Coastal marine sediment and water quality: contaminant verses pollutant risk assessment in relation to the Tasmanian salmonid industry.

Dr Julie Mondon
Centre for Integrative Ecology
Life and Environmental Sciences
Faculty of Science and Technology
Deakin University
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Future planning for increased production of the salmonid industry to include doubling of production and expansion from inshore coastal to oceanic water leases requires pragmatic consideration in relation to ecological risk from contamination and potential pollutant input deriving from intensive cage sea farming practices.

Contamination concerns outlined in this briefing document relate specifically to the following:

- nutrient enrichment of sediment and water column from biosolids waste comprising expelled faeces and waste pellets,
- benthic habitat loss through elevated sedimentation and burial,
- fragmentation and broadcast dispersion of fouling organisms, including recognised pest species, to the water column from *in situ* biofouling removal from nets and cage infrastructure,
- direct discharge of untreated disinfectant wastewater to the marine environment.

The term Contaminant is used to designate any chemical or physical change in the environment that exceeds normal levels: contaminants can originate from a natural source, or be human derived. The term Pollutant designates any chemical or physical change, directly, or indirectly, of substances or energy in the environment resulting in deleterious effects as to harm living resources, present a hazard to human health, or reduce environmental amenities due to human activity[1]. In the context of the marine environment, this designation would extend to harm to aquatic biota, impairment of quality of seawater for biota, hinder use of aquatic activities including fishing, and reduce coastal amenity with respect to tangible and intangible value.

[1] Clark 2005 Marine Pollution Oxford University Press; cited GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection.

Nutrient enrichment of waters and sediments from excess feed and salmon faecal wastes do not otherwise occur in nature in the southern hemisphere marine environment. The waste organic material is subject to bacterial degradation, the efficiency of which is constrained by the biological oxygen demand (BOD) of the material and oxygen availability at the sediment water interface and water column above the seabed. When biological oxygen demand from decomposition of deposited organic waste by oxygen utilising bacteria exceeds oxygen supply, anoxic conditions in sediments and overlying waters are established. Increased incidence of anoxic (zero dissolved oxygen, DO) and hypoxic (less than 2.0 mg/L DO) events indicates aquaculture effort is exceeding the carrying capacity of the geographical area occupied by the aquaculture operation. Extended anoxic conditions enables anaerobic bacterial respiration production of hydrogen sulphide. Nitrification, which the process in which bacteria oxidise ammonium, from breakdown of proteins, to nitrite and nitrate, is inhibited under anoxia or exposure to hydrogen sulphide[2], causing a lowering of denitrification efficiency. As a result, nitrogen is recycled to the water column as ammonium. Both ammonium and hydrogen sulphide are toxic to oxygen requiring organisms, thereby adding to the potential toxicity load in the water column. Anoxia, ammonium and hydrogen sulphide generation from salmon cage waste indicates a significant decrease in marine sediment and water quality[3], habitat modification, and loss of ecosystem integrity[4], supporting neither long term aquaculture operations nor benthic ecosystem sustainability. It can be argued that, with the advancement of scientific knowledge with respect to elevated sediment nutrient enrichment from aquaculture farm practice, what at one time was considered to represent a harmless level of contamination, now represents a damaging biological pollutant source if the volume of enrichment matter exceeds the carrying capacity of the marine environment into which it is discharged.

Sedimentation and burial of substrate and benthos, ie. plant and animal communities normally inhabiting the seabed, occurs when sediment or particulate matter is deposited more rapidly that tolerated by the benthic communities present[5]. Elevated sedimentation equates to habitat loss for sandy and reef community organisms, including benthic and reef finfish and abalone. Increased sedimentation rates facilitate greater opportunity for anoxic degradation of organic matter present due to the shortened exposure to dissolved oxygen in the water column. Sediment –bound nutrients and toxicants also tend to increase in association with increased rates of sedimentation[6] as a function of sediment adsorbed transport. Vertical sedimentation of particulate material from salmon cages to the seabed below is not in dispute:

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[2] Joye, S.B. and Hollibaugh, J.T., 1995. Influence of sulfide inhibition of nitrification on nitrogen regeneration in sediments. *Science* 270, 623-625

[3] ANZECC/ARMCANZ (October 2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. (www.ea.gov.au/water/quality/nwqms/#quality)

[4] National Land and Water Resources Audit 2008

[5] Hancock, G.J., Olley, J.M. and Wallbrink, P.J. 2001. Sediment transport and accumulation in Western Port, Report on Phase 1 of a study determining the sources of sediment to western Port, CSIRO Land and Water, Environmental Hydrology, Canberra Technical Report 47/01, November 2001.

