Institution: Edinburgh Napier University

Unit of Assessment: 7 - Earth Systems and Environmental Sciences

Title of case study: Defining and sustaining healthy seas

1. Summary of the impact

Managing and conserving the marine environment requires defining what constitutes healthy ecosystems and understanding the effects of pollution. Edinburgh Napier University (ENU) research defining 'undesirable disturbance' allowed the United Kingdom (UK) to mount a successful defence at the European Court of Justice in 2009 against alleged infraction of UK obligations under the Urban Waste Water Treatment Directive. This saved UK taxpayers £6 billion in estimated additional costs. The European Union (EU) Marine Strategy Framework Directive uses a definition of good status for pelagic habitats derived from work at ENU, which benefits policy makers and marine stakeholders by facilitating the establishment of Marine Protected Areas.

2. Underpinning research

ENU has a long history of applied marine research including the first UK Master's degree in the biology of water resource management (1979), and early work on pollution in the Forth. Three related questions underpin this work from these origins until today: 1) How do we know what conditions are 'natural' or 'healthy'? 2) How can we detect changes from a healthy state? 3) How can we predict the impacts of pollution and disturbance on marine systems? Answering these questions for phytoplankton communities was the main focus of the group led by Professor Paul Tett (ENU, 1996 – 2009, when the research underpinning this case was conducted). Using modelling, field sampling and laboratory approaches, the Tett group explored the relationships between nutrient inputs and phytoplankton growth. They explained seasonal cycles under natural conditions in Scotland (e.g. with J. Lee, ENU, 1996 – 2002)[3.4] and in Northern Ireland (with E. Capuzzo, 2005 – 2011 funded by the Loughs Agency), and under conditions of enhanced nutrient inputs (with V. Edwards, 1997 – 2001, co-supervised with the Scottish Environment Protection Agency; (SEPA))[3.5].

This work modelled the 'assimilative capacity' of water bodies. The concept of assimilative capacity informs policy on pollution control. It assumes that there are acceptable quantities of pollution that can be absorbed by natural environments. Exceeding these limits results in detectable impacts that should be avoided. For example, inputs of nutrients that exceed limits can lead to eutrophication. The core predictive model developed and refined by the Tett team (with the Scottish Association for Marine Science, (SAMS)) is known as the CSTT (after the 'Comprehensive Studies Task Team' established by the UK Government). This predicts plankton biomass given nutrient and light conditions. Model predictions were validated, by ENU, SAMS and others, against observations from the Mediterranean to the Arctic in the European project OAERRE[3.3], and in Loch Creran by ENU-SAMS PhD student C. Laurent [3.2].

Applying biological understanding to policy required clear definitions of terms. The Urban Waste Water Treatment Directive (EEC 1991) gives the following definition of eutrophication: "The enrichment of waters by nutrients… causing an accelerated growth of algae… to produce an *undesirable disturbance* to the balance of organisms present in the water". Hence defining 'undesirable disturbance' is of crucial importance in applying this directive. Work led by Prof. Tett, funded by the UK Government (Department for Environment, Food and Rural Affairs; DEFRA) and with other permanent ENU staff (Mark Huxham, 1995 – present, Teresa Fernandes, 1994 – 2012 and Linda Gilpin, 1996 – present), and colleagues from SAMS, the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Hull University and elsewhere, produced a working definition of this term that has since been used by policy makers[3.1].

The latest developments in using phytoplankton science to inform policy have come from the Tett team's invention of the Phytoplankton Community Index (PCI). Work on *undesirable disturbance*

showed how biomass alone was an insufficient indicator: the balance of types of organisms is also crucial. The PCI applies life form theory to phytoplankton modelling which allows an understanding of when ecosystems are moving towards less desirable states, without the burdensome requirement to identify all taxa to species level.

3. References to the research

Selected peer reviewed papers:

3.1 Tett, P., R. Gowen, D. Mills, T. Fernandes, L. Gilpin, M. Huxham, K. Kennington, P. Read, M. Service, M. Wilkinson and S. Malcolm (2007) Defining and detecting Undesirable Disturbance in the context of Eutrophication. *Marine Pollution Bulletin* 55, 282-297.

