Fish Farms, Maerl & Sea Grass: Scientific Literature

N.B. at present this list contains only literature referring to the effects of fish farms on the coralline red alga Maerl (*Phymatolithon calcareum*) and of eutrophic pollution on Sea Grass (*Zostera marina*).

Birkett, D.A., C.A. Maggs & M.J. Dring (1998). Maerl (volume V). *An overview of dynamic and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science. (UK Marine SACs Project).[1]

> "The positioning of cages over a maerl biotope is likely to lead to fish faeces and partly consumed food pellets contaminating the maerl bed and resulting in anaerobiosis due to the oxygen demand of the decomposing material. The detrital rain from the cages could act in a similar way to terrigenous silt, reducing light penetration through the water column and smothering the maerl surface so that the stabilizing epiphytic algae could no longer establish themselves. As a minimum impact the increase in nutrient levels might produce local eutrophication effects."

Grall, J. & J.M. Hall-Spencer (2003). Problems facing maerl conservation in Brittany. *Aquatic Conservation: Marine & Freshwater Ecosystems*. 13: S55-S64.[2]

> "Other major impacts on local maerl bed habitats include the spread of the invasive gastropod Crepidula fornicata, industrial and urban sewage, aquaculture and demersal fishing. These impacts have increased sharply since the 1970s and are causing widespread damage to Breton maerl beds.
>
> "Such declines in one of the most diverse habitats of European waters (BIOMAERL, 1999) have not previously been reported and emphasize the urgent need for maerl bed conservation in France and Europe. The west coasts of Norway, Scotland and Ireland provide similar 'hot-spots' for maerl (Birkett et al., 1998; BIOMAERL, 1999) where active conservation policies are essential if the Breton experience is to be avoided."

Hall-Spencer, J., N. White, E. Gillespie, K. Gillham & A. Foggo (2006). Impact of fish farms on maerl beds in strongly tidal areas. Marine Ecology-Progress. 326: 1-9. Grall J, Hall-Spencer JM (2003). Problems facing maerl conservation in Brittany. *Aquatic Conservation: Marine Freshwater Ecosystems*. 13:55-64.[3]

> "Visible waste was noted up to 100 m from cage edges, and all 3 farms caused significant reductions in live maerl cover, upon which this habitat depends. Near-cage infaunal samples showed significant reductions in biodiversity, with small Crustacea (ostracods, isopods, tanaids and cumaceans) being particularly impoverished in the vicinity of cages, and significant increases in the abundance of species tolerant of organic enrichment (e.g. *Capitella* spp. complex, *Ophryotrocha hartmanni*). Relocation of fish farms to areas with strong currents is unlikely to prevent detrimental effects to the structure and organisation of the benthos, and 'fallowing' (whereby sites are left unstocked for a period of time to allow benthic recovery) is inadvisable where slow-growing biogenic habitats such as maerl are concerned, as this may expand the area impacted."

Haskoning UK Ltd. (2006). Investigation into the impact of marine fish farm depositions on maerl beds. *SNH/SEPA/Marine Harvest Commissioned Report No. 213.*[4]

> "All three fish farm sites had a significant build-up of feed and faeces trapped within maerl near the cages. Evidence of gross organic enrichment was recorded up to 100m away from the cage edges. The organic enrichment was found to affect a number of different aspects of the benthic community.
>
> "Deposition from the fish farms affected the percentage of maerl on the seabed that was live versus dead. All three sites had more dead/dying maerl near to the cages than at the reference sites and at stations distant from the cages. Live maerl close to cage edges had a mottled, unhealthy appearance due to phycobilin pigment loss.
>
> "Marked reductions in species diversity of infaunal communities associated with the maerl were recorded around the fish farms in Shetland and Orkney. Organic enrichment effects on community structure were also noted around the fish farms in Shetland and South Uist.
>
> "… maerl fragments are often transported in and out of areas of the seabed during storm events. Thus "impacted" maerl fragments close to a fish farm may be transported by waves to a nonimpacted area of seabed. The effect of this is essentially to increase the area of seabed affected by the fish farm."

