Journal of Applied Ecology

DR LOUISE FIRTH (Orcid ID : 0000-0002-6620-8512)

MISS FABIO BULLERI (Orcid ID : 0000-0002-7335-6791)

MS KATHRYN O'SHAUGHNESSY (Orcid ID : 0000-0002-8587-4473)

Article type : Commentary

Handling Editor: Melinda Coleman

Greening of grey infrastructure should not be used as a Trojan horse to facilitate coastal development

L.B. Firth[1], L. Airoldi[2], F. Bulleri[3], S. Challinor[4], S.-Y. Chee[5], A.J. Evans[6], M.E. Hanley[1], A.M. Knights[1], K.O'Shaughnessy[1], R.C. Thompson[1], S.J. Hawkins[7,8]

[1]School of Biological and Marine Sciences, University of Plymouth, UK

[2]Dipartimento di Scienze Biologiche, Geologiche e Ambientali, University of Bologna, Italy

[3]Dipartimento di Biologia, University of Pisa, Italy

[4]Green Room Environmental Consultancy Services Ltd, Exeter, UK

[5]Centre for Marine and Coastal Studies, Universiti Sains Malaysia, Penang, Malaysia

[6]Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, UK

[7]The Marine Biological Association of the United Kingdom, UK

[8]School of Ocean and Earth Science, University of Southampton, UK

Corresponding author: L.B. Firth, School of Biological and Marine Sciences, University of Plymouth, UK, louise.firth@plymouth.ac.uk

ABSTRACT

1. Climate change and coastal urbanisation are driving the replacement of natural habitats with artificial structures and reclaimed land globally. These novel habitats are often poor surrogates for natural habitats.
2. The application of integrated greening of grey infrastructure (IGGI) to artificial shorelines demonstrates how multifunctional structures can provide biodiversity benefits whilst simultaneously serving their primary engineering function. IGGI is being embraced globally, despite many knowledge gaps and limitations. It is a management tool to compensate anthropogenic impacts as part of the Mitigation Hierarchy. There is considerable scope for misuse and 'greenwashing' however, by making new developments appear more acceptable, thus facilitating the regulatory process.
3. We encourage researchers to exercise caution when reporting on small-scale experimental trials. We advocate that greater attention is paid to when experiments 'fail' or yield unintended outcomes. We advise revisiting, repeating and expanding on experiments to test responses over broader spatio-temporal scales to improve the evidence base.
4. *Synthesis and applications.* Where societal and economic demand makes development inevitable, particular attention should be paid to avoiding, minimising and rehabilitating environmental impacts. Integrated greening of grey infrastructure (IGGI) should be implemented as partial compensation for environmental damage. Mutual benefits for both humans and nature can be achieved when IGGI is implemented retrospectively in previously-developed or degraded environments. We caution however, that any promise of net biodiversity gain from new developments should be scrutinised and any local ecological benefits set in the context of the wider environmental impacts. A 'greened' development will always impinge on natural systems, a reality that is much less recognised in the sea than on land.

RESUMEN

1. Cambio climático y urbanización costera están causando el reemplazo de hábitats naturales con estructuras artificiales y aprovechamiento del territorio a nivel mundial. Estos nuevos hábitats a menudo son sustitutos pobres de los hábitats naturales.
2. La aplicación de 'Integrated greening of grey infrastructure' (IGGI) a costas artificiales, demuestra como estructuras multifuncionales pueden proporcionar beneficios a la biodiversidad mientras cumplen simultáneamente su función principal. IGGI está siendo adoptada a nivel mundial, a pesar de un gran deficit en nuestro conocimiento en cuanto a su efectifidad. Es una herramienta de gestión para compensar los impactos antropogénicos, usada como parte de la Jerarquía de Mitigación. Sin embargo, existe un margen considerable para que sea usada de forma inapropiada y como 'ecoblanqueamiento', hacienda que los nuevos explotaciones parezcan más aceptables, lo que facilita el proceso de regulación.
3. Animamos a los investigadores a tener precaución al informar sobre pruebas experimentales desarrolladas a pequeña-escala. Recomendamos que se preste mayor atención cuando los experimentos 'fallan' o producen resultados no deseados. Recomendamos revisar, repetir y ampliar los experimentos para evaluar las respuestas en escalas espacio-temporales más amplias para mejorar la base empirica.
4. *Síntesis y aplicaciones*. Donde la demanda social y económica hace que el desarrollo sea inevitable, se debe prestar especial atención a evitar, minimizar y rehabilitar el impacto ambiental. IGGI debe implementarse como compensación parcial por los daños ambientales. Se pueden lograr beneficios mutuos para los humanos y la naturaleza cuando IGGI se implementa retrospectivamente en entornos previamente-desarrollados o degradados. Sin embargo, advertimos que cualquier promesa de ganancia neta de biodiversidad a partir de nuevos desarrollos debe ser analizada a fondo y cualquier beneficio ecológico local debe establecerse en el contexto de los impactos ambientales más amplios. Un desarrollo 'ecológico' siempre afectará a los ecosistemas naturales, una realidad que es mucho menos reconocida en el mar que en la tierra.