3.2 Laurent, C., P. Tett, T. Fernandes, L. Gilpin and K. J. Jones (2006) A dynamic CSTT model for the effects of added nutrients in Loch Creran, a shallow fjord. *Journal of Marine Systems* 61, 149-164.

3.3 Tett, P., L. Gilpin, H. Svendsen, C. P. Erlandsson, U. Larsson, S. Kratzer, E. Fouilland, C. Janzen, J.-Y. Lee, C. Grenz, A. Newton, J. G. Ferreira, T. Fernandes and S. Scory (2003) Eutrophication and some European waters of restricted exchange. *Continental Shelf Research* 23, 1635-1671.

3.4 Lee, J.-Y., P. Tett and K.-R. Kim (2003) Parameterising a Microplankton Model. *Journal of the Korean Society of Oceanography* 38, 185-210.

3.5 Edwards, V. R., P. Tett and K. J. Jones (2003) Changes in the yield of chlorophyll a from dissolved available inorganic nitrogen after an enrichment event - applications for predicting eutrophication in coastal waters. *Continental Shelf Research* 23, 1771-1785.

3.6 Gowen, R.J., P. Tett, K. Kennington, D.K. Mills, T.M. Shammon, B.M. Stewart, N. Greenwood, C. Flanagan, M. Devlin and A. Wither (2008) The Irish Sea: is it eutrophic? *Estuarine, Coastal and Shelf Science* 76, 239-254.

Key grants related to research covered in this case study:

S.N.I.F.F.E.R. `Yield of marine phytoplankton chlorophyll from dissolved inorganic nitrogen under eutrophic conditions' ($35579 for 3 years from October 1997, a research studentship jointly supervised by P. Tett, K. Jones (Natural Environment Research Council Dunstaffnage Marine Laboratory) and R. Park (SEPA).

DEFRA `Understanding of Undesirable Disturbance in the context of eutrophication, and development of UK assessment methodology for coastal and marine waters' (£45,992 in 2004, to a consortium led by ENU: other members were, Heriot-Watt University, Liverpool University, CEFAS, and the Department of Agriculture and Rural Development).

DEFRA /CEFAS: `Research supporting the development of eutrophication monitoring and assessment' (CEFAS contract leader was Dr D. Mills, Subcontract ME2202 from CEFAS to ENU for £57,818, September 2004 to February 2007; extended into 2009, and used as a vehicle for providing advice to DEFRA in relation to the 'Scientific analysis and contributions to UK evidence and arguments concerning eutrophic status of estuaries and coastal waters in UWWTD case 1998/2265'.

DEFRA/CEFAS: `Development of a phytoplankton trophic index'. (CEFAS, CSA 6754 contract leader was Dr D. Mills; subcontract ME2204 to ENU for £35,700, December 2004 to March 2006).

4. Details of the impact

The most significant impact arising from this work was the role it played in determining UK policy in response to the Urban Waste Water Treatment Directive (UWWTD). Specifically, the work led by Professor Tett saved the UK approximately £6 billion (as estimated by the Environment Agency) with UK taxpayers as the ultimate beneficiaries.

The UWWTD governs how member states should treat sewage discharges into coastal waters. It requires the application of tertiary treatment to remove nutrients when discharges occur into

eutrophic waters. In 1999, the European Commission (EC) accused the UK of infracting the UWWTD by failing to identify certain coastal waters in England and Wales as eutrophic, and the case came before the European Court of Justice (ECJ) in 2007. Defending the case involved empirical work on the relationships between nutrients and algal growth and conceptual clarity around what was meant by the key term *undesirable disturbance* taken from the UWWTD definition of eutrophication.

In anticipation of this case, in 2004, DEFRA commissioned a review of 'undesirable disturbance in the context of eutrophication' from a group led by Tett. The group (see Tett *et al*., 2007)[3.1] concluded that '*an undesirable disturbance is a perturbation of a marine ecosystem that appreciably degrades the health or threatens the sustainable human use of that ecosystem'*, and proposed methods for detecting such disturbance. The methods were applied by a team including Tett and colleagues from SAMS, CEFAS, the Agri-Food and Biosciences Institute, and elsewhere, to show lack of undesirable disturbance in the Irish Sea, one of the contested areas (Gowen *et al*., 2008)[3.6].