[6] Chenhall, B.E. *et al*. 1995. Anthropogenic marker evidence for accelerated sedimentation in Lake Illawarra, New South Wales, Australia. *Environmental Geology* 26, 124-135,

horizontal transportation of suspended particulate material from salmon cages to the seafloor across a significant distance is. Identification of the source of inputs and level of contribution to the sedimentation rate beyond the aquaculture site boundary is necessary to establish the spatial extent of aquaculture farm-derived particulate dispersal, contribution to sedimentation load, and composition of inorganic and organic particulate matter, if wide spread dispersion does occur.

The current practice of high pressure washing to remove fouling organisms from in situ cages and infrastructure has been introduced worldwide to phase out the necessity for heavy metal antifoul paints and treatments. It should be recognised that there are potential pollutant implications to washing *in situ*. The concentration of biomass removed from infrastructure is not contained during the blasting process. The heavier components of the biomass will drop to the seafloor to decompose. Fouling biomass adds to the BOD load required for decomposition, significantly adding to localised nutrient enrichment of the seafloor.

Pressure washing blasts fouling organisms from structures, fragmenting the colonies present and resuspending trapped sedimentary particles to the water column. Competitive colonising organisms including sponges, hydroids ascidians and tunicates, including introduced pest species, are relocated. Water pressure treatment on *Botryllus schlosseri* for example, results in fragmentation of the parent colony to produce viable fragment colonies theoretically capable of recolonizing other surfaces up to 18 days after fragmentation.[7] This implies that survival of the tunicate colony is not contingent on being settled on a substrate. Fragmentation through pressure washing can elicit larval release and broadcast dispersion in the water column, which increases the likelihood of a wider spatial distribution of colonisation aided by transportation via the blasting process. Fragmentation from the parent colony also enhances asexual budding[8], thereby increasing the survival potential through stimulus of both sexual and asexual reproduction.

Importantly for the salmon industry, damage to gills of farmed fish occurs from settled hydroids, and from hydroid polyps in the water column displaced from the colony by high pressure washing. [9] The colonial or polyp stage of Hydrozoa, or hydroid, is similar to that of tunicates: the hydroid settles as a larvae on a substrate and multiplies to form a spreading colony. High pressure washing fragments the colony, releasing polyp heads and larvae into the water column. Hydroid polyps eject a toxin via the nematocyst, which is activated by physical contact. Once the spines have penetrated the predator (or prey), neurotoxin is injected along the tubule and into the skin that has been penetrated. Nematocysts will activate in both free floating polyps and settled polyps. Pathological response in gills to the toxin is cell death resulting in necrosis and loss of the epithelial (external) layer of cells, and significant haemorrhage.[10]

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[7] Paetzold & Davidson 2010 Viability of golden star tunicate fragments after high-pressure water treatment. Aquaculture 303, 105-107

[8] Ibid.

[9] Baxter et al. 2012 Biofouling of the hydroid *Ectopleura larynx* on aquaculture nets in Ireland: Implications for finfish health. 17-29

[10] Gershwin 2013 Stung: on jellyfish blooms and the future of the ocean. University of Chicago press

The hydroid *Ectopleura crocea* has established in Victorian mussel leases. Hydroids predominantly settle on the body and to a lesser extent on the edge and dorsal section of the shell.[11] Black mussels fouled with the hydroid exhibited a 23% reduction in flesh weight. It is suggested hydroid interference in relation to competition for food (planktonic diatoms) and disturbed filtration flow across the mussel gill is potentially responsible. Additionally, hydroids selectively prey on the mussel larvae, which could affect settlement and recruitment rates of mussels through predation.

Field evaluation is strongly recommended to identify if survival of fragmented colonies released in *in situ* marine environments are as robust and capable of re-settlement and vigorous growth as *Botryllus schlosseri* and *Ectopleura crocea,* particularly in areas adjacent to salmon farms employing *in situ* pressure washing. Evidence for sponge, hydroid and tunicate resettlement on mussel lines situated near a salmon farm employing pressure washing in southern Tasmanian waters, warrants investigation, particularly given that the species present are capable of both sexual and asexual reproduction, increasing the likelihood of rapid colony growth and further proliferation once settled.