---

[1] http://www.ukmarinesac.org.uk/pdfs/maerl.pdf

[2] http://www.ukmpas.org/pdf/Grall_Hall-Spencer_2003.pdf

[3] http://www.int-res.com/articles/feature/m326p001.pdf

[4] http://www.snh.org.uk/pdfs/publications/commissioned_reports/reportno213.pdf

Hall-Spencer, J. & R. Bamber (2007). Effects of salmon farming on benthic crustaceans. *Ciencias Marinas.* 33(4): 353-336.[5]

> "… this study confirmed that maerl habitats are highly susceptible to the effects of fish-farm deposition (possibly compounded by the effects of lice treatment toxicity), showing significant disturbances to the associated crustacean fauna. High organic loading results in the long-term loss of living maerl, upon which formation of the [maerl] habitat depends, and many species are intolerant of smothering by inorganic particulates."

Sanz-Lázaro, C., M.D. Belando, L. Marín-Guirao, F. Navarrete-Mier, A. Marín (2011). Relationship between sedimentation rates and benthic impact on Maërl beds derived from fish farming in the Mediterranean. *Marine Environmental Research.* 71(1): 22–30.[6]

> "This work shows that the level of fish farm impact on the benthic community might be underestimated if it is assessed by only taking into account data obtained from waste dispersion rates. The unattached coralline algae habitat studied [maerl] seems to be very sensitive to fish farming compared with other unvegetated benthic habitats."

The Scottish Government, Scotland's Marine Atlas, Inshore and Shelf Subtidal Sediments, **Priority Marine Features.**[7]

> "Maerl beds are extremely sensitive to physical disturbance and smothering, as a result of scallop dredging, bottom trawling, aquaculture and extraction as a fertiliser."

European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC).[8]

> "… evidence suggests that maerl continues to be under threat from damaging human activities, such as fisheries and fish farm operations. Eutrophication is also considered to be an important threat to maerl beds.
>
> "The positioning of [fish farm] cages over a maerl bed is likely to lead to fish faeces and partly consumed food pellets contaminating the maerl bed and resulting in anaerobiosis (due to the oxygen demand of the decomposing material). The detrital rain from cages could act in a similar way to terrigenous [land-derived] silt, reducing light penetration through the water column and smothering the maerl surface so that the stabilizing epiphytic algae could no longer establish themselves. As a minimum impact the increase in nutrient levels might produce local eutrophication effects. Indeed, Maggs and Guiry (1987a) noted that maerl below fish cages was covered with *Beggiatoa* sp., which had a detrimental impact on this habitat.
>
> "Hall-Spencer *et al*. (2006) have demonstrated the impacts of Scottish salmon fish farms on maerl and revealed significant reductions in live maerl cover. Indeed visible waste was noted up to 100 m from cage edges and near-cage infaunal samples showed significant reductions in biodiversity, with small Crustacea being particularly impoverished in the vicinity of the cages and significant increases in the abundance of species tolerant of organic enrichment. Maerl is particularly sensitive to hydrogen sulphide, as that generated by fish farm waste (Wilson *et al.* 2004)."

Greathead, G., E. Guirey & B. Rabe (2012). Development of a GIS Based Aquaculture Decision Support Tool (ADST) to Determine the Potential Benthic Impacts Associated with the Expansion of Salmon farming in Scottish Sea Lochs. *Scottish Marine and Freshwater Science* Vol 3 No 6.[9]

> "Within sea lochs there are varying proportions of Priority Marine Features (PMFs), such as Maerl beds that are particularly sensitive to sedimentation and organic enrichment (Hall-Spencer *et al.*, 2006)."

