Institution: University of the Highlands and Islands

Unit of Assessment: 7 Earth Systems and Environmental Science

Title of case study:

Safeguarding human health and sustainable aquaculture through monitoring programmes developed from research into harmful algal bloom (HABs) dynamics

1. Summary of the impact (indicative maximum 100 words)

Harmful Algal Blooms (HABs) are a serious risk to human health and the sustainability of the aquaculture industry. Research by Prof. Davidson has improved understanding of temporal and spatial trends in marine HABs and detection of toxins in farmed shellfish. Knowledge gleaned from this research has been adopted by the Food Standards Agency (FSA) in the design of the HAB Monitoring Programme for Scotland. Prof. Davidson leads the FSA HAB Monitoring Programme. The research findings also underpin the Crown Estate's finfish monitoring programmes and are used to advise aquaculture businesses on ways to reduce economic impact of HAB events.

2. Underpinning research (indicative maximum 500 words)

Planktonic algae are microscopic aquatic organisms found in the water-column. Some marine algal species produce biotoxins which can cause damage to, and mass mortality in, fish and other organisms. Human ingestion of shellfish contaminated by algal biotoxins can cause poisoning which may be manifest in illnesses ranging from mild gastrointestinal problems to respiratory and neurological disorders or even death. Toxic algal populations can rapidly increase, forming large naturally occurring accumulations known as harmful algal blooms (HABs).

For >60 years UHI scientists have researched phytoplankton ecology (Drs Marshall & Orr, 1950s), growth theory (Dr Droop 1960s), and the relationship between harmful algal species and finfish mortalities in Scottish sea lochs (Drs Gowen, Jones and Tett).

Since 1998 UHI HAB research has been led by Prof. Davidson and is centred on understanding the environmental interaction of specific HAB species, including the influence of environmental conditions on HAB movement, toxicity levels and risk to the aquaculture industry, producing >60 peer-reviewed publications. This research may be divided into 2 categories:

1. Algae Harmful to Finfish

In 2006, Prof. Davidson's group tracked the movement of a large bloom of a HAB genus, deadly to finfish, called *Karenia*. Bloom movement was tracked from the waters of southwest Scotland, northeast to the Shetland Islands and the North Sea. These studies enabled determination of temporal and spatial trends in *Karenia* bloom movement in response to environmental conditions (including temperature, salinity & weather conditions)[1]. The research found that bloom events are influenced by local fluctuations in salinity[1]. In collaboration with Plymouth Marine Laboratory, remote sensing methods were developed to detect and track *Karenia* blooms[2].

2. Algae Harmful to human health

In 1999, 49,000km^2 of western Scottish waters were closed to shellfish harvesting due to the risk of Amnesic Shellfish Poisoning (ASP) caused by shellfish contaminated by the HAB species *Pseudo-nitzchia*. Prof. Davidson's team researched this closure and subsequent *Pseudo-nitzchia* bloom events, developing an understanding of the environmental factors influencing temporal and spatial trends in HAB movement and seasonal patterns in growth and toxicity such as temperature and nutrient cycles[3]. It was found that silica limitation, linked to seasonal fluctuations in nitrogen:silica ratios, promoted enhanced toxicity in *Pseudo-nitzchia*[3].

If ingested by humans, toxins from the HAB genus *Alexandrium*, can cause Paralytic Shellfish Poisoning (PSP). Prof. Davidson's studies of *Alexandrium* have revealed the co-occurrence of

highly toxic and non-toxic forms of the species *Alexandrium tamarense* which are morphologically identical, but molecularly distinct. The group have developed laboratory and field techniques to aid discrimination of toxic and non-toxic forms[4].

Prof. Davidson's group has discovered much about the influence of environmental conditions on HAB species biology and behaviour. This research led to further collaborative studies to evaluate the likelihood of factors such as climate change, anthropogenic nutrients and ballast water transfer causing the invasion of UK waters by new toxic phytoplankton species, or changing the abundance and toxicity of indigenous species[5,6]. This has allowed us to establish a temporal/spatial understanding of HAB risk that is used by the Food Standards Agency to underpin their shellfish safety policy.

