

Institution: University of the Highlands and Islands
Unit of Assessment: 7 - Earth Systems and Environmental Science
Title of case study: DEPOMOD & AutoDEPOMOD: Models changing aquaculture planning practices in Scotland and worldwide
1. Summary of the impact (indicative maximum 100 words) <p>DEPOMOD, and AutoDEPOMOD, are models, developed by Prof. Black's research team, which predict the impact of fish-farm discharges on the seabed in order to optimise the operation of aquaculture sites to match the environmental capacity. Since being adopted by the Scottish Environment Protection Agency, AutoDEPOMOD now forms a compulsory stage in the aquaculture planning consent process in Scotland, and has been used in the development of all presently operational salmon sites in Scotland. DEPOMOD and AutoDEPOMOD software have 122 licences in 25 countries worldwide.</p>
2. Underpinning research (indicative maximum 500 words) <p>Fish-farms discharge waste (fish faeces, food waste and chemical treatments) accumulates on the seabed causing organic enrichment which can lead to conditions toxic to marine life. The Scottish Environment Protection Agency (SEPA) monitors and regulates aquaculture discharges and specifies Environmental Quality Standards (EQS) for sea-floor sediments which are enforced for all aquaculture sites in Scotland.</p> <p>Predicting how discharge levels will impact seabed environmental quality in order to plan new, or for expansion to existing, aquaculture operations is difficult due to the complex site-specific predictive modelling required.</p> <p>For >20 years UHI researchers (Black, Nickell, Cromey) have studied the aquaculture - marine environment interaction, investigating aquaculture pollution, disease and parasite management and recovery processes in fish-farm sediments. In 1998, Prof. Black's research team began a 2 year project to model how fish-farm waste settles on the seabed. The project developed a model, named DEPOMOD, which took into account site specific conditions such as current speed, water depth, fish biomass and feed volume to predict discharge amount and deposition area. DEPOMOD was the first aquaculture discharge model which could be accurately adapted for individual sites. The project steering committee comprised SEPA and representatives from the aquaculture industry including the Scottish Salmon Growers Association (now SSPO). SEPA recognised the development of the model as a means to accurately predict effects on the seabed below fish-farms. In 2001 SEPA supported further development of the model by the research team to examine the discharge of sea-lice medicine from fish-farm sites in order to derive appropriate limiting license conditions for discharge.</p> <p>DEPOMOD has since been adapted to aquaculture practices in other parts of the world: from 1999-2003 the UHI research team led an EU consortium to develop MERAMOD for Mediterranean fish-farms to model the predicted deposition of particulate waste faeces and feed from sea bass and bream farms. Prof. Black (UHI) also led the development of TROPOMOD (2006-2008) to analyse the environmental impact of aquaculture in the Philippines. The model assesses the impact of milkfish and tilapia, the two most important fish cultured in the Philippines.</p> <p>DEPOMOD provided accurate prediction of fish-farm waste deposition and impact to the seabed, however the functionality of the model was limited as any changes to specific parameters meant all parameters had to be re-set. Since 2001 work has been on-going to enable the user to change individual parameters within a live model. This development, named AUTODEPOMOD, increased the use of the model to enable it to be used in optimising fish-farm capacity. AUTODEPOMOD allows individual parameters (such as biomass) to be changed until the modelled discharge level reaches the EQS set by SEPA, thereby advising the optimum fish farm capacity within</p>

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environmental limits.

In 2005 AUTODEPOMOD was adopted by SEPA as a compulsory step in the planning process for new and expanding aquaculture sites. Prof. Black and his team continue to work to improve the model and are currently integrating sulphur chemistry into AutoDEPOMOD and have been commissioned by the Scottish Government to re-parameterize and recode AutoDEPOMOD.

