



Application of biotic and abiotic indicators for detecting benthic impacts of marine salmonid farming among coastal regions of Tasmania

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ABSTRACT

Analysis of sediment and macrofaunal samples collected during the Tasmanian marine farming finfish monitoring program – a six-year partnership between industry, management and researchers – revealed several univariate indicators to be useful for detecting effects of aquaculture on the benthic environment. Comparisons with reference sites revealed a significant decline in sediment redox potential to at least 4 cm depth at farm sites, and increased proportional abundance of capitellids and decreased bivalve/total mollusc ratio. At compliance sites located 35 m out from lease boundaries, sediment redox potential and faunal assemblage composition were intermediate between patterns found at farm and reference sites. Redox potential at the sediment surface declined on average by 178 eV at reference sites converted to farm sites, with this indicator proving the most sensitive for detecting regional impacts of farming activity. Fish farm effects that extended to regional scales could not be adequately assessed within the project because reference regions without fish farms were not monitored; however, a significant decrease through time at reference and compliance sites in surface redox potential, and increases in sediment organic matter and total macrofaunal abundance, were suggestive that organic enrichment may have extended at low levels across regional scales. Given the implications to biodiversity conservation of region-wide impacts and a need to distinguish fish farm effects from unrelated long-term environmental change, monitoring of reference sites in regions lacking fish farms is urgently needed.

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1. Introduction

Environmental changes to seabed habitats and benthic communities caused by marine fish farming activities are frequently reported near cages within farms (Karakassis et al., 2000; Macleod et al., 2004; Pereira et al., 2004; Tomassetti and Porrello, 2005). Farming impacts can manifest as changes within the physico-chemical environment (e.g. dissolved oxygen, sulphide production, and redox potential) or changes to benthic community structure (e.g. macrofaunal density, species richness, abundance of opportunistic animals such as capitellid polychaetes, and abundance of pollution-sensitive animals such as bivalves). At within farm scales, environmental impacts are of primary interest to farm managers because hydrogen sulphide production and other deleterious environmental changes can affect health of fish stocks and associated husbandry practices (Black et al., 1996). Environmental managers, on the other hand, are generally more interested in impacts of marine farming that propagate across broader spatial scales because

of the potential for such effects to adversely impact regional biodiversity and coastal ecological processes.

In order to track the temporal and spatial influences of farming impact at broad scales, coastal managers require quantitative indicators of environmental condition that are both cost effective and practical (Borja et al., 2009; Janowicz and Ross, 2001; McMahon, 2000). The search for appropriate indicators has, however, been hindered by the fact that broad-scale aquaculture effects are typically subtle and spatially variable, differing in magnitude between locations with dissimilar local environmental conditions (Black, 2001; Macleod et al., 2007). A consequence of this high spatial variability is that few overarching conclusions can be gained from studies of individual farms (Sanz-Lázaro and Marin, 2006).

Moreover, approaches based on the use of densities of indicator species for monitoring impacts, while extremely valuable in local situations, rarely have good predictive power when applied at previously-unstudied sites because the particular indicator species may be patchily distributed (Karakassis et al., 2000). For broad-scale monitoring of impacts, multivariate information on ecological communities is best distilled into a practical form using univariate metrics. An ideal indicator should unambiguously discriminate organic impacts associated with fish farms from other impacts, and possess a conceptual underpinning.

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Response variables assessed as potential indicators of farm impacts in this study included five sediment and seven macrofaunal indicators (Table 1). These indicators are readily measured within monitoring programs and included the most important indicators of farm impacts identified by Edgar et al. (2005). In the case of routine environmental monitoring, impact indicators should be easy to apply. For this reason, and their comparatively recent development, promising but technically-demanding potential indicators based on porewater sulphides, acid volatile sulphides, porewater oxygen consumption, and ammonium release (Aguado-Giménez et al., 2007; Giles, 2008; Sanz-Lázaro and Marin, 2006) were not considered here. Isotopic ratios were not investigated because of cost when applied at regional scales, and a lack of good discriminatory power in an investigation of fish farm impacts in southeastern Tasmania (Edgar et al., 2005).

In Tasmania, government regulators require appropriate marine farm impact indicators for monitoring. Environmental regulations associated with fish farm operations stipulate “no unacceptable visual, chemical or biological impact on the benthos 35 m beyond the boundary of the marine farming lease area. Relevant environmental parameters must be monitored in the lease area, 35 m from the boundary of the marine farm lease area and at any control site(s)” (Crawford, 2003). To comply with these regulations, routine monitoring of the benthic environment using systematic methods was mandatory for all Tasmanian salmonid farms during the period 1997 to 2003 (Woods et al., 2004).

During the six-year period of systematic benthic monitoring, habitat condition at replicated sites (i) within farms, (ii) at compliance monitoring sites located 35 m from farm boundaries, and (iii) at more distant reference locations, was monitored by video and by sampling benthic invertebrates and sediments at 2-year intervals using cores and grabs. We here describe results from the invertebrate and sediment sampling component of this long-term program, which at the time arguably represented world's 'best-practice' for a government-mandated environmental monitoring scheme.