During the defence, the UK was able to cite the undesirable disturbance work and the arguments were accepted by the Court (e.g. para. 330, 332 - they refer to the paper as the Gowen report 2007)[5.1,5.2]. In addition, evidence from Tett and Gowen on the biology of phytoplankton growth was presented orally to court in April 2009. This drew on the CSTT work and demonstrated that most UK coastal waters were light limited because of turbidity, which was crucial in winning the case[5.1]. In December 2009, it was announced that the UK had won the relevant part of its case (ECJ, 2009), thus avoiding fines, and the necessity for very expensive tertiary sewage treatment plants. The work has influenced other areas of UK response to EU legislation, for example the EU's Marine Strategy Framework Directive (adopted in June 2008). This aims to protect the marine environment across Europe by achieving 'good environmental status' of the EU's marine waters by 2020, and to protect the resource base upon which marine-related economic and social activities depend. As in the case of the UWWTD, implementing the legislation requires conceptual clarity about key terms and the scientific tools and procedures to measure the relevant variables. In particular, it requires that the commission should lay down criteria and methodological standards to allow consistency of approach in evaluating the extent to which Good Environmental Status (GES) is being achieved. The Commission established Task Groups of experts to achieve this for each of the descriptors in the directive. Task group 5 reported on eutrophication in 2010[5.3]. It included Tett as one of the expert authors, and drew on the work on undesirable disturbance and the plankton community index to establish standards that will be used in implementing the directive across the EU, thus helping to maintain and enhance the health of the marine environment within the EU.

Impacts of the work in defining assimilative capacity and undesirable disturbance included policy on aquaculture, in particular on the siting of finfish and shellfish farms[5.4]. Tett and Fernandes were authors on the Huntington *et al*. 2006 report to the Directorate-General for Fish and Maritime Affairs of the EC on 'Some Aspects of the Environmental Impact of Aquaculture in Sensitive Areas'. This has been used by the EC to inform policy on aquaculture. It has also informed the application of the Marine Stewardship Council (MSC) sustainable fisheries certification in Scottish waters. For example, the Shetland and Scottish Mainland Rope Grown mussel Enhanced fishery was certified by the MSC in April 2012, using Huntington *et al.* 2006 to support their 'principle 2 – ecosystem sustainability'[5.5]. This industry is growing rapidly, with more than 7,000 tonnes produced in 2010. Its further growth will be supported by the MSC accreditation.

Hence, the ENU work on healthy seas has established a strong tradition of interpreting fundamental ecological concepts, such as ecosystem health, and facilitating their application by policy makers in settings from pollution control to ecosystem restoration.

5. Sources to corroborate the impact

[5.1]Corroboration from key individual: Science Leader at CEFAS. This person can corroborate the impacts of the UWWTD related work.

[5.2]ECJ (2009). Commission of the European Communities v United Kingdom supported by Portuguese Republic. Judgement of the European Court of Justice (3rd chamber) on 10 December 2009, In Case C-390/07, under Article 226 EC for failure to fulfil obligations, pursuant to Articles 3(1) and (2) and 5(1) to (3) and (5) of, and Annex II to, Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment (OJ 1991 L 135, p. 40).

A link to this judgement from the European court – note paragraphs 330 and 332 as examples of references to the work described here:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:62007CJ0390:EN:NOT.

[5.3]Report of the Marine Strategy Framework Directive task group 5 on eutrophication, with Tett as an expert author:
http://ec.europa.eu/environment/marine/pdf/5-Task-Group-5.pdf.

[5.4]Programme manager for Marine Spatial Planning with Marine Science Scotland. This individual can corroborate the importance of the aquaculture impacts and siting work.

[5.5]For evidence of the use of assimilative capacity in aquaculture see, e.g. p 94 from the Marine Stewardship Council accreditation documents:

http://www.msc.org/track-a-fishery/fisheries-in-the-program/certified/north-east-atlantic/shetland_and_scottish_mainland_rope_grown_mussel_enhanced_fishery/assessment-downloads-1/20120503_FR.pdf.