3. References to the research (indicative maximum of six references)

1. Cromey, C.J., **Black, K.D.**, Edwards, A. and Jack I.A. (1998) Modelling the deposition and biological effects of organic carbon from marine sewage discharges. *Estuarine Coastal and Shelf Science*, 47, 295-308 (IF 2.247, 5IF 2.622, 19 citations)
2. Cromey, C. J., **Nickell, T. D. & Black, K. D.** (2002). DEPOMOD - modelling the deposition and biological effects of waste solids from marine cage farms. *Aquaculture* 214, 211-239. (IF 2.041, 5IF 2.696, 111 citations)
3. Cromey, C. J., **Nickell, T. D., Black, K. D.**, Provost, P. G. & Griffiths, C. R. (2002). Validation of a fish farm waste resuspension model by use of a particulate tracer discharged from a point source in a coastal environment. *Estuaries* 25, 916-929 (IF 2.109, 35 citations)
4. Cromey, C.J., **Nickell, T.D.**, Treasurer, J., **Black, K.D.**, **Inall, M.**, (2009). Modelling the impact of cod (*Gadus morhua* L) farming in the marine environment-CODMOD. *Aquaculture* 289, 42-53. (IF 2.041, 5IF 2.696, 7 citations)
5. Dean, R. J., **Shimmiel, T. M. and Black, K. D.** (2007). Copper, zinc and cadmium in marine cage fish farm sediments: an extensive survey. *Environmental Pollution* 145, 84-95. (IF 3.746, 5IF 3.987, 30 citations)
6. Cromey, C.J., Thetmeyer, H., Lampadariou, N., **Black, K.D.**, Kögeler, J., Karakassis, I., (2012). MERAMOD - predicting the deposition and benthic impact of aquaculture in the Eastern Mediterranean. *Aquaculture Environment Interactions*. 2, 157-176 (IF 2.2 , 0 citations)

Key grant-funded projects:

- **DEPOMOD**, the original modelling project, supported also by SEPA and Marine Harvest: NERC LINK (1997), £127,647
- **Meramed** provided the opportunity to develop MERAMOD at Greek fish farms: EU FP5 (1999), £177,300
- **DEPOMOD** developed the model to predict medicine residues in sediments: SEPA (1999), £9,703
- **ECASA** tested the model at a range of European sites (www.ecasatoolbox.org.uk): EU FP6 (2004), £1,657,504
- **Depobiomass** developed a new front-end to allow iterative operation: AutoDEPOMOD: SEPA (2004), £12,268
- **Cod Environment** developed the model for application at cod farms: SEAFISH/CEC/HIE (2005), £178,909
- **Philmanaq** developed the model for operation in the Philippines: EU FP6 (2005), £92,478
- **Benthic recovery** added a diagenetic model based on sulphur cycling to predict seabed recovery: SARF (2007), £149,498
- **Large Sites** developed code to allow model-derived spatially varying currents at large sites: SSPO (2008), £88,015
- **Sulphides** extended the Benthic recovery project to further develop carbon diagenesis and predict sulphide concentrations in sediments: SARF (2012), £99,922
- **New AutoDEPOMOD** addresses perceived weaknesses in the model's resuspension processes and recodes the model in Java and ensures platform and third party software independence: Scottish Govt EFF (2012), £576,400

4. Details of the impact (indicative maximum 750 words)

Scottish aquaculture is a major industry with an estimated value of £584.7 million (2011). Scotland is also the largest producer of farmed salmon in the EU. Where adequate regulation is absent, aquaculture can have a detrimental environmental impact, affecting not only the marine environment but the overall sustainability and performance of a site. Discharges are a primary environmental concern when it comes to planning or expanding sites. Determining appropriate limits for discharges has been a difficult task for environmental regulators, because they lacked a reliable model to accurately predict the impact on the local ecosystem. In Scotland, SEPA are responsible for the monitoring and regulation of aquaculture sites, enforcing environmental quality standards for sea-floor sediment at all aquaculture sites.

Prior to the work of Prof. Black's team in the development of DEPOMOD, SEPA used a simple empirical matrix as the main planning tool for consent. This matrix could not optimize farms to their environmental surroundings, creating a 'trial and error' approach to finding the optimum farm size, leading many farms to close due to pollution problems^{4,5}. Research by Prof. Black's team (1998-2000) saw the development of DEPOMOD. As part of the original steering committee, SEPA realized this model could provide a means to apply scientific rigor to their aquaculture planning process and enable plans to be optimized to the site-specific conditions. SEPA supported the work of Black and his team to further develop and streamline DEPOMOD leading to the development in 2005 of AutoDEPOMOD^{4,5}. AutoDEPOMOD has the capability to automatically iterate towards a solution which will optimise productivity whilst remaining within Environmental Quality Standards.

In 2005 AutoDEPOMOD was adopted by SEPA as a compulsory stage in the planning process. Since 2005 (and continuing), any operator wanting to develop a new aquaculture site or expand an existing one must use AutoDEPOMOD to identify the sustainable size for a proposed farm^{4,5}. All presently operational salmon sites in Scotland have used AutoDEPOMOD, enabling site developers to accurately match farm size to the capacity of the environment providing the industry with a streamlined process to enable farm optimisation from the outset whilst ensuring environmental standards are maintained.