Since 2003, the scale of the Tasmanian finfish monitoring scheme has been greatly reduced (Woods et al., 2004). All new farms are still required to undertake a baseline survey; however, existing farms are now only required to undertake annual qualitative video surveys, and these are generally conducted by the marine farmers themselves. In the event that the video surveys reveals unacceptable visual impacts then licence conditions allow for quantitative physio-chemical and biological survey to be required.

In addition to a comparative assessment of useful indicators of fish farm impacts, the present study also aimed to characterise environmental impacts of fish farms on the benthic environment across a biogeographic 'provincial' scale using analyses based on time-series data and also a 'before–after control-impact' (BACI) statistical design

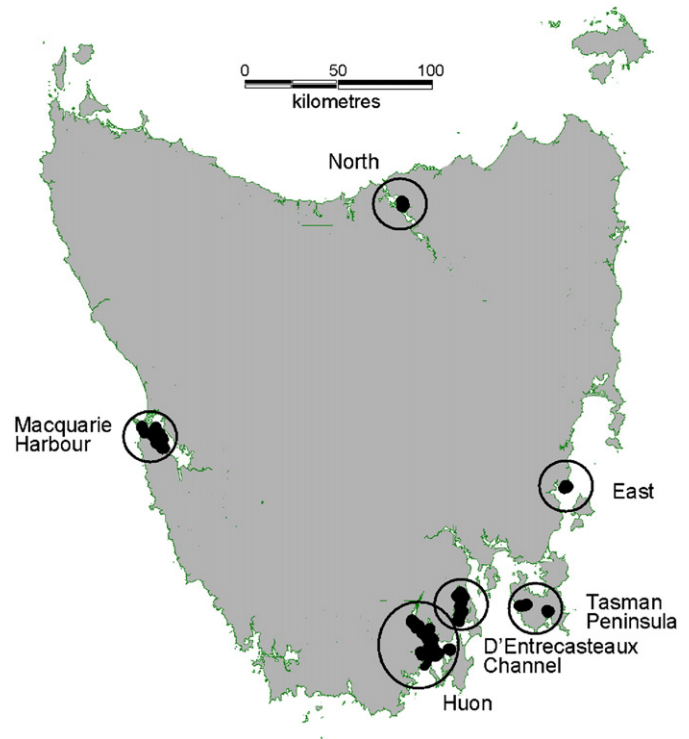


Fig. 1. Regions of Tasmania with salmonid fish farm leases.

(Green, 1979). The study greatly extended an earlier investigation of broad scale effects of salmonid aquaculture in southeastern Tasmania (Edgar et al., 2005) by encompassing all salmonid growing regions in the state and including investigation of changes through time. Analysis of systematically-collected monitoring data from 42 separate fish farm leases extending over > 1500 km coastline distance allowed indicators of fish farm impact with general relevance to be identified.

2. Materials and methods

2.1. Sampling protocols

Environmental and biological data were obtained in collaboration with, and in some cases by, salmonid farm operators at 42 separate farm lease locations distributed in five regions around Tasmania (Fig. 1). Regions considered were Tasman Peninsula, D'Entrecasteaux Channel and Huon Estuary (southeastern Tasmania), Tamar Estuary (northern Tasmania) and Macquarie Harbour (western Tasmania).

Table 1

Mean-square values (MS) and F-ratios resulting from two-way ANOVAs (fixed factor: farm effect, random factor: region) for 12 potential indicators of farming impacts: ***, $P < 0.001$; **, $0.001 < P < 0.01$; * $0.01 < P < 0.05$.

Indicators	Farm effect		Region		Farm effect x region		Error
	df = 2		df = 4		df = 8		df = 69
	MS	F	MS	F	MS	F	MS
Particle size	0.69	2.07	10.47	8.61***	0.33	0.27	1.21
Silt-clay	53	0.23	2741	4.95***	227	0.41	553
Redox 0 cm	32,000	14.65**	32,100	4.34***	2180	0.30	7400
Redox 4 cm	26,700	9.86**	41,100	14.85***	2700	0.98	2770
Organic matter	1.0	0.06	302.9	8.78***	17.5	0.51	34.6
Total species	155	1.91	1815	12.06***	82	0.54	151
Total abundance	45,300	3.42	201,000	12.51***	13,200	0.82	16,100
Dominance	0.022	2.00	0.033	1.50	0.011	0.51	0.022
Simpson's index	14.7	3.07	38.8	2.75*	4.8	0.34	14.1
Introduced species	20	0.71	1874	6.27***	29	0.10	299
Capitellids	479	2.83	344	4.39***	169	2.16*	78
Bivalves/molluscs	1279	5.11*	3103	8.36***	250	0.67	371

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