Institution: Newcastle University

Unit of Assessment: UoA 7: Earth Systems and Environmental Sciences

Title of case study: Cost-effective restoration strategies for at risk / damaged coral reefs

1. Summary of the impact

Newcastle University research has made significant contributions to international best practice guidelines used to restore coral reefs. Coral reefs are the most biologically diverse eco-systems on earth, directly and indirectly providing an estimated $375 billion per year in ecosystem services. Despite their importance, very little work had been undertaken to assess the strategies used to rehabilitate damaged reefs prior to the Newcastle research. Research findings have subsequently been incorporated into international best practice guidelines which are used by a diverse group of users including reef managers who use them to plan more ecologically robust reefs and maritime insurers who use them to assess insurance claims related to reef damage by grounded ships.

2. Underpinning research

Newcastle Researchers *Prof Alasdair Edwards* (*Senior lecturer, 1990 – 2010; Professor of Coral Reef Ecology, 2010 – present*) *Dr Susan Clark* (*Senior Research Assistant, 1998 – 2001*) and *Dr James Guest* (*Research Assistant, 2005* – 2008) studied reef rehabilitation in the Maldives and the Philippines actively between 1993 and 2008. This body of work led to a number of influential papers [**P1**, **P3** - **P6**] which were incorporated directly into reef restoration guidelines, manuals and advisory papers which are used extensively by practitioners and policy makers.

The key research insight from Newcastle work in the Maldives was that coral communities are resilient when not under anthropogenic stress [**P4**, **P6**]. Provided that a stable substrate is available they are able to recover quickly (typically within a decade) from disturbance without active restoration interventions such as coral transplantation. Previously reef managers had emphasised transplantation as essential to the recovery strategy. Newcastle's research showed that this strategy was often not cost-effective and sometimes did more harm than good [**P1**]. The research also showed that the current practice of transplanting weed-like fast-growing branching coral species which grew readily to bare artificial substrates within months of deployment [**P6**] were very susceptible to climate change related bleaching events [**P3**]. They showed that if active restoration was adopted, then more attention should be devoted to transplanting slow-growing, slowly recruiting massive coral species that survive bleaching, disease and transplantation significantly better than faster-growing branching species.

Subsequent research in the Philippines (2005-2008) focused on an area which had seen significant human disturbance (through overfishing) where there had been negligible natural recovery from a mass-bleaching in 1998 and which therefore warranted active interventions to accelerate recovery. Thus, in the face of climate change [**P2**, **P3**] there had to be effective management of local human impacts so that natural recovery processes could occur. The Newcastle research bridged knowledge gaps in active restoration; primarily how to reduce collateral damage to healthy reefs from transplantation using asexual and sexual rearing technologies [**P5**]. Following the development and testing of these new technologies, results were disseminated and then used by Non-Governmental Organisations (NGOs) and local governments.

Newcastle's research was the first to contest active restoration techniques as a panacea for coral reef conservation and instead stress their use as a last resort. The research into the efficacy of coral transplantation [**P1**, **P4**] and rearing of corals from egg to adult [**P5**], coupled with the lessons learned during bleaching events [**P3**] directly resulted to changes in the way reef restoration was being carried out. Collectively these insights underpinned *Reef Restoration Concepts & Guidelines: making sensible management choices in the face of uncertainty* (Edwards, & Gomez 2007), the *Reef Rehabilitation Manual* (Edwards 2010) and the *Reef Restoration & Rehabilitation* (*World Bank Coral Reef Targeted Research program*, CRTR 009/2010) advisory paper. These have influenced the practices of NGOs, coastal managers, the maritime insurance industry and decision makers at

a local and national governmental level.

3. References to the research

[**P1**] ***Edwards, A.J. and Clark, S.** (1998). Coral transplantation: a useful management tool or misguided meddling? *Marine Pollution Bulletin* 37: 474-487. doi:6/S0025-326X(99)00145-9 (Impact factor: 2.503; 52 Scopus citations; stimulated debate on efficacy of active interventions in coral reef restoration)

[**P2**] *Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, D.R., Sale, P.F., **Edwards, A.J.,** Caldeira, K., Knowlton, N. Eakin, C.M., Iglesias-Prieto, R., Muthinga, N., Bradbury, R.H., Dubi, A. and Hatziolos, M.E. (2007). The carbon crisis: coral reefs under rapid climate change and ocean acidification. *Science* 318:1737-1742. doi: 10.1126/science.1152509 (Impact factor: 31.201; 923 Scopus citations; influential summary of scenarios for coral reefs under climate change)

[**P3**] **Edwards, A.J., Clark, S.,** Zahir, H., Rajasuriya, A., Naseer, A. and Rubens, J. (2001). Coral bleaching and mortality on artificial and natural reefs in Maldives in 1998, sea surface temperature anomalies and initial recovery. *Marine Pollution Bulletin* 42: 7-15. doi:10.1016/S0025-326X(00)00200-9 (Impact factor: 2.503; 45 Scopus citations; mass-bleaching and mortality of corals in 1998 changed outlook on reef restoration)

