6 Reduction in seal and dolphin kill, harassment and damage to salmon

An investigation of ways of reducing seal and dolphin kill is needed; literature review, working group discussion, implementation through RCP and by negotiated agreement with DOC.

7 Use of contaminants

Ascertain the range, type, quantities of various chemicals used (or likely to be used) in the salmon farm operations. There may be a need to review the literature on the likely effect of certain potentially environmentally damaging ones.

8 Refuge Site

Monitor impact on seabed and water column at refuge site; establish timeframe over which damage persists.

9 Water clarity

Get WQC model recalculated with refined parameters to calculate the level of salmon production likely to conspicuously affect water clarity in the bay.

Matters primarily of concern to industry:

Dissolved oxygen levels: compare present siting (depths, spacings) to WQC recommended guidelines. Taking dissolved oxygen measurements at finer spatial resolution and over a period of a year would allow for seasonal variation particularly in water temperature and in current flow rates and directions in different parts of the bay. These could then be used to check the WQC recommendations[13]. Measure seasonal variability at salmon farm sites

Refinement of "early warning system" for salmon farmers, which could include coastal water nutrient measurements and weather patterns

Macro- and micro-nutrient requirements of *Heterosigma* and other toxic/nuisance phytoplankton species (whilst this is primarily in the industry's interest it may also be part of establishing environmental sustainability if repeated *Heterosigma* blooms occur).

7.2 PLANNING FRAMEWORK

The scope and diversity of the above topics, as well as issues surrounding existing consents and the roles of management agencies, means that some sort of action is required in order to progress. Firstly, there are considerable gaps in our knowledge of issues critical to sustainable management. A research plan needs to be developed which provides a framework setting out priorities, providing guidance to research providers and establishing funding responsibilities and opportunities. This research plan should be developed in conjunction with the monitoring programme currently being drawn up.

The second major issue that must be addressed is the question of roles and responsibilities. Unless this is done there is a danger of duplication, confusion, and unnecessary cost being imposed on users and other parties. This paper makes some suggestions as to how roles could be better organised but some degree of overlap is inevitable if not necessary when dealing with such a complex range of issues. Duplication and inefficiencies could be minimised by the development of agreements or protocols between agencies such as MAF Fisheries, SRC and DOC.

A third issue that should be addressed is the lack of necessary resource consents for existing salmon farm operations. It is important that this situation is regularised as soon as possible so that all parties can move forward quickly to address issues such as sustainable management and the opportunities offered for better administration under the RCP.

The future planning framework is in fact the final issue that needs to be addressed. Some additional investigation work may be necessary before at least an interim planning framework can be put in place in the RCP. This should include the establishment of environmental bottomlines which, given the uncertainty of some potential effects, may need to be conservatively based. Special provision should be made for the unique features of salmon farming, such as susceptibility to toxic algae blooms and the need for refuge areas.

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APPENDIX 1

SUMMARY OF WORK UNDERTAKEN TO ESTABLISH A LEVEL OF SUSTAINABLE SALMON PRODUCTION

INTRODUCTION

The content of this appendix is based on the initial two WQC repots. It was refined as a result of questions asked by the Department of Conservation, and in response to a Big Glory Bay Salmon Farm Working Group meeting in April 1992. NB This appendix is concerned with only the potential for eutrophication; the two other aspects covered in the WQC reports, acceptable water clarity and dissolved oxygen limits, are considered in the main body of this report.

2 METHOD

It was assumed that nitrogen, not phosphorous, was the nutrient likely to limit phytoplankton growth (based on the average ratio of particulate N to particulate P measured during February 1988); ie nitrogen concentration would limit the maximum concentration of phytoplankton that could occur in the bay if there were no other constraints. Hence estimates of phytoplankton abundance were based only on nitrogen predictions[4].

A phytoplankton mathematical sub-model was constructed to predict phytoplankton biomass in embayments. This was based on the theoretical maximum phytoplankton concentration that can exist in a given embayment at a given time, as determined by the nutrient in shortest supply[6]. Inputting a given chlorophyll concentration usually associated with nuisance blooms (judged to be the maximum acceptable chlorophyll level), the sub-model was solved to give a corresponding estimate of particulate nitrogen (PN) concentration. Since the model was based on the theoretical maximum phytoplankton concentration, at this time all dissolved inorganic nitrogen (DIN) would be used by phytoplankton and "available" nitrogen would consist only of this particulate form. The sub-model incorporated a regression equation between maximum observed chlorophyll concentration and particulate nitrogen concentration constructed from published New Zealand data[6,16].