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

1. **Davidson K**, Miller PI, **Wilding T,** Shutler J, Bresnan E, Kennington K, **Swan S** (2009) A large and prolonged bloom of *Karenia mikimotoi* in Scottish waters in 2006. Harmful Algae 8:349-361 (Journal Impact factor 4.3)
2. Shutler, JD, **Davidson K**, Miller PI, Swan SC, Grant MG, Bresnan E (2012) An adaptive approach to detect high biomass algal blooms from EO chlorophyll-*a* data in support of harmful algal bloom monitoring. Remote Sensing Letters 3: 101-110 (Journal impact factor: new)
3. Fehling J., **Davidson** K., Bolch C.J., Bates S.S. (2004) Growth and domoic acid production of *Pseudo-nitzschia seriata* (P.T. Cleve) H. Peragallo (Bacillariophyceae) under Phosphate and Silicate limitation. J. Phycology 40: 674-683 (Journal impact factor: 2.239)
4. Touzet N., **Davidson K.,** Pete R., Flanagan K., McCoy GR., Amzil Z., Maher M., Chapelle A. & Raine R (2010) Co-occurrence of the West European (Gr. III) and North American (Gr. I) ribotypes of *Alexandrium tamarense* (Dinophyceae) in Shetland, Scotland. Protist 161: 370-384 (Journal Impact factor 3.3)
5. **Davidson K,** Gowen R, **Tett P**, Bresnan E, Harrison PJ, McKinney A, Milligan S, Mills DK, Silke J, Crooks (2012). Harmful algal blooms: How strong is the evidence that nutrient ratios and forms influence their occurrence? Estuarine, Coastal and Shelf Science 115, 399-413. (Journal Impact factor: 2.6)
6. Gowen RJ, **Tett P**, Bresnan E, **Davidson K**, McKinney A, Milligan S, Mills DK, Silke J, Gordon A, Crooks AM (2012). Anthropogenic Nutrient Enrichment and Blooms of Harmful Micro-algae. Oceanography and Marine Biology: An annual review. 50: 65-126. (Journal Impact factor 8.5)

Key grants:

- Food Standards Agency: Research to support a monitoring programme for new or emerging biotoxins in shellfish in UK waters (2005-2012)
- EU FP7: Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms (€300K, 2009)
- NERC: The competitive dynamics of toxic and non-toxic ribotypes of the harmful dinoflagellate *Alexandrium tamarense* (£70K, 2009)
- EU Interreg: Warning of Algal Toxin Events to support Aquaculture in the NPP coastal zone Region "WATER" (€250K, 2009)
- DEFRA: Harmful algae, nuisance blooms and anthropogenic nutrient enrichment (£75K, 2008)
- Crown Estate: Analysis of the exceptional 2006 *Karenia mikimotoi* bloom in Scottish waters (£58K, 2007)

- EU interreg: Forecasting the INitiation of harmful ALgal blooms "FINAL" (€420K, 2006)

Evidence of quality of research:
The research of Prof. Davidson and his team has been cited >3800 times since 2008.

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

Harmful algal blooms (HABs) generate natural biotoxins that are harmful to humans who ingest shellfish that have concentrated the toxins in their flesh. Examples include paralytic shellfish poisoning (PSP) of which there are ~2000 recorded cases annually worldwide, with 15% mortality. HAB events can have a catastrophic effect on the sustainable development of the aquaculture industry worldwide due to economic loss resulting from regulatory closures of shellfish farms and farmed fish mortalities.

HAB research by Prof. Davidson's team underpins monitoring programmes and advice to the Crown Estate, Food Standards Agency (FSA), aquaculture businesses and industry bodies such as Seafood Shetland to ensure UK shellfish safety, human health and economically sustainable aquaculture[1].

Research by Prof. Davidson's team to track and study the 2006 *Kareina* bloom led to the development and implementation in 2008 of a monitoring programme to protect finfish aquaculture on the Scottish west coast. As blooms of this organism move around the coast, monitoring provides early warning to allow the industry to plan finfish husbandry operations and the routing of fish transport by well boat. Operating since 2008, the programme has been successful in providing early warning of elevated *Karenia* densities and hence preventing significant losses/costs to industry. This monitoring programme is on-going, commissioned by the Crown Estate and Scottish Salmon Producers Organisation. Prof. Davidson's team also developed, on behalf of the Crown Estate, a report which provides a series of recommendations on predicting the progression of *Karenia* along the Scottish coastline and the potential impact for fish farming[2]. Published in 2009, the report provides finfish aquaculture businesses with advice on how to reduce the impact of *Karenia* blooms through operational changes such as cessation of feeding and reduction in fishfarm husbandry during bloom events.