Institution: Edinburgh Napier University

Unit of Assessment: 7 - Earth Systems and Environmental Sciences

Title of case study: New Paths to Mangrove Conservation

1. Summary of the impact

The Mikoko Pamoja project uses carbon credits for conservation and development in Africa. It is one outcome of Edinburgh Napier University's (ENU) work on mangrove ecology which has local, national and international impacts. With public and private support, the project has recruited >140 international volunteers, trained 46 African scientists, and funded development including schools and pumps. It is pioneering community control of mangroves using new legal instruments and informing the national management plan. A regional forum founded by the team facilitates international networking. The work has been highlighted by the United Kingdom (UK) Department for International Development as good practice and has generated ACES (Association for Coastal Ecosystem Services), a new charity.

2. Underpinning research

Mangrove ecosystems provide vital services at local, regional and global scales, including nursery grounds for fish, protection of coastlines from erosion and storm damage, filtration of sediments and pollutants and carbon sequestration. Despite this high value they are being rapidly destroyed, at rates exceeding those for terrestrial tropical forest, through coastal development, aquaculture and logging. This case study describes novel research (from 2002-2013) on mangroves and application of this new understanding in practical ways to conserve them. Initial research led by Professor Mark Huxham (ENU, 1995-2013), including PhD students and research assistants at ENU, demonstrated juvenile fish use of Kenyan mangroves using natural chemical tracers retained in adult fish[3.6]. This helped make the case for the importance of mangroves as nursery sites. Research then explored the processes of ecosystem recovery, driven by the need to restore large areas devastated by industrial wood extraction some 30 years previously. Two Kenyan and one Sri Lankan PhD students, registered at ENU, as well as scientists from Kenya (specifically, Dr James Kairo of the Kenya Marine and Fisheries Research Institute), Sri Lanka (Professor Loku Jayatissa) and the UK (especially Dr Martin Skov, Bangor University and Professor Maurizio Mencuccini, Edinburgh University) were heavily involved in this work, which has been supported throughout by the Non-Governmental Organisation (NGO), Earthwatch Institute. Large scale experiments (planting 5872 trees) revealed the key physical and chemical constraints preventing natural regeneration (increased wave impact and salinization), and determined the nursery techniques and target species to be used in active restoration[3.3, 3.4]. In addition to these practical applications, ENU work addressed questions of fundamental interest to ecosystem science, including the role of species richness in ecosystem functions and of positive facilitation in plant growth in harsh environments[3.1]. We demonstrated for the first time how higher species richness and higher density can contribute to survival and ecosystem restoration in mangroves, and how altering planting strategies affects the forests' ability to keep up with sea-level rise by raising the level of their substrates[3.5].

Mangrove forests are amongst the most efficient natural carbon sinks and are of global importance as carbon stores. One strand of ENU work has focused on quantifying carbon flows in the forests, for example by looking at rates of decomposition of below-ground carbon, and at the impacts of cutting trees on greenhouse gas fluxes. We have translated this field scale knowledge to national scale information by using remote sensing to quantify rates of forest loss and areas of high future risk of deforestation in Kenya (work conducted between 2009-2012 with Dr Rob Briers, ENU, 2003-2013)[3.2, 3.4]. We have quantified the stocks and flows of above and below-ground carbon at our field site and elsewhere, in order to allow valuations of this ecosystem service on the voluntary carbon market. In addition, socio-economic and policy research, collaborating with social scientists in Kenya and elsewhere has assessed the use and market values of different mangrove ecosystem goods and services and the policy options available for conserving mangroves through payments

for ecosystem services.