Using the mass balance model, this critical nitrogen concentration was combined with the average concentration of available nitrogen in Paterson Inlet and estimated hydraulic residence time of Big Glory Bay, to calculate the maximum total nitrogen input to the bay which would maintain these acceptable chlorophyll concentrations.

This critical nitrogen input, plus estimated nitrogen input from the salmon farms (nitrogen per kilogram of fish produced per year) was used to calculate a production level of salmon which would result in that chlorophyll concentration not being exceeded (Table 4)[4].

3 LIMITATIONS OF THE MODEL AND DATA INPUTTED

Several parameters lie on the critical path to the carrying capacity figure.

3.1 Estimate of critical chlorophyll concentration

15mg m^{-3} chlorophyll was chosen as the concentration most likely to pose a risk to the long-term sustainability of salmon farming.

This figure "was based on a thorough search of the literature (marine and freshwater) and on over 10 years research experience on phytoplankton ecology. There are arguments for choosing both higher and lower chlorophyll concentrations but none is more justified than another". At concentrations below this "there should be no dissolved oxygen problems or noticeable change in water clarity ... There is no "safe" chlorophyll concentration if the predominant phytoplankton are toxic or smother fish gills"[16].

This poses the question - what are the arguments for higher or lower concentrations?

This figure is a key parameter in the calculations of both the critical nitrogen loading of Big Glory Bay and the estimate of sustainable production.

NB: The choice of this value as the critical chlorophyll concentration that should not be exceeded relates to the sustainability of long term salmon production and to water clarity; whilst it may also be a suitable level or environmental bottom-line in terms of environmental sustainability, this should be investigated.

3.2 Hydraulic residence time

Based on an ideal of total exchange, of the total prism (estimated at 10%) the mean residency time of the bay is estimated as 5 days. In moderate winds this was estimated to decrease to 7-9 days and during light winds (<5 cms^{-1} = 18km/hr) to 10-13 days. These are likely upper bound estimates of the exchange rate and hence yield lower bound estimates of nutrient concentration (critical nitrogen input) in Big Glory Bay".[4]

> *A critical parameter in the model is the residence time of water in the bay. WQC 1988 Table 4 shows that an increase in residence time from 7-9 days to 10-13 days reduces the salmon production by 45%[4]. Thus an accurate residence time is essential to estimating maximum salmon production.*

The residence time is estimated using conventional tidal prism method with adjustments for wind conditions on the basis of observations. The tidal prism method assumes that water leaving the bay does not return on the following flood tide. In WQC88 notes that "little of the water which leaves the bay during the ebb tide escapes past the Bravo Islands and that most returns on flood tide"[4]. The degree of mixing between water leaving Big Glory and flow through the Bravo Island is critical. By doubling the tidal prism residence time of 5 days to 10-13 days in light winds, the authors are presumably allowing for a 50% dilution of Big Glory Bay water by water coming through Bravo Islands. This dilution factor is critical to the residence time and would warrant further work. This could be done by hydrographic measurements over a much longer period.

It should be noted that residence times in WQC1988 are average times for Big Glory Bay[4]. The variation within the bay could be large. For example, much of the water entering the bay on the flood tide may stay near the entrance to the bay giving a very low residence time in that area. Residence times over the remainder of the bay would be very long while the average over the bay could be similar to the quoted values. It would be useful to determine residence times for various sections of the bay to use in a more sophisticated box model for the bay and hydrographic work[17].

More sophisticated modelling of the hydrodynamics of Big Glory Bay and Paterson Inlet was also considered by Pridmore[16].

A mean residence time must be used in our model (see derivation, Pridmore and Rutherford[6], pages 4-6). If more sophisticated models were developed this would not be the case, but the cost of developing such models and acquiring the appropriate data for Big Glory Bay would be considerable ($>1000,000 for a 2-D or 3-D numerical model) ... A 3-D model would be required to predict spatial patterns within the bay, especially for motile phytoplankton such as Heterosigma...

Knowing more about the hydrodynamics of Paterson Inlet would greatly assist our understanding of the field data and help us to determine the influence of coastal waters on Paterson Inlet nutrient and chlorophyll concentrations. This information, however, is not required in our present model and would not alter our model predictions[16].

Pridmore considers that future effort should be directed towards modelling three dimensional water circulation patterns and their interaction with plankton migrations. He also lists the hydrodynamics of Paterson Inlet and its exchange with coastal waters as one of the topics would should be further investigated[16].