[**P4**] ***Clark, S. and Edwards, A.J.** (1995). Coral transplantation as an aid to reef rehabilitation: Evaluation of a case study in Maldive Islands. *Coral Reefs* 14: 201-213. doi: 10.1007/BF00334342 (Impact factor: 3.878; 69 Scopus citations; showed limited benefits of active interventions like transplantation but resilience of reef ecosystem)

[**P5**] Baria, M.V.B., **Guest, J.R., Edwards, A.J.**, Aliño, P.M., Heyward A.J. and Gomez, E.D. (2010) Caging enhances post-settlement survival of juveniles of the scleractinian coral *Acropora tenuis*. *Journal of Experimental Marine Biology and Ecology* 394: 149-153. doi: 10.1016/j.jembe.2010.08.003 (Impact factor: 1.875; 8 Scopus citations; one of six papers so far arising from Newcastle led EC and World Bank/GEF research that underpinned “Manual” and “Guidelines”).

[**P6**] **Clark, S. and Edwards, A.J**. (1999). An evaluation of artificial reef structures as tools for marine habitat rehabilitation in the Maldives. *Aquatic Conservation: Marine and Freshwater Ecosystems* 9 (1): 5-21. doi: 10.1002/(SICI)1099-0755(199901/02)9 (Impact factor: 1.929; 40 Scopus citations; underpinned advice on use of artificial structures in “Manual” and “Guidelines”)

***** papers that best indicate the quality of the research

Grants:

A.J. Edwards, Long-term cost-effectiveness of restoration interventions and factors influencing natural recovery processes, Global Environment Facility (GEF)/World Bank Coral Reef Targeted Research (CRTR) program, 2005–2009, $172,132.

A.J. Edwards, Developing ubiquitous restoration practices for Indo-Pacific reefs, European Commission 6th Framework Programme, 2005–2008, €258,450. (Dr J. Guest was research associate employed on this grant.)

A.J. Edwards, Chairing research of the Restoration and Remediation Working Group, Global Environment Facility (GEF)/World Bank Coral Reef Targeted Research (CRTR) program, 2004–2010, $332,635.

A.J. Edwards, Temporal and Spatial Patterns of Recovery of Coral Reefs from Physical Damage, NERC Connect B grant in collaboration with International Tanker Owners Pollution Federation and maritime insurance industry, 1998-2001, £319,974. (Dr S. Clark was research associate employed on this grant).

A.J. Edwards, Rehabilitation of degraded reefs using artificial reef blocks in the Maldives (1.5 year extension), Overseas Development Administration, 1993-1994, £77,000. (Dr S. Clark was research associate employed on this grant).

4. Details of the impact

Research at Newcastle has made significant contributions to international best practice guidelines used worldwide to restore damaged coral reefs.

The need

Coral reefs provide food and livelihoods, prevent coastal erosion, attract tourism and host a wide variety of biodiversity. Globally, the value of the economic goods and services provided by coral reefs has been estimated at US$375 billion per year (Costanza et al. 1997, Nature, **387**: 253 – 260).

This essential resource is however under threat. In 2008 it was estimated (by Wilkinson, C. (ed.), 2008, Global Coral Reef Monitoring Network and Reef and Rainforest Research Center, Australia) that:

- 20% of the world's coral reefs have been effectively destroyed with no immediate prospects of recovery
- 24% of the world's reefs are under imminent risk of collapse through human pressures,
- 26% are under a longer term threat of collapse.

Reef restoration offers a potential solution but the cost of active restoration can be up to £4 million per hectare (depending on the region and approach; [**E1**]). Thus there is a need for management guidelines to ensure cost-effective restoration.

Meeting the need

Research at Newcastle effectively assessed strategies for coral reef restoration the results of which were worked into a series of international guidelines. The '*Reef Restoration Concepts & Guidelines*' [E1]: Edwards & Gomez 2007) (translated into Indonesian, French and Spanish [**E1**]), rehabilitation manual [E1] (Edwards 2010) and advisory paper [**E1**] (CRTR 009/2010) have led to measurable changes to the practices of NGOs, coastal managers, and the maritime insurance industry. Documented impacts have occurred post 2008 and coral reef conservation practice and policy continue to be informed by the research.

Impacts on NGO's

Two thousand print copies of the *Reef Restoration Concepts & Guidelines* have been distributed and over 1000 electronic copies downloaded from the CRTR website (www.gefcoral.org) per year while this was monitored (2008-2009). Additionally 1000 print copies of the *Reef Rehabilitation Manual* were distributed within 4 months of publication. The manual and guidelines have been requested by and sent to practitioners in at least 66 different countries. Newcastle has received feedback from the users that the guidance has been used on at least 26 reef restoration projects in 19 different countries on every continent except Antarctica [**E2**]. Of the 56 reef restoration practitioners and researchers who have responded to our end-user questionnaire (see [**E2**]) 42 had carried out a reef restoration project post 2008 and 41 (97.6 %) of these had made use of the guidelines and/or manual.