KEYWORDS

biodiversity offsetting, dual-use dilemma, environmental damage, marine planning, mitigation hierarchy, novel ecosystem, sustainable development, Integrated greening of grey infrastructure

Greening of the grey: making space for nature in the marine built environment

Climate change and urbanisation is driving 'artificialisation' of the global coastline (Fig. 1, Firth et al., 2016). Artificial structures that support human activities (e.g. seawalls, breakwaters, artificial islands) are replacing natural habitats with myriad negative environmental impacts (Dafforn et al., 2015; Airoldi et al. 2021). The resultant marine built environments have been likened to 'novel ecosystems' (Bulleri et al., 2020) because they have been deflected irrevocably from their historical trajectories. The novel ecosystem concept has generated intense debate with some arguing that it is an inevitable, and even necessary consequence of the challenges and opportunities facing conservationists (Perring et al., 2013), and others claiming that it provides a 'license to trash' nature for prospective developments (Murcia et al., 2014).

Integrated Greening of Grey Infrastructure (IGGI) is a new conservation strategy that involves biodiversity enhancement of hard infrastructure that cannot be replaced with green solutions (Naylor et al., 2017). In an effort to promote more sustainable marine built environments, IGGI is being used to improve multifunctionality; in particular the ecological value of hard infrastructure. The field has flourished recently (Strain et al., 2018), with many successful examples emerging (see O'Shaughnessy et al., 2020 for review). It remains a comparatively young science, however, and has not been subject to the long-term experimentation, implementation and critical evaluation that is necessary before being considered a mainstream solution. Nevertheless, governmental agencies and planning authorities are recommending and implementing IGGI as compensation for environmental damage caused by new developments (Dafforn et al., 2015; Evans et al., 2019).

IGGI raises some challenging ethical considerations. Whilst it aims to promote biodiversity and ecosystem services enhancement, there is scope for it to be misused for greenwashing purposes. Through enabling new coastal developments to be viewed more favourably by regulators and the public, this potentially facilitates the regulatory process and increases likelihood of consent (Rijks et al., 2015); the "dual-use dilemma", where science can be used for good or bad (Miller & Selgelid, 2007). We discuss the potential for IGGI to be misused for greenwashing. Specifically, we explore three topics central to this debate: (1) What are the arguments for and against IGGI; (2) what is the scope for greenwashing; and (3) where are the opportunities and risks? Additionally, we identify knowledge gaps and research priorities that will lead to improved understanding of the future role of IGGI.

Arguments for/against IGGI

The very concept of sustainable development demands implementation of IGGI. The *Mitigation Hierarchy* has emerged as a best-practice framework for achieving sustainable development (CSBI, 2015). Practitioners seek to limit negative impacts on biodiversity through a series of steps: avoid, minimise, restore/rehabilitate, and compensate. Compensation is intended as a last resort for developers seeking to compensate for unavoidable damage, after having applied all other stages. The goal is to achieve no net loss in terms of biodiversity and increasingly, net gain. As developments are typically permanent, the ensuing habitat loss can only be compensated and not mitigated (Elliott & Cutts, 2004).