Pridmore and Rutherford[6] discuss the sensitivity of the nitrogen model to changes in three parameters. Their analysis (the data for which is not given) showed that 10% change in hydraulic residence time resulted in a 3% charge in the predicted critical nitrogen concentration of Big Glory Bay.

> *The validity of the model is tested by concentrations of nitrogen and phosphorus measured on one day with the values predicted by the model. This is done by assuming that the bay is in a steady state after a fortnight of light winds when the flushing time is 10-13 days by their estimates. They use this steady state as the start up value N (t^o) for the model. With a flushing time of 10-13 days a fortnight is not sufficient time to reach steady state. The actual N(t^o) for the model will change depending on the concentration in the bay at the beginning of the period of light winds. This in turn will be dependent on the history of flushing rates inputs and Paterson Inlet nutrient concentrations. If we assumed that there were no inputs prior to the light wind in Paterson Inlet [sic, presumably Big Glory Bay] then the concentration after 14 days with their reported inputs would be approximately 10mg/m^3 below the 66mg/m^3 used as N(t^o). This is an extreme example; the actual N (t^o) may be higher or lower than 66. More measurements over a longer period would be needed to* improve the accuracy of N(t^0[17].

Whilst this question has not been specifically addressed in any of the Water Quality Centre reports, it has been tested; the model was not very sensitive to changes in N(t^0) (Pridmore pers. comm.)

3.3 Inputs of nutrients

Direct measurements were made of food inputs, food composition, total particulate loss from cages and recycling from sediments. Estimates of salmon assimilation, egestion and excretion were taken from the literature[6]. When calculating the level of salmon production, nitrogen input from the salmon farms was first estimated as 258g per kilograms of fish produced per year[4]. Total 'available' nitrogen input into Big Glory Bay was initially estimated at 452 kg d^{-1} (Table 2); however when the model was tested on data measured on 24/2/88 it gave predicted nitrogen concentrations lower than those observed (Table 3[2]: 69±3 mg m^{-3} calculated from Table 8 Pridmore and Rutherford[6] - by adding NH_4^+-N, NO_3^--N and PN). The standard error was calculated from the new data and is lower than that of the individual components which comprise total nitrogen, because the variability in these components is higher than in the total nitrogen (Pridmore pers. comm.) The estimated total nitrogen input was increased to 564 kg d^{-1} to remove the discrepancy between observed and predicted concentrations. This corresponded to an input of 258g N per kilogram fish produced per year, from excretion, egestion and sediment release and is within the range of values reported from overseas farms[4]. It is not specified whether kilograms of fish produced is live or dressed weight.

Note that the model has at least six parameters: the flushing time Q/V, the bay volume V, the input nitrogen and phosphorus and the concentrations of nitrogen in Paterson Inlet. With the exception of bay volume, the parameters are not accurately known. This model was validated against two observed concentrations on one day. There are many different combinations of the parameters which would give equally good agreement with the observations. As a best guess, the authors alter the nitrogen input to improve comparison with the observations. Daily measurements over several weeks would provide a more reliable validation of the model[17].

The nutrient input estimates are refined in Pridmore and Rutherford[6]. Total of nitrogen inputs from fish excretion and sediment release in Table 8[6] correspond to an input of 171 g(N) kg^{-1} (fish produced) yr^{-1}. The factor for catchment run-off is reduced from 20 kg d^{-1} (Table 2) to 4.0 t yr^{-1} (11kg d^{-1} (Table 4,[6])). This is as a result changing the estimate of yield of nitrogen from the catchment from 5 to 2.8 kg (N) ha^{-1} yr^{-1}.

The effect of these changes on the estimate of sustainable salmon production is not discussed.

However the sensitivity analysis in Pridmore and Rutherford[6] showed that a 10% change in the nitrogen input resulted in 3.0% change in the predicted nitrogen concentration of Big Glory Bay.

The significance of the total estimated 'available' nitrogen input into Big Glory Bay is that it was used to test the validity of the mass-balance model. The significance of the estimated nitrogen input from the salmon farms is that it is used to calculate from critical nitrogen input for the bay to determine the salmon production rate corresponding to this.

The authors[4] had a major concern about the nitrogen inputs per unit of salmon production. "The overall uncertainty in these inputs is high, perhaps up the order approximately 50%". This is one of two reasons given, why they applied a large safety margin and shifted down the recommended salmon production to 3000 t yr^{-1} (from the calculated 5000) (p14).

Pridmore[16] recommends further investigation of the nitrogen excretion, egestion and assimilation by salmon in Big Glory Bay.