UK Marine SACs Project (2001)

> "Fish farms The positioning of cages over a maerl biotope is likely to lead to fish faeces and partly consumed food pellets contaminating the maerl bed and resulting in anaerobiosis due to the oxygen demand of the decomposing material. The detrital rain from the cages could act in a similar way to terrigenous silt, reducing light penetration through the water column and smothering the maerl surface so that the stabilizing epiphytic algae could no longer establish themselves. As a minimum impact the increase in nutrient levels might produce local eutrophication effects."[10]

---

[5] http://redalyc.uaemex.mx/src/inicio/ArtPdfRed.jsp?iCve=48033403

[6] http://www.researchgate.net/publication/47532981_Relationship_between_sedimentation_rates_and_benthic_impact_on_Marl_beds_derived_from_fish_farming_in_the_Mediterranean

[7] http://www.scotland.gov.uk/Publications/2011/03/16182005/48

[8] http://jncc.defra.gov.uk/pdf/Article17/FCS2007-S1377-audit-Final.pdf

[9] http://www.scotland.gov.uk/Resource/0040/00405906.pdf

[10] http://www.ukmarinesac.org.uk/communities/maerl/m6_1.htm

SOME POLLUTION EFFECTS ON SEA GRASS *Zostera marina* AND MACROALGAE WHICH MAY BE CONSIDERED IN CONNECTION WITH EFFLUENT FROM SALMON FISH FARMS

Cebrian, J., Corcoran, D. & Lartigue, J. (2014). Eutrophication-Driven Shifts in Primary Producers in Shallow Coastal Systems: Implications for System Functional Change. *Estuaries and Coasts*, 37:1 Supplement, 180-197.[11]

ABSTRACT **Significant progress has been made recently towards a better understanding of the nature, causes, and consequences of anthropogenic eutrophication of shallow coastal systems. It is well established that, in pristine systems dominated by seagrasses, incipient to moderate eutrophication often leads to the replacement of seagrasses by phytoplankton and loose macroalgal mats as the dominant producers.** However, less is known about the interactions between phytoplankton and loose macroalgae at intense eutrophication. **Using a combination of original research and literature data, we provide support for the hypothesis that substantial macroalgal decline may occur at intense eutrophication due to severe water column shading.** Our results suggest that such declines may be widespread. However, we also show that intense eutrophication is not always necessarily conducive to severe water column shading and large macroalgal declines, possibly due to short water residence time and/or elevated grazing on phytoplankton. Furthermore, **we provide support to the hypothesis that the occurrence of hypoxic/anoxic conditions in eutrophication-driven shifts in dominant primary producer assemblages influences the nature and extent of functional change in the system. Focusing on the macroalgal blooms and seagrass decline that often occur at incipient/moderate eutrophication, we show the blooms have a positive effect on epifaunal abundance under well-oxygenated conditions, but a negative effect if pervasive anoxic/hypoxic conditions develop with the bloom.** These findings provide support to prior suggestions that secondary productivity in shallow coastal systems may increase as seagrasses get replaced by loose macroalgal stands if the stands remain well oxygenated. In concert, our results contribute to an improvement of our current model of eutrophication of shallow coastal systems and suggest that further effort should be put on ascertaining the mechanisms that may prevent severe water column shading and large macroalgal decline at intense eutrophication, as well as thorough documentation of the impacts of anoxic/hypoxic conditions on system functionality at different stages of eutrophication.

Burkholder JoAnn M., Katherine M. Mason, Howard B. Glasgow, Jr. (1992). Water-column nitrate enrichment promotes decline of eelgrass *Zostera marina:* evidence from seasonal mesocosm experiments. *Marine Ecology Progress Series*, 81: 163-178.