The FSA, the regulatory body responsible for monitoring food safety, monitor biotoxin producing phytoplankton for aquaculture safety. Prof. Davidson's research on understanding the ecology and environmental interaction of key shellfish poisoning causative genera (*Pseudo-nitzchia* and *Alexandrium*) has been used to inform FSA shellfish monitoring policy, and since 2005 Prof. Davidson has led the operation of the FSA Official Control Biotoxin Producing Phytoplankton Monitoring Programme[3,4,8]. This programme is on-going and in compliance with the EU shellfish hygiene directive that requires all shellfish harvesting countries to monitor the abundance of potential biotoxin producing phytoplankton to ensure shellfish safety and safeguard human health. Knowledge of the temporal and spatial trends of important harmful algal species gained from Prof. Davidson's research was used to developed a network of inshore representative monitoring points (RMPs) that are currently monitored on a weekly basis to give optimal country-wide spatial and temporal coverage of HAB events in shellfish harvesting areas. Weekly water samples from 36 monitoring sites are tested for a number of biotoxic phytoplankton. This data is reported against regulatory thresholds and used by the FSA to determine whether shellfish are safe to be marketed in the UK or abroad[3,4,8].

Additional Impacts:

- **Provision of advice to the aquaculture industry:** Since 2006 Prof. Davidson's team has worked closely with European aquaculture businesses, most notably Seafood Shetland[5], to develop and evaluate methods of HAB early warning and of detecting shellfish toxicity. This included the evaluation of commercially available, Enzyme-Linked Immunosorbent Assay (ELISA) kits for the determination of Diarrheic Shellfish Poisoning (DSP). This evaluation, as part of an EU consortium, recommended commercial use of DSP-ELISA to be replaced by a

protein phosphatase based method due to erroneously high toxin readings in the former method. Recommendations were presented at a project meeting in Shetland (2011) to aquaculture regulators and operators from Scotland, Norway, Ireland and Faroe Islands[5].

- **Informing standards:** Commissioned by the UK National Reference Laboratory (UKNRL) for Biotoxins, UHI in collaboration with the Agri-Food Biosciences Institute (AFBI) reviewed monitoring of the algae thought to produce azisporacid shellfish toxins. This review paper was presented to the UKNRL for Biotoxins and was used as a template for the regulatory monitoring of these organisms[6]. Prof. Davidson's team was subsequently commissioned by the FSA to develop a molecularly based method of identification and numeration of *Azadinium.* This method was completed in April 2013 and its implementation is currently being reviewed.

- **Advice to the International Council for the Exploration of the Sea (ICES):** ICES, an intergovernmental organisation, provides scientific advice to governments on the use and management of the marine environment. Since 2007 Prof. Davidson has been a member of the ICES Working Group on Harmful Algal Bloom Dynamics[7]. UHI hosted the 2012 annual ICES Working Group Meeting which reported fish-killing algal events in ICES regions[7]. This report is used by ICES to advise member states on HAB issues and management.

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

1. Details of UHI research activities relating to HABs and FSA monitoring Programmes can be found on the UHI website at http://www.UHI.ac.uk/keith-davidson/toxic-plankton-monitoring/?searchterm=FSA. Details of the Crown Estate funded project can be found at http://www.UHI.ac.uk/keith-davidson/karenia-mikimotoi-hab

2. The Crown Estate Report, authored by Prof. Davidson on predicting the progression of *Karenia* along the Scottish coastline and the potential impact for fish farming: http://www.thecrownestate.co.uk/media/211054/karenia.pdf

3. Food Standards Agency Official Control Biotoxin Monitoring Programme: UHI operate this monitoring programme on behalf of the FSA and developed the representative monitoring points for the programme. Up to date monitoring data is published on the web: http://www.food.gov.uk/business-industry/farmingfood/shellfish/algaltoxin/

4. Prof. Davidson's Report on behalf of the FSA on the Monitoring Programme for the Presence of Toxin Producing Plankton in Shellfish Production Areas in Scotland http://www.food.gov.uk/multimedia/pdfs/monitoring-planton-rep2011.pdf

5. Seafood Shetland is a Scottish Industry body which can provide corroboration of the use of outputs of Prof. Davidson's research and FSA Monitoring data by the shellfish industry to plan their harvesting activities and of the industry uptake of the recommendations related to the use of DSP ELISA.

6. The minutes of the UK National Reference Laboratory Meeting 21st July 2011 confirm that the *Azadinium* review paper produced by UHI & AFIB has led the Food Standards Agency to commission a research project to develop testing methods for *Azadinium* species. This development project is commissioned by the Food Standards Agency. Contact *Food Safety Monitoring and Policy, Food Standards Agency. Tel: 01224 285111*

7. International Council for the Exploration of the Sea, working group on Harmful Algal Bloom Dynamics Meeting Report: http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGHIE/2012/WGHABD12.pdf

8. The Food Standards Agency, Shellfish Monitoring and Policy Advisor can corroborate the contribution of the Prof. Davidson's research to regulatory monitoring and policy.