3.4 Nitrogen and chlorophyll concentrations in Paterson Inlet

Applicability of the model is dependent on 'available' nitrogen and chlorophyll concentrations in Paterson Inlet remaining at or near their current levels (Rutherford et al.[4], p14).

Pridmore judges that it unlikely salmon operations in Big Glory Bay would significantly increase nitrogen concentrations in Paterson Inlet if total production was limited to 3000 tonne/year[16].

Sensitivity analysis showed the model was very sensitive to changes of nutrient concentrations in Paterson Inlet (a 10% change in nitrogen concentration of the inlet resulted in 7% change in predicted nitrogen concentration for Big Glory Bay. A 10% change in chlorophyll concentration in the inlet would produce a 3% change in the predicted chlorophyll concentration in Big Glory Bay using the 1989 field data)[6].

The second major concern which caused the authors[4] to shift the recommended level of salmon production down to 3000 tonnes/year was how much chlorophyll and nitrogen concentrations would vary long term in Paterson Inlet.

Bradford et al.[29] reported high year to year variability is the concentrations of NO_3-N and chlorophyll in Foveaux Strait, including off north-east Stewart Island during four consecutive summers (1977-1980). This appears to be associated with sporadic incursions of fertile high salinity water into Foveaux Strait from the south "and is the likely cause of observed differences in Paterson Inlet nutrient concentrations between 1988 and 1989"[6].

The mechanism of these incursions was not investigated; two origins were suggested, upwelling or the incursion of surface water from the south[29].

This suggests that greater variability in nutrient concentrations in Paterson Inlet, which flushes into Foveaux Strait, probably occurs than that recorded during January 1988 (on one day) and February 1989. (Both studies were conducted at the same time of year). Seasonal nutrient levels of Paterson Inlet may exist. Monitoring these at various places in the inlet and adjacent outer coast, for at least a year would help establish this variation[17].

Concentrations of chlorophyll and nitrogen in Paterson Inlet increased markedly in January 1989 (compared to February 1988)[16]. The model reliably predicted the spatially-averaged chlorophyll concentrations in Feb 88. However in 1988 predicted chlorophyll concentration for Big Glory Bay was lower than that measured and outside the 95% confidence interval. At that time phytoplankton growth was not restricted by nitrogen[6]. The model will not work when there is a surplus of nitrogen (Pridmore pers. comm.).

In January 1989 concentrations of chlorophyll and nitrogen in Paterson Inlet were markedly higher than in February 1988. "This meant that our model of sustainable salmon production in Big Glory Bay (ie 5000 t yr^{-1} would have to be revised (because it was based on lower nitrogen and chlorophyll inputs from Paterson Inlet) ...There seems little point in re-estimating the carrying capacity of Big Glory Bay with our existing model since we know toxic blooms of *Heterosigma* can occur at moderately low nutrient concentrations"[16]. However Pridmore lists refinement of the "early warning system" for salmon farmers, including coastal water nutrients measurements and weather patterns as a topic meriting further investigation[16].

4 RECALCULATION OF THE LEVEL OF SUSTAINABLE SALMON PRODUCTION

In mid-April, the WQC nitrogen/phytoplankton model was rerun by Rick Pridmore.

Using known worst case conditions, ie:

Hydraulic flushing time for Big Glory Bay	**15 days**
Available nitrogen concentrations in Paterson I. (measured at 77.4)	**80mg m^{-3}**
Chlorophyll concentration in Paterson Inlet (measured at 2.1)	**2.5mg m^{-3}**

Phytoplankton growth rate of 1 division per day.

(The critical maximum chlorophyll figure used was 12mg m^{-3}; very high phytoplankton growth for a very long time was assumed).

This produced figures of: 483*t* y^{-1} nitrogen and 6800*t* y^{-1} food. This equates to 3000*t* y-1 salmon (total biomass produced) at a food conversion rate of 2.27.

At the request of Big Glory Bay Seafoods the model was run a second time with less stringent parameters:

Flushing time	**14 days**
Available nitrogen, Paterson Inlet	**75mg m-3**
Chlorophyll, Paterson Inlet	**2.0mg m-3**

Under these conditions 515*t* y^{-1} of nitrogen would be acceptable ie 7250*t* y^{-1} of food, 3194 *t* y^{-1} salmon) Note: this is slightly less stringent than the worst case situation already encountered, ie the *Heterosigma* bloom in 1989 at 1200 *t* y^{-1} of salmon production in the bay.