Pressure washing markedly increases turbidity and suspended particulate load in the water column. Particulate size composition represents a hazard to filter feeding organisms, including bivalves. Suspended particles filtered by the green-lipped mussel for example, can abrade the cilia on gill filaments responsible for filtering seawater to extract food particles. Loss of cilia is due to mechanical abrasion as opposed to chemical abrasion. Particles larger than 63 µm (silt), within the range of greater than 63 µm to 250 µm (very fine-125 µm to fine - 250 µm sand) cause the greatest cilia abrasion and loss in gill filament structure. Particles larger than fine sand can be too large to be easily filtered. Concentrations of suspended particles comprising very fine to fine sand particle size at 500 mg L and above results in an increased area of cilia loss exceeding approximately 70% - 80%, with no evidence of cilia replacement after a 3+ week recovery period.[12]

Implications related to gill filament damage extends to reduction in the effective gill surface area for food extraction. The affected animal will need to pump water at a higher rate, requiring greater energy, to extract sufficient food particles from the seawater. At the same time, reduced oxygen uptake is also likely to due to filament damage and therefore ability to metabolise the filtered food is reduced due to a reduction in metabolic rate: a low oxygen uptake leads to low respiration rate, leading to decreased metabolic rate, decreasing cellular energy levels, resulting in inhibited growth. Reduced body size prevents financial loss if the bivalve is a marketable species.

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[11] Fitridge and Keough (2013) 'Ruinous resident: the hydroid Ectopleura crocea negatively affects suspended culture of the mussel *Mytilus galloprovincialis*', Biofouling 29(2) 119-131

[12] Cheung and Shin 2005 Size effects of suspended particles on gill damage in green-lipped mussel *Perna viridis* Marine Pollution Bulletin 51 801-810

High turbidity generated from re-suspension of biological and inorganic particulate matter represents a risk irrespective of what the particles consist of. The physical size of particles does not need to be large to cause damage. Level of damage to gill filament increases with increasing concentration of suspended particles.[13] Furthermore, the actual shape and composition of particles is important. Fragmentation of sponges through high pressure washing generates release of spicules to the water column Spicules form the structural 'skeleton' of the sponge, which are either calcareous or siliceous, and of varying size and shape. Spicule size is species dependent, ranging from microsclere (small spicules ranging from 10 to 60 µm ie. equivalent to silt), to megasclere (large spicules ranging from 60 to 2000 µm ie. from course silts through to very coarse sand equivalent of 2 mm diameter). Additionally, spicules are shaped to deter predators (needle sharp, hooked, barbed, serrated, spiny), which catch and rip delicate external and internal tissues, including gills. Consequently, even though the spicule may be too large to be physically filtered by the bivalve, movement of spicules across the gill surface drawn along with the filter current could result in impalement and tearing of surface gill filament structure.

The Tasmanian salmonid industry uses chloramine-T disinfectant in off-shore fish baths. Disinfectant wastewater is then released directly to the environment. The benefit of chloramine –T (sodium *N*-chloro 4-methylbenzenesulfonamide trihydrate), also trading as Halamid®, chlorazene, halacon, aktiven, mianine,[14] is that it is soluble in seawater. Chloramine –T is an efficient anti-bacteria agent, that binds to enzymes altering the characteristic activity of the enzyme. Chloramine-T is metabolised by fish to form the major degradate product, p-toluenesulfonamide[15], also known as p-TSA, which is then eliminated from the body (further metabolites may also exist).[16] The parent chemical is not species or organism selective.[17] Chloramine-T inhibits cell division and growth by 25 – 50 % at concentration exposures of 4 and 8 mg/L in several groups of marine microalgae (dinoflagellate *Glenodinium halli,* microflagellate *Isochrysis galbana,* diatoms *Skeletonema costatum* and *Thalassiosira* sp.*)*.[18] Mortality has been observed in hard clam larvae at far lower exposures of 0.001 mg/L (48-hr LC50). The relative toxicity to exposed environmental

[13] Ibid.

[14] (Axcentive SARL 2005 Material Data Safety Sheet, available online at http://www.halamid.com/halamid_safety_sheet.pdf.