Biodiversity offsetting (hereafter offsetting) is an increasingly popular compensation approach (Biodiversity Consultancy, 2017), offering (arguably) potentially powerful ways of balancing conservation and development. Offsetting has been criticised because quantitative decision-making guidelines are lacking, ecological equivalence regulations are being relaxed, many offsets fall short of their goals; and there is concern that offsets could be used as a "licence to trash nature" by making development projects appear more acceptable (McKenney & Kieseker, 2010). If applied as part of the Mitigation Hierarchy as compensation for environmental damage, IGGI could represent a form of offsetting, and much can be learnt from the criticisms of it.

The emerging field of IGGI in the marine environment is producing numerous examples of multifunctional structures yielding multiple biodiversity benefits. This has been achieved through myriad techniques, including manipulating building materials composition, building in topographic complexity and transplanting organisms directly onto substrata (see O'Shaughnessy et al. 2020 for review). To date, much of this has been done by the research community on experimental scales and has typically been applied retrospectively to existing artificial structures. Despite the many possible ecological benefits of IGGI, limitations and knowledge gaps remain. All experiments have the potential to be oversold, fail, or yield unintended outcomes (Fig. 2, Chapman & Underwood, 2011). IGGI has typically been implemented over limited spatio-temporal scales, with bias towards intertidal and temperate systems (Strain et al., 2018). Often benefits are measured for species, habitats or processes that are not those originally impacted or lost. The goal is typically to encourage colonisation of native species, but responses are unpredictable, particularly under future climate scenarios. 'Success' is typically assessed using ecological metrics (e.g. species richness) or probability tests which have already proven to be inefficient for assessment of restoration success (Palmer & Filoso, 2009). Little is known about the role of multifunctional structures in facilitating the spread of pathogens and non-native species (Firth et al., 2016). Indeed, they may function as ecological traps (reducing fitness of colonising organisms) or environmental filters; leading to biotic and functional homogenisation (McKinney, 2006). There remains a dearth of large demonstration tests that show how interventions will perform when scaled-up operationally in 'real' developments (Evans et al., 2019).

Seattle, USA and Sydney, Australia have pioneered the implementation of IGGI at ecologically-relevant scales through large-scale urban regeneration (Toft et al., 2013). The incorporation of IGGI in redevelopment/regeneration projects represents a win-win or '*laurel wreath*', with measurable benefits for humans and nature. The promise of making space for nature in new developments that involve breaking ground in natural environments, or through land reclamation is much more limited. Not only could the practice of IGGI be viewed as a '*fig leaf*'; covering up the environmental damage caused by the development; but if used prospectively to gain consent on the development, it could be viewed as a '*Trojan Horse*'; deliberate strategy causing environmental damage.

What is the scope for greenwashing?

We are increasingly hearing consultants, developers and local authorities discussing how implementing IGGI can expedite, facilitate and reduce costs of regulatory processes. Through implementation of the Mitigation Hierarchy there is a clear incentive for implementing IGGI. Artificial reefs (analogous to IGGI), have long been deployed as compensation for habitat loss associated with coastal development. Unlike IGGI, artificial reefs have been subject to criticism (Baine, 2001). Here, we draw on the lessons learnt from artificial reefs to illustrate how IGGI could potentially be misused for greenwashing.

All artificial structures have the capacity to function as 'artificial reefs' as they inevitably provide habitat and refuge for marine life. The word "reef" often conjures up images of healthy, diverse biological communities; and may be more acceptable or appealing to developers than sedimentary habitats that may be perceived as "barren". For instance, the developers of the *Palm Jumeirah* artificial island, Dubai claim that not only is this the 'world's largest artificial reef', but that the construction of *The World* artificial island development actually 'improved the quality of the seawater surrounding the islands' in comparison to that tested along the shoreline of Dubai (Nakheel, 2018). Although the breakwaters do support diverse marine life, the new communities differ greatly from natural reefs (Burt et al., 2013). We view this example as a *fig leaf*; covering up the damage caused by the construction of the island on sedimentary and coral reef habitats (Burt et al., 2008). Some planned artificial reefs are even more pernicious. Whilst some proponents argue that artificial reefs are prudent recycling projects creating valuable fisheries for recreation, many artificial reefs are merely disguised ocean dumping (Fig. 1b). We view such examples as *Trojan Horses* which may be the result of either wilful or misguided intent to dispose of material at sea.