“The present study indicates that, for eelgrass, nitrate should be regarded as more than a potential source of nutrient in N-limited coastal habitat, and as more than an indirect source of algal turbidity. Instead, **chronic exposure to nitrate-enriched waters is directly lethal to *Zostera marina* even at low enrichment levels, and likely represents an important causative agent in the disappearance of eelgrass meadows from many quiet embayments and coastal lagoons throughout the world.**”

Burkholder, JoAnn M., David A. Tomasko, Brant W. Touchette (2007). Seagrasses and eutrophication. *Journal of Experimental Marine Biology and Ecology* 350: 46–72.

“Indirect effects on trophic structure can also be critically important, for example, the loss of herbivores, through increased hypoxia/anoxia and other habitat shifts, that would have acted as “ecological engineers” in promoting seagrass survival by controlling algal overgrowth; and shifts favoring exotic grazers that out-compete seagrasses for space. **Evidence suggests that natural seagrass population shifts are disrupted, slowed or indefinitely blocked by cultural eutrophication, and there are relatively few known examples of seagrass meadow recovery following nutrient reductions.**”

Butcher, R. W. (1934). Report on the Present Condition of Eel Grass on the Coasts of England, based on a Survey during August to October, 1933. *Fisheries Research Station, Alresford, Hampshire*. 49-65.

QUESTIONS: Have *Zostera marina* populations recovered since 1933-4 and to what extent? Do we know the distribution of *Zostera marina* in the West Highlands before 1933 and how does that compare to distribution today?

Carstensen, Jacob, Daniel J. Conley, Jesper H. Andersen2 and Gunni Ærtebjerg (2006). Coastal eutrophication and trend reversal: A Danish case study. *American Society of Limnology and Oceanography*, 51(1, part 2): 398–408.

---

[11] http://link.springer.com/article/10.1007%2Fs12237-013-9689-x

Deegan, Linda A. (2002). Lessons Learned: The Effects of Nutrient Enrichment on the Support of Nekton by Seagrass and Salt Marsh Ecosystems. *Estuaries* 25 (4b): 727–742.

"**Nutrient enrichment may compromise the ability of these [seagrass] habitats to support fish and invertebrates before the habitat itself is gone**."

Deegan, Linda A., Amos Wright, Suzanne G. Ayvazian, John T. Finn, Heidi Golden, Rebeka Rand Merson & John Harrison (2002). Nitrogen loading alters seagrass ecosystem structure and support of higher trophic levels. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12: 193–212.

"Anthropogenic-derived nutrient inputs to coastal environments have increased dramatically worldwide in the latter half of the 20th century and are altering coastal ecosystems. We found that **a shift in primary producers from eelgrass to macroalgae in response to increased nutrient loading** alters habitat physical and chemical structure and food webs. **As nitrogen load increased we found increased macroalgal biomass, decreased eelgrass shoot density and biomass, decreased fish and decapod abundance and biomass, and decreased fish diversity**."

Frederiksen, Morten, Dorte Krause-Jensen, Marianne Holmer, Jens Sund Laursen (2004). Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. *Aquatic Botany* 78: 167–181.

"Thus, while deep-water **eelgrass populations have declined markedly over the last century in response to eutrophication**, long-term changes in shallow-water populations are less equivocal and seem more stochastic."

Hauxwell, Jennifer, Just Cebrian, Ivan Valiela (2006). Light dependence of Zostera marina annual growth dynamics in estuaries subject to different degrees of eutrophication. *Aquatic Botany*, 84: 17–25.

"We examined the coupling between eelgrass growth dynamics and surface irradiance over an annual cycle in four shallow estuaries of the Waquoit Bay system (MA, USA) that have similar physical characteristics, but are subject to different land-derived nitrogen loading rates and eutrophication. Contrary to our hypothesis, the **results show that most measures of eelgrass demographics were positively correlated with surface irradiance** in all four estuaries. Of the 45 regression models adjusted between irradiance and demographic variables (density, plastochrone intervals, and above- or belowground biomass, growth, and production, on both a per shoot and areal basis), only nine were non-significant, and only six of those corresponded to the eutrophic estuaries. There was a lack of correlation between shoot density and irradiance in the eutrophic estuaries, in contrast to the strong coupling in estuaries with the lowest nitrogen loads. Severe light limitation and other deleterious impacts imposed by macroalgal canopies on newly recruiting shoots in the eutrophic estuaries likely contributed to the lack of correlation between shoot density and irradiance at the water's surface. Because the range in eutrophication included the range of conditions at which eelgrass can survive, the relatively consistent temporal coupling between surface irradiance and most eelgrass demographic variables found here may also be a feature of other shallow temperate systems undergoing eutrophication, and indicates a measure of plant recruitment (density) to be one of the first parameters to become uncoupled from light reaching the water's surface."