[15] Organisation for Economic Cooperation and Development (OECD). 1994. Screening Information Data Set (SIDS) of OECD High Production Volume Chemicals Programme, 1994.

[16] Dou et al. Environmental aspects of drug and chemical use in aquaculture: an overview. 2009 In: Rogers (ed.) Basurco (ed.). The use of veterinary drugs and vaccines in Mediterranean aquaculture.

[17] Massuyeau 1990. Contribution à l'étude d'une méthode de recherche des résidus de chloramine T dans les produits d'aquaculture. Thèse de doctorat vétérinaire, Ecole Nationale Vétérinaire de Nantes, 86 p.

[18] Erickson and Freeman 1978 Toxicity screening of fifteen chlorinated and brominated compounds using four species of marine phytoplankton. Pages 307–310 *in* R. L. Jolley et al., editors. Water chlorination: Environmental impact and health effects. Vol. 2. Ann Arbor Science Publishers, Ann Arbor, Michigan

organisms therefore is expected to vary considerably, but higher sensitivity to chloramine is clearly evident in early growth phases of life cycles.[19]

The known environmental fate of chloramine –T as it enters the aquatic system points to potential pollutant concern. Chloramine-T degrades to p-TSA, both of which are toxic and available to non-target organisms, and both are taken up by sediment. Chloramine-T inhibits bacterial nitrification[20,21], so that ammonium build and release from sediments is expected. Since both chloramine-T and metabolites are unstable in water and difficult to measure *in situ*, it is probably difficult to obtain reliable data on their toxicity and degradability in the receiving environment.[22] Prevention of discharge to the marine environment will negate the need for costly and highly technical post impact monitoring.

Future planning for increased production of the salmonid industry to include doubling of production and expansion from inshore coastal to oceanic water leases requires pragmatic consideration in relation to ecological impact from contamination and pollution inputs to the coastal marine environment deriving from intensive cage sea farming.

In summary,

- nutrient enrichment of sediment and water column from bio-solids waste comprising expelled salmon faeces and waste pellets, and biofouling biomass decomposition, constitutes a physico-chemical pollution risk by exceeding the ANZECC/ARMCANZ (October 2000) Australian and New Zealand Guidelines for coastal marine sediments and water.

- benthic habitat loss through elevated sedimentation and burial, represents a contaminant risk to sedentary and benthic organisms potentially resulting in loss of community structure and ecological function. Benthic invertebrates are considered especially useful indicators of environmental quality over long periods because of their limited mobility. If elevated sedimentation is fish farm derived, then the classification of contamination is elevated to a physico-chemical pollution risk status.

[19] The Nippon Foundation 2010. Ocean Policy Research Foundation October 2010, Final report on the comprehensive management against biofouling to minimize risks on marine environment.

[20] GESAMP, 1997. Joint Group of Experts on the Scientific Aspects of Marine Pollution. Towards safe and effective use of chemicals in coastal aquaculture. Rep. Stud. GESAMP, (65), 37 p. http://www.fao.org/fi/publ/report/gesamp/r65/r65.asp#CHEMICALS.

[21] Nimenya et al 1999. Short term toxicity of various pharmacological agents on the *in vitro* nitrification process in a simple closed aquatic system. *Alternative to Laboratory Animals*, 27, 1, p. 121-135.

[22] The Nippon Foundation. Ocean Policy Research Foundation October 2010, Final report on the comprehensive management against biofouling to minimize risks on marine environment.

- fragmentation and broadcast dispersion of fouling organisms, including recognised pest species, to the water column from *in situ* biofouling removal from nets and cage infrastructure, represents a biological contaminant risk.

  Facilitated transfer of introduced pest species, such that a new species settling in a new area can cause change in biota health, and or the expulsion of native species and decreased biodiversity, represents a biological pollutant risk. It is anticipated that 'transfer of biofouling organisms' will eventually be controlled by internationally binding regulations, similar to those adopted for ballast water management.[23]

- direct discharge of untreated disinfectant wastewater to the marine environment represents a contamination risk. If reduction in denitrification efficiencies is exacerbated in the receiving waters and sediment, and toxicity to water column microalgae and benthic diatoms is evident, then the classification of contaminant is elevated to a pharmaceutical pollution risk.

[23] The Nippon Foundation. Ocean Policy Research Foundation October 2010, Final report on the comprehensive management against biofouling to minimize risks on marine environment.