AutoDEPOMOD continues to be a compulsory stage in the aquaculture planning process and Prof. Black and his team continue to work with SEPA and aquaculture industry representatives, including the Scottish Salmon Company⁶ and Marine Harvest⁷ to update the model to support future industry developments. The research team have been awarded a grant of £576,400 from the Scottish Government (2012-2014) to recode AutoDEPOMOD and to improve the modelling of resuspension processes.

International Impact

- The DEPOMOD model developed by Black and his team has international presence within the aquaculture arena. At present, 122 DEPOMOD licence holders exist in 25 countries, 26 of which have been issued in the period 2008-2013, including 21 commercial licences and 5 non-commercial licences¹. In 2012 the Canadian Department of Fisheries and Oceans requested DEPOMOD to regulate the aquaculture industry and was used to predict benthic impacts at new and proposed Salmon farms in Southwestern New Brunswick (2009, 2012)⁸.
- Black led the development of DEPOMOD for specific regions including the Mediterranean (MERAMOD) and Philippines (TREPOMOD). At present, 25 licence holders of MERAMOD and TREPOMOD exist, 11 of which have been issued since 2008¹.

Additional Impacts

- The development of AutoDEPOMOD means that a greater level of confidence can be applied to measuring the sustainability of a fish-farm at any given site. In 2010 SEPA Aquaculture Specialist commented to NERC (funders of the original DEPOMOD project 1998-2000): "*The development of DEPOMOD and subsequently AutoDEPOMOD as tools to be used in the regulatory process has significantly improved the means by which SEPA*

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assesses the size of fish farm which can be sustained at any given site and has provided an increased level of scientific rigour in defining local environmental capacity^{2,5}.

- In recognition of his international reputation in aquaculture environment impact research and development of DEPOMOD, Prof. Black (UHI) became a member of the Scottish Government Working Group on Aquaculture⁸ as an expert in aquaculture environment impacts (2002-2013).
- AutoDEPOMOD has facilitated a positive impact to the natural environment by placing environmental health at the centre of aquaculture planning. Since AutoDEPOMOD has been implemented in Scottish aquaculture planning, farms have been re-scaled to match local environmental capacity and many former polluted sites are no longer used. Overall, Scottish aquaculture now has, and continues to have, a relatively lower seabed impact than pre-2005 due to better planning through AutoDEPOMOD^{4,5,6,7}.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. The Head of IT at SAMS, controls licence distribution for DEPOMOD and AutoDEPOMOD and provides support to licence holders. Steve can corroborate licence distribution figures and provide further details where possible.
2. In 2010, the Natural Environment Research Council (NERC) published an Impact Statement detailing the research and impact of DEPOMOD. This case study provides an overview of the scientific research, the funding inputs, research partners, industry collaborations and the resulting socio-economic impacts. The case study also provides comment from an Aquaculture Specialist at SEPA. <http://www.nerc.ac.uk/business/casestudies/documents/scottish-ing.pdf>
3. PHILMINAQ: mitigating impact from aquaculture in the Philippines. This project developed Depomod for the Philippines. Here is an independent account of that project: <http://www.gefcoral.org/LinkClick.aspx?fileticket=T79qyZpH-cs%3D&tabid=3260>
4. Head of Operations (North), SEPA – a key figure representing Scottish Government in terms of the Ministerial Working Group on Aquaculture and driving the SEPA approach to fish farm regulation.
5. Aquaculture Specialist, SEPA – the key fish farm regulator in Scotland who is intimately associated with the application and development of DEPOMOD to the Scottish fish farming industry.
6. Environmental Manager, Scottish Salmon Company – can provide insight into the direct impact that DEPOMOD makes on the business environment in the fish farming sector, from the point of view of a large enterprise.
7. Representative of Marine Harvest – This individual will be able to give an insight into the direct impact that DEPOMOD makes on the business environment in the fish farming sector from the point of view of a multi-national company, Scotland's largest fish farmer.
8. DEPOMOD is used by the Department for Fisheries and Oceans of Canada to regulate aquaculture activities in the region. Evidence of the use of DEPOMOD by the Canadian Authorities can be found: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ScRS/2012/2012_035-eng.pdf
9. More information about DEPOMOD and DEPOMOD projects can be found on the UHI webpages at <http://www.sams.ac.uk/kenny-black>