Hauxwell, Jennifer, Just Cebrián1, Ivan Valiela (2003). Eelgrass *Zostera marina* loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. *Marine Ecology Progress Series*, 247: 59-73.

"In this paper, **we explicitly link changes in community structure of estuarine primary producers to measured nitrogen loading rates** from watersheds to estuaries, and quantify the relationship between nitrogen load, annual dynamics of algal growth and *Zostera marina* L. productivity, and **overall eelgrass decline** at the watershed-estuarine scale in estuaries of Waquoit Bay, Massachusetts, USA. Substantial eelgrass loss (80 to 96% of bed area lost in the last decade) was found at loads of ~30 kgN ha–1 yr–1, and total disappearance at loads ≥60 kg N ha–1 yr–1. Estimated total primary production by coastal assemblages in the Waquoit Bay system was 135% higher in estuaries receiving relatively high versus low loads of land-derived nitrogen, suggesting important trophic and biogeochemical alterations to temperate estuarine ecosystems as a result of eutrophication."

Havens KE, Hauxwell J, Tyler AC, Thomas S, McGlathery KJ, Cebrian J, Valiela I, Steinman AD, Hwang SJ. (2001). Complex interactions between autotrophs in shallow marine and freshwater ecosystems: implications for community responses to nutrient stress. *Environmental Pollution*, 113(1): 95-107.

"In Waquoit Bay, MA (estuary), controlled experiments documented that **blooms of macroalgae were responsible for the loss of eelgrass beds at nutrient-enriched locations**. Macroalgae covered eelgrass and reduced irradiance to the extent that the plants could not maintain net growth. In Hog Island Bay, VA (estuary), a dense lawn of macroalgae covered the bottom sediments. In Lake Brobo there also was evidence that phytoplankton growth was stimulated following a die-off of vascular plants. The case studies from Waquoit Bay and Lake Okeechobee support conceptual models of succession from vascular plants to benthic algae to phytoplankton along gradients of increasing nutrients and decreasing under-water irradiance.”

Howarth, Robert W. and Roxanne Marino (2006). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over three decades. *American Society of Limnology and Oceanography*, 51(1, part 2): 364–376.

“Over the past two decades, a strong consensus has evolved among the scientific community that N is the primary cause of eutrophication in many coastal ecosystems. Even though N is probably the major cause of eutrophication in most coastal systems in the temperate zone, optimal management of coastal eutrophication suggests controlling both N and P, in part because P can limit primary production in some systems.”

Lin, H. J., S. W. Nixon, D. I. Taylor, S. L. Granger, & B. A. Buckley (1995). Responses of epiphytes on eelgrass, *Zostera marina* L., to separate and combined nitrogen and phosphorus enrichment. *Aquatic Botany*, 52: 243–258.

Nielsen, S. L., K. Sand-Jensen, J. Borum, & O. Geertz-Hansen. (2002*a*). Depth colonization of eelgrass (*Zostera marina*) and macroalgae as determined by water transparency in Danish coastal waters. *Estuaries*, 25: 1025-1032.

Nielsen, S. L., K. Sand-Jensen, J. Borum, & O. Geertz-Hansen. (2002*b*). Phytoplankton, nutrients, and transparency in Danish coastal waters. *Estuaries*, 25: 930-937.