The total biomass of salmon produced per year is not the same as either the green weight or processed weight harvested that year. Processed weight is generally 87% of the green weight harvested. It is not possible to definitely calculate green weight as a proportion of the total biomass produced each year. The relativity will depend on the water temperature, which differs at different locations in the bay and the food used on each farm. It has been estimated as being 105-120% higher than green weight harvested[8]. 20-30% of growth is in new fish being brought into the bay each year.

APPENDIX 2

REVIEW OF SOURCES ON CAGE ROTATION AND FALLOWING

1 REVIEW

The following is a summary of pertinent research that might provide guidance to the manner in which cage rotation may be effectively used and likely environmental effects of this:

Gowen et al.[10]: a Scottish study in a sea-loch; farm had been on site for 3 years; 6 cages, each 18 x 30m mature fish (presumed to be Atlantic salmon).

The sediment at edge of cages appeared to have reverted to a state typical of the loch after a period of 8 months. The time taken for sedimentary conditions to recover did not appear proportional to the length of time the cages were in position.

After 3 months a slight recovery of macrofauna was observed, however it remained highly disturbed even after 8 months. The authors suggested that it may take several years for the macrofauna to return to normal. The time taken for macrofaunal recovery, even when changes in the macrofaunal community were only slight, is much longer than for sediment recovery.

Rate of recovery was thought to be influenced by:

* period of time the site has been in use
* stocking density of fish in cages
* hydrography of the site.

Woodward et al.[26]: a Tasmanian study of the relationship between stocking and time to recover to threshold respiration of the benthos. Based on a site in Huon estuary, where only the first 25% of biomass growth is achieved before cages are towed out to sea; site was approximately 4.5 ha, with an experimental stocking density of 2.62 kg/m3, and an average biomass of 4500 kg. Species farmed was presumed to be trout. Site had been used for 16 months prior to the study.

The authors sought to predict recovery time beneath the experimental cage by fitting a hyperbolic relationship between sedimentation rate and threshold recovery time, also between average stocking biomass and threshold recovery time. The equations could be applied "to the spatial distribution of loadings to suggest suitable fallowing times for a given point". Threshold recovery time was taken as the threshold point where anoxic conditions are replaced by oxic conditions once again.

After the study ended, other researchers, using the same site, found that up to 6 months later benthic respiration rates were still high. Based on meiofaunal community structure, it was suggested there had been a period of disturbance to the community due to an unknown environmental perturbation. Therefore the authors caution against the reliability of their fitted hyperbolic relationship over extended periods of extrapolated time.

With regard to predicted recovery times, each approximate doubling of stocking density leads to successively greater recovery times especially at sites close to the centre of the cage.

However the authors also concluded it is probable that at some stage the sedimentation rate reaches a point where it exceeds the capacity of the benthos to cope, causing a sharp change in the benthic response as measured by benthic respiration. On the fitted relationship between threshold recovery time and sedimentation rates, rates of 0 to approx 120 $g/m^2/day$ were the range within the area of reasonable confidence. Pridmore and Rutherford's[6] measurements of sedimentation in traps beneath 4 farms in Big Glory Bay in February 1988 were 87, 90, 252 and 262g (dry wt)/m^2/d. Two of these measurements are far greater than the area of reasonable confidence in Woodward et al.[26]. These high levels reflect greater food supply rates used at Big Glory Bay sites (and presumably higher stocking densities).

No examination was made of how the recovery time for a site varies as a function of the previous cumulative input of faeces and waste food. Woodward et al.[26] did not study macrofauna effects.

The authors consider the possibility of long term "souring" of a site through continual use, even with periodic following, is very real.

2 SUGGESTIONS FOR FALLOWING/CAGE ROTATION

Gowen et al.[10] give approximate guidelines for Loch Spelve only:

- to be worthwhile cages should be in position for only a short time (6 months - 1 year)
- the old area should be left vacant for a longer period of time than the cages were *in situ* (1-2 years).

Different hydrographic characteristics result in different impact and recovery times.

Woodward et al.[26] suggest setting stocking limits that prevent significant impact on sediments outside the farm boundaries. Their idea of fallowing is based on the premise that the benthos of a farm site can be managed as a mosaic of discrete areas, as benthic effects are limited to within 50m from the cages.

They recognised that there is a penalty in using a higher stocking density within a cage in that the affected area around a farm is increased. Fallowing schemes should be based on both the lateral spread and total loadings of solids emanating from a cage was recommended [NB P29 Table 6 - threshold distances.] They suggest also bearing in mind that having too many cages crowded along of current flow means downstream ones can suffer considerably reduced flow.