For example, the restoration of the Mithapur Reef in India and the set-up of the *in situ* nursery at Lakshadweep and Gujarat was informed by the Manual. This project led to successful transplantation of *Acropora* species and in 4 out of the 10 artificial reef sites juvenile recruitment of *Montipora*, *Favia* and *Goniastrea* was observed in the first year (2011). Following this success a further 23 artificial reefs were developed at Lagu and Mithapur with help from Tata Chemical Limited, the Indian Navy, the Indian Coastguard, the Gujarat Forest Department, the Zoological Survey of India (ZSI) and local fishing communities during April 2013 [**E3**].

Impacts on ecological consultancies

The guidelines constitute "scientific best practice in the consideration and planning of proposing coral transplantation as a mitigation measure related to IFC PS6 [International Finance Corporation- World Bank – Performance Standard 6] and biodiversity offsetting" [**E4**]. ERM is one such company which has adopted the guidelines, with 140 offices in 39 countries it provides coral

transplantation plans for international projects in many countries including Indonesia, Jordan, Hong Kong and Colombia. For each project "the guidelines and manual provided the research and case study evidence as to the rationale for purporting coral transplantation as a viable option" and also "the necessary management and monitoring programmes required to ensure a successful outcome" [**E4**].

Creocean is an international environmental consultancy which has used the Newcastle Research and subsequent guidelines in mitigating the impact of construction of the Balhaf plant and shipping terminal for Yemen Liquid Natural Gas (YLNG). The research was used to underpin the coral transplant strategy for this US$5 billion plant construction:

"[B]because these [damaged] areas were too large to be integrally transplanted and to increase the chances of coral survival, it was decided *a priori* to selectively transplant the largest colonies, the rare or uncommon species, the slow growing species, and only the colonies in good health. Edwards and Clark (1998)[1] argued that there has been too much focus on transplanting fast-growing branching corals instead of slowly recruiting massive species, which generally survive transplantation well but often recruit slowly." This ensured only minor transient reef damage and healthy reefs have since spawned an estimated 100,000 - 140,000 coral recruits onto new substrates created by the development [**E5**].

Impacts on the International shipping industry

CTL Consult Ltd based in the UK has made use of the guidelines and manual in 4 international ship-grounding cases. The "publications have provided CTL with a robust and justifiable foundation for the advice provided to ITOPF [International Tanker Owners Pollution Federation] and the P&I Clubs [ship insurers] which has allowed us to produce an argument [which]… substantially reduce[d] their liability in all four cases" [**E6**]. The research has been used to show that damage to the reefs could be repaired through natural processes and hence compensation claims have been reduced. For example, the settlement of Hanjijn Istanbul's grounding claim contributed "to a reduction in the claim against the ship owners from US$6,500,000 to a settlement less than US$600,000" [**E6**]. Both the reputation of the Newcastle authors and the auspices of the World Bank and GEF as funders of the work has meant that the manuals are readily accepted as international best practice helping to direct decision making regarding damage assessment and restoration options for coral reefs" [**E6**].

5. Sources to corroborate the impact

[**E1**] Edwards, A.J. & Gomez, E.D. 2007 *Reef Restoration Concepts & Guidelines: making sensible management choices in the face of uncertainty* (ISBN 978-1-921317-00-2). This was translated into French by Coral Reef InitiativeS for the Pacific (CRISP) and into Bahasa Indonesia by a conservation NGO, Yayasan Terumbu Karang Indonesia (TERANGI) in 2008, and into Spanish in 2009. The "Guidelines" were followed in 2010 by Edwards, A.J. (Ed.) *Reef Rehabilitation Manual* (ISBN 978-1-921317-05-7). Finally a 4 page Advisory Paper: *Reef Restoration & Rehabilitation* (CRTR 009/2010) was also issued for policy makers.

[**E2**] Results of survey of end-users of guidelines and manual in the CRTRC database

[**E3**] Collaborating contact: Assistant Manager, Wildlife Trust of India – Mithapur Reef Recovery Project.

[**E4**] Email from Team Lead - Marine, Environmental Resources Management Australia Pty Ltd (ERM)

[**E5**] Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008. Session number 24: Seguin, F., Le Brun, O., Hirst, R., Al-Thary, I. and Dutrieux, E. "Large coral transplantation in Bal Haf (Yemen): an opportunity to save corals during the construction of a Liquefied Natural Gas plant using innovative techniques".

[**E6**] E-mail from CTL Consult Ltd. on use in ship grounding compensation claims in Philippines, Indonesia and Mexico.