3. References to the research (ENU researchers are in **bold**)

3.1 **Huxham, M., Kumara, M.P**., Jayatissa, L.P., Krauss, K.W., Kairo, J., **Langat, J**., Mencuccini, M., Skov M.W. and **Kirui B**. (2010) Intra and inter-specific facilitation in mangroves may increase resilience to climate change threats. *Philosophical Transactions of the Royal Society* 365, 2127-2135. DOI: 10.1098/rstb.2010.0094. ***This paper was part of a prestigious special edition on biological interactions with climate change.***
3.2 **Kirui, K.B**., Kairo, J.G., Bosire, J., Viergever, K., **Rudra, S**., **Huxham, M**. and **Briers, R.A**. (2012) Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. *Ocean and Coastal Management*, DOI:10.1016/j.ocecoaman.2011.12.004.
3.3 **Kirui B.,** Skov M.W., Kairo, J., Mencuccini, M. and **Huxham, M**. (2012) Effects of species richness, identity and environmental variables on growth in planted mangroves. *Marine Ecology Progress Series* 465, 1-10. DOI: 10.3354/meps09999. ***This paper was selected as the open access 'special featured paper' of this edition.***
3.4 **Rideout, A**., Joshi, N., Viergever, K., **Huxham, M**. and **Briers, R.A**. (2013) Making predictions of mangrove deforestation: a comparison of two methods in Kenya. *Global Change Biology*. DOI: 10.1111/gcb.12176.
3.5 **Kumara, M.P.,** Jayatissa, L.P., Krauss, K.W., Phillips, D.H. and **Huxham, M.** (2010) High mangrove density enhances surface accretion, surface elevation change, and tree survival in coastal areas susceptible to sea-level rise. *Oecologia* 164:545-553. DOI: 10.1007/s00442-010-1705-2. ***This paper was covered in the ecological press and showed how high density mangrove forests can raise the level of their substrates.***
3.6 **Huxham, M.,** Kimani, E., Newton, J. and **Augley, J.** (2007) Stable isotope records from otoliths as tracers of fish migration in a mangrove system. *Journal of Fish Biology* 70, 1554-1567. DOI: 10.1111/j.1095-8649.2007.01443.x.

Selected grants (all peer reviewed by Research Council or similar processes):

- Natural Environment Research Council (NERC)/Department for International Development (DfID)/Economic and Social Research Council (ESRC) (the Ecosystems Services and Poverty Alleviation, ESPA, programme). 2010-2012. Swahili seas. £ 249,855 (awarded to M. Huxham)
- NERC/DfID/ESRC (the ESPA programme). 2009 -2010. Capacity building for mangrove assessment, restoration and valuation. £105,612 (awarded to M. Huxham)
- Climate and Development Knowledge Network (DfID). 2012 - 2014. iCoast. £449,100 (awarded to M. Huxham)
- NERC 2008-2010. The mangrove carbon cycle – understanding below-ground processes and managed cutting. £ 48,891 (awarded to M. Huxham).

4. Details of the impact

Our work has had local (environmental and social improvements), national (policy development and implementation) and international (formation of regional and international practitioner networks) impacts; has informed policy makers and has raised awareness and understanding among the general public in Kenya and the UK.

Coastal communities in Kenya suffer from chronic poverty. They rely heavily on natural resources, particularly fish, and are vulnerable to environmental degradation. The 3,000 people living in the Gazi Bay area of Kenya benefit directly from Mikoko Pamoja, a project designed by the Huxham team (from 2008-2013), based on the research described in section 2, that uses carbon credits to fund forest conservation and community development. Mikoko Pamoja is accredited by the charity Plan Vivo and is managed by a committee of local stakeholders (advised by international experts). Our work was the first to develop a technical specification for the accreditation of mangrove carbon (2011) (using site-specific work described in section 2). It is designed to act as a template for future projects; and has been showcased by the Kenyan government[5.1]. Impacts at other sites in East Africa are facilitated through our networking body, the East African Forum for Payments for

Ecosystem Services (EAFPES) [5.2] and our charity, the Association for Coastal Ecosystem Services. The work has funded development including a new school building (benefitting 600 children), new water pumps (supplying 50 households) and the sponsorship, through primary, secondary and tertiary education, of dozens of local children.

We worked with Government in pioneering new uses for legal instruments for community based conservation. With the Kenya Forest Service (KFS) and the Kenya Marine and Fisheries Research Institute we developed a Community Forest Association (CFA; established 2012), the first for a mangrove forest. Our work contributes to the national plan for the United Nations' Reduced Emissions from Forest Degradation and Deforestation (REDD) programme (it is supported by KFS as a demonstration site for this), the production of a national mangrove management plan, and the identification of areas of high forest quality and high risk. Data from ENU work[3.2] were requested by the Kenyan Government.