It has long been recognised that oil platforms support diverse marine life and they have been likened to novel ecosystems (van Elden et al., 2019). The decommissioning of rigs to become artificial reefs (Rigs-to-reefs) is common practice in the Gulf of Mexico, saving the industry millions of dollars in removal costs. Claisse et al. (2014) reported that Californian platforms supported the highest secondary production in marine habitats globally. The standard unit was seafloor surface area, which did not consider the vertical nature of the structures. Media outputs had irresponsible headlines like “why abandoned oil-rigs are better than coral reefs” (Global Citizen, 2018). Assertions that artificial structures support better fisheries than natural habitats, may prospectively cause environmental damage through influencing governments to relax regulations or develop policies (e.g. US National Fishing Enhancement Act, BSEE, 2018) which may play a role in facilitating the proliferation of oil platforms and further environmental damage. These structures will inevitably degrade, potentially losing their reef functions and causing pollution. This highlights the importance of full life-cycle-analysis for all marine artificial structures. Whilst we do not question the integrity of scientists in honestly reporting data as they see them, there is nonetheless, obvious potential for misrepresentation by the media and misuse by the industry (Macura et al., 2019).

Arguably, there is already evidence for greenwashing with megaprojects. For instance, an online search using the term ‘artificial islands’ reveals myriad futuristic utopian paradises where people can live and play in newly-urbanised, eco-friendly island cities and resorts. Whilst these projects may have impressive ecological designs, they are all constructed on reclaimed land, and any biodiversity benefits must be viewed in the context of the wider environmental damage caused by the construction.

Furthermore, with global coastal artificialisation, it is inevitable that perceptions about what is acceptable is becoming normalised towards the degraded/artificial through shifting baseline syndrome (Pauly 1995; Strain et al., 2019). Not only are we accustomed to heavily modified coastal environments, but the public often prefer the aesthetics of a neat seawall to a natural shoreline. This preference can be driven by perceived ‘ecosystem disservices’ that are associated with natural wetlands; mangroves in particular are associated with darkness and disease (Freiss, 2016). One of the most insidious environmental threats is perhaps that the artificial legacy left behind by current coastal developments will re-position baseline perceptions and standards for future generations.

Where do the opportunities lie?

IGGI can easily be applied retrospectively to existing coastlines to enhance ecological functioning and ecosystem services. This is particularly true for large projects that can apply hybrid approaches combining hard engineered structures with rehabilitation of pre-existing biogenic habitats (Morris et al., 2018). For example, the global restoration of native oysters is yielding many success stories, even in highly urbanised areas. In New York, the Billion Oyster Project (www.billionoysterproject.org) is using artificial structures (e.g. bulkheads, gabions) to install oysters with widespread success. Such regeneration/rehabilitation projects represent '*laurel wreaths*'; win-win for both humans and nature.

Many megadevelopments are being built with little or no consideration for nature. For instance, Penang Island, Malaysia is experiencing rapid economic and population growth; driving large-scale land reclamation and artificial island construction (Chee et al., 2017). Where a project has been consented (and therefore IGGI has not facilitated the process), arguably opportunities abound for implementing operational-scale IGGI, including hybrid approaches. Where such projects emerge, researchers, engineers and local authorities should collaborate to provide vital testing of the practice and test for spill-over effects on the wider environment (Toft et al., 2013).

Where are the places that are most at risk in the future?

Over the last 30 years, Asia and the Middle East have experienced the greatest population and urban growth (United Nations, 2017). Coincidentally, many of these (e.g. United Arab Emirates, Qatar) have constructed some of the most ambitious and iconic land reclamation projects (Fig. 3), yet few have biodiversity offsetting policies (Biodiversity Consultancy, 2017). While controversial, the implementation of offsetting at least gives some indication of willingness to compensate environmental damage. Of the top 50 countries expected to experience the fastest population growth from 2020-2100, 86% are African; 72% of which are coastal (United Nations, 2017). Many of these countries are characterised by some of the largest remaining stretches of ‘unaltered’ coastlines (Firth et al., 2016), but with limited environmental protection policies (Biodiversity Consultancy, 2017). Whilst megadevelopments continue apace in Asia and the Middle East, arguably, these African countries are the most vulnerable to future habitat loss and megadevelopment.