In 2009, we established EAFPES for regional and Africa-wide networking on payments for ecosystem services (PES) projects to help with co-ordination of coastal PES projects (particularly those involving 'blue carbon' stored in marine ecosystems). EAFPES is supported by the UK Government Ecosystem Services for Poverty Alleviation (ESPA) programme and WWF Kenya. It has run workshops aimed at East African managers and stakeholders, drawing on the work described in section 2, and showcasing the 'our ecosystem' on-line tool that allows managers to assess the value of, and threats, to their mangrove resource[5.3]. It provides a virtual source of information and networking informed by our research and experience. ACES (charity no. SC043978), established in May 2013, facilitates the flow of funds from international donors, corporations and individuals for coastal development and conservation in Africa.

We were invited to the All Party Parliamentary Group on International Development in February 2012[5.4], receiving a special commendation from Stephen O'Brien MP, Minister for International Development, who wrote: 'I found the Making an Impact series informative, especially noting the innovative engagement with Aviva in the Kenya mangrove project'.

We presented a keynote at the Aquatic Resources of Kenya 2010 national conference attended by the Minister for the Environment, which led to a request for data to inform the national mangrove plan. We organised a special session on REDD readiness, carbon credits and mangroves at the West Indian Ocean Marine Science Association October 2011 conference, attracting 55 delegates including regional decision-makers and NGOs.

We have had coverage in the Kenyan and UK press (e.g. BBC 2010[5.5]), using this to inform and educate but also to help recruit volunteers and raise charitable funding. We collaborated with the ASCUS science and art fund to produce a video drawing on our work on Kenyan experiences and perspectives on climate change seen by more than 300 people, in Edinburgh, in February 2012.

Practical conservation outcomes over the past decade (2004-2013) have included the planting of more than 10,000 mangrove trees and the restoration of ~20 ha of degraded land[5.6, 5.7]. Hundreds of Kenyan school children have visited our site, and > 40 developing country researchers have worked with us. Kenyan scientists, trained to Masters and PhD level through our project, with funding from charities and businesses (Aviva Ltd and Zurich International), have progressed to Kenyan Government and academic positions, vindicating our strategy to strengthen capacity for mangrove conservation and management within Kenya.

5. Sources to corroborate the impact

[5.1] Film produced by the Kenyan Ministry of Environment and Mineral Resources showcasing our work and the Mikoko Pamoja project; our project is featured from 8.05 minutes onwards: http://www.youtube.com/watch?v=xgI_XY37c5E&feature=em-share_video_user.

[5.2] For the East African Forum for Payments for Ecosystem Services, including documents proving legal confirmation of local groups and management plans: http://www.eafpes.org/.

5.3 For the on-line tool for local managers in Kenya to assess the carbon contents and risk status of their mangrove forests: http://icoast.ourecosystem.com/interface/ (to operate this application requires a login that can be provided on request).
5.4 For All Party Parliamentary Group on International Development and the Environment, go to: http://www.appgide.org/meetings and scroll down the page to "Previous meetings". See also: http://www.appgide.org/sites/appg.iiedlist.org/files/pdf/ESPA-APPG-James-Kairo.pdf.
5.5 For an example of journalism/press coverage see BBC: http://news.bbc.co.uk/1/hi/sci/tech/8893767.stm.
5.6 For work with the international NGO Earthwatch Institute, including details of education and the site: http://www.earthwatch.org/exped/huxham.html.
5.7 For an overview of some of the impacts described by ESPA, a key UK government supporter that uses this project as a case study, see: http://www.espa.ac.uk/projects/ne-i003401-1.

Corroborating Organisations: contact information for relevant individuals within the following organisations provided separately.

- Associate Director, Kenya Marine and Fisheries Research Institute – to corroborate all claims about policy and local impacts in Kenya, and importance of the research to Kenyan national policy.
- Associate Director, Earthwatch Institute – to corroborate long-term commitment to local site and people, educational impacts and outreach, and communication impacts.
- Director, Ecosystem Services for Poverty Alleviation Programme – to corroborate work with UK policy makers, corporations and funders.