Moving forward, what can be done?

Whilst it is impossible for scientists to prevent their science being used for harm, there are a number of things that they can do to improve the science and to reduce the risk of such practice. The majority of IGGI projects have been conducted in few locations, under particular environmental conditions and over short timescales. These experiments should be revisited, repeated and expanded on (e.g. Hsiung et al. 2020) to improve the evidence base for policy development. The rise of the global research network (e.g. www.worldharbourproject.org) represents a great platform for implementation of large-scale experiments and information sharing. Furthermore, the research and practice should move together in tandem. New developments and redevelopments should trial and implement IGGI. Such projects will provide essential insight into how biological communities will respond at anthropogenically and ecologically relevant scales. The information gathered from such experiments should be collated in an evidence-based catalogue (Evans et al., 2019) that is constantly updated and made available to policy makers and practitioners in a globally available and accessible format such as Conservation Evidence (www.conservationevidence.com).

We urge researchers to go beyond simple biodiversity measures and measure functional responses and other biologically-meaningful responses (Perkins et al. 2015). Importantly, this needs to go beyond simply comparing “like-with-like” reef habitats (which may not have been the habitat that was lost), but should also develop ways of comparing pre-existing sedimentary and new hard artificial habitats.

Finally, we advocate that greater attention is given to when experiments ‘fail’ or yield unintended outcomes. Researchers should not be afraid to point out shortcomings and limitations to ensure broader progress; and should be careful not to oversell short-term, localised experimental trials. In an age of Open Science, research 'impact', and "perverse incentives and hypercompetition" in academia (Edwards & Roy 2017), now more than ever, researchers must maintain standards and scientific integrity. It is important that researchers exercise nuance in the manner in which they communicate their findings, and that developers, planners and decision-makers responsibly use the research-based knowledge available to them. Furthermore, the point above about failure and unintended outcomes could also be extended to funders and publishers in particular. Publication bias, whereby studies reporting positive outcomes are more likely to be published and cited more, is particularly prevalent in the applied and biological sciences with implications for scientific and social agendas (Fanelli, 2013). We urge that publishers actively encourage and promote null and negative results in an effort to reduce the risk from this potentially harmful practice.

Conclusions

The artificialisation of the global coastline is driving humanity to develop novel solutions to halt biodiversity loss and enhance the marine built environment. Whilst IGGI has demonstrated real promise in experimental trials and redevelopment projects, there are many limitations and unknowns. Now is the time to have an open discussion about the risks and benefits of the practice.

Acknowledgements

LBF was supported by British Ecological Society (5546-6590) and Royal Society (IE150435). LBF, LA, MEH, RCT, SJH were supported by EU-FP7.2009-1 Contract 244104. LF, RCT, SJH were supported by Esmée Fairbairn Foundation. FB was supported by University of Pisa PRA 2017. AJE was supported by European Regional Development Fund Ireland-Wales Cooperation Programme 2014-2020. Conversations between co-authors during the joint foresight/ECORES workshop (supported by Euromarine & World Harbour Project) inspired some content of this paper. Thanks to Gee Chapman for commenting on early drafts of this paper.

Authors' contributions

LF conceived the concept following discussions with all authors. All authors contributed critically to the drafts and gave final approval for publication.

Data availability statement

This article does not use data.

References

Airoldi, L., Beck, M.W., Firth, L.B., Bugnot, A., Steinberg, P.A., Dafforn, K.A. (2021). Emerging Solutions to Return Nature to the Urban Ocean. Annual Review of Marine Science, 13:X–X https://doi.org/10.1146/annurev-marine-032020-020015

Baine, M. (2001). Artificial reefs: a review of their design, application, management and performance. Ocean & Coastal Management, 44, 241-259. doi:10.1016/S0964-5691(01)00048-5

Biodiversity Consultancy, (2017). https://portals.iucn.org/offsetpolicy/). 28/03/2019.

BSEE, Bureau of Safety and Environmental Enforcement (2018) https://www.bsee.gov/what-we-do/environmental- focuses/rigs-to-reefs. 26/4/18

Bulleri, F., Batten, S., Connell, S., Benedetti-Cecchi, L., Gibbons, M., Nugues, M.M. et al. (2020). Human pressures and the emergence of novel marine ecosystems. Oceanography and Marine Biology: an Annual Review. In press.

Burt, J., Bartholomew, A. & Usseglio, P. (2008). Recovery of corals a decade after a bleaching event in Dubai, United Arab Emirates. Marine Biology, 154, 27-36. doi:10.1007/s00227-007-0892-9

Burt, J.A., Feary, D.A., Cavalcante, G., Bauman, A.G. & Usseglio, P. (2013). Urban breakwaters as reef fish habitat in the Persian Gulf. Marine Pollution Bulletin, 72, 342-350. doi:10.1016/j.marpolbul.2012.10.019

Chee, S.Y., Othman, A.G., Sim, Y.K., Adam, A.N.M. & Firth, L.B. (2017). Land reclamation and artificial islands: Walking the tightrope between development and conservation. Global Ecology and Conservation, 12, 80-95. doi:10.1016/j.gecco.2017.08.005

Claisse, J.T., Pondella, D.J., Love, M., Zahn, L.A., Williams, C.M., Williams, J.P. et al. (2014). Oil platforms off California are among the most productive marine fish habitats globally. Proceedings of the National Academy of Sciences USA, 111, 15462-15467. doi:10.1073/pnas.141147711d

CSBI, Cross Sector Biodiversity Initiative (2015). http://www.csbi.org.uk/our-work/mitigation-hierarchy- guide/) 22/05/19.

Dafforn, K.A., Glasby, T.M., Airoldi, L., Rivero, N.K., Mayer-Pinto, M. & Johnston, E.L. (2015). Marine urbanization: An ecological framework for designing multifunctional artificial structures. Frontiers in Ecology and the Environment, 13, 82–90. doi:10.1890/140050

Edwards, M.A. & Roy, S. (2017). Academic research in the 21st century: Maintaining scientific integrity in a climate of perverse incentives and hypercompetition. Environmental Engineering Science, 34, 51-61. doi:10.1089/ees.2016.0223

Elliott, M. & Cutts, N.D. (2004). Marine habitats: loss and gain, mitigation and compensation. Marine Pollution Bulletin, 49, 671-674. Doi:10.1016/j.marpolbul.2004.08.018

Evans, A.J., Firth, L.B., Hawkins, S.J., Hall, A.E., Ironside, J.E., Thompson, R.C. et al. (2019). From ocean sprawl to blue-green infrastructure–A UK perspective on an issue of global significance. Environmental Science & Policy, 91, 60-69. doi:10.1016/j.envsci.2018.09.008

Fanelli, D. (2012). Positive results receive more citations, but only in some disciplines. Scientometrics, 94, 701–709. doi:10.1007/s11192-012-0757-y

Firth, L.B, Knights, A.M., Thompson, R.C., Mieszkowska, N., Bridger, D., Evans, A., et al. (2016). Ocean sprawl: challenges and opportunities for biodiversity management in a changing world. Oceanography and Marine Biology: an Annual Review, 54, 193-269.

Firth, L.B., Thompson, R.C., Bohn, K., Abbiati, M., Airoldi, L., Bouma, T.J., et al. (2014). Between a rock and a hard place: environmental and engineering considerations when designing coastal defence structures. Coastal Engineering, 87, 122-135. doi:10.1016/j.coastaleng.2013.10.015

Friess, D. (2016). Ecosystem services and disservices of mangrove forests: insights from historical colonial observations. Forests, 7, 183. doi:10.3390/f7090183

Global Citizen (2016). https://www.globalcitizen.org/en/content/why-abandoned-oil-rigs- are-better-than-coral-reefs/). 2/2/2020

Hsiung, A.R., Tan, W.T., Loke, L.H.L., Firth, L.B., Heery, E.C., Ducker, J., Clark, V., Pek, Y.S., Birch, W.R., Ang, A.C.F., Hartanto, R.S., Chai, T.M.F., Todd, P.A. (2020). Little evidence that lowering the pH of concrete supports greater biodiversity on tropical and temperate seawalls. Marine Ecology Progress Series. In Press

Macura, B., Byström, P., Airoldi, L., Eriksson, B.K., Rudstam, L., & Støttrup, J. (2019). Impact of structural habitat modifications in coastal temperate systems on fish recruitment: a systematic review. Environmental Evidence, 8, 1-22. doi:10.1186/s13750-019-0157-3

McKenney, B.A., & Kiesecker, J.M. (2010). Policy development for biodiversity offsets: a review of offset frameworks. Environmental Management, 45, 165-176. doi:10.1007/s00267-009-9396-3

McKinney, M.L. (2006). Urbanization as a major cause of biotic homogenization. Biological Conservation, 127, 247-260. doi:10.1016/j.biocon.2005.09.005

Miller, S., & Selgelid, M.J. (2007). Ethical and philosophical consideration of the dual-use dilemma in the biological sciences. Science and Engineering Ethics, 13, 523-580. doi:10.1007/s11948-007-9043-4

Morris, R.L., Konlechner, T.M., Ghisalberti, M., & Swearer, S.E. (2018). From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence. Global Change Biology, 24, 1827-1842. doi:10.1111/gcb.14063

Murcia, C., Aronson, J., Kattan, G.H., Moreno-Mateos, D., Dixon, K., & Simberloff, D. (2014). A critique of the 'novel ecosystem' concept. Trends in Ecology & Evolution, 29, 548-553. doi:10.1016/j.tree.2014.07.006

Nakheel 2018. https://www.nakheel.com/en/environment/artificial-reefs.) 25/03/19

Naylor, L.A., Kippen, H., Coombes, M.A., et al. (2017). Greening the Grey: a framework for integrated green grey Infrastructure (IGGI). http://eprints.gla.ac.uk/150672/

Palmer, M.A., & Filoso, S. (2009). Restoration of ecosystem services for environmental markets. Science, 325, 575-576. doi:10.1126/science.1172976

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology & Evolution, 10, 430. doi:https://doi.org/10.1016/S0169-5347(00)89171-5

Perkins, M.J., Ng, T.P., Dudgeon, D., Bonebrake, T.C. and Leung, K.M. (2015). Conserving intertidal habitats: what is the potential of ecological engineering to mitigate impacts of coastal structures?. Estuarine, Coastal and Shelf Science, 167, 504-515. doi:https://doi.org/10.1016/j.ecss.2015.10.033

Perring, M.P., Manning, P., Hobbs, R.J., Lugo, A.E., Ramalho, C.E., & Standish, R.J. (2013). Novel urban ecosystems and ecosystem services. In R.J. Hobbs, E.S. Higgs & C. Hall (Eds.). *Novel* *ecosystems: intervening in the new ecological world order* (pp.310-325). Chichester, UK: Wiley-Blackwell.

Rijks, D.C., Aarninkhof, S.G.A., van Spreeken, A., & Legierse, E. (2015) Eco-engineering opportunities for offshore marine infrastructure projects. Offshore Technology Conference. doi:10.4043/26207-MS

Strain, E.M., Olabarria, C., Mayer-Pinto, M., Cumbo, V., Morris, R.L., Bugnot, A.B., et al. (2018). Eco-engineering urban infrastructure for marine and coastal biodiversity: Which interventions have the greatest ecological benefit?. Journal of Applied Ecology, 55, 426-441. doi:10.1111/1365-2664.12961

Strain, E.M., Alexander, K.A., Kienker, S., Morris, R., Jarvis, R., Coleman, R., et al. (2019). Urban blue: A global analysis of the factors shaping people's perceptions of the marine environment and ecological engineering in harbours. Science of the Total Environment, 658, 1293-1305. doi:10.1016/j.scitotenv.2018.12.285

Toft, J.D., Ogston, A.S., Heerhartz, S.M., Cordell, J.R., & Flemer, E.E. (2013). Ecological response and physical stability of habitat enhancements along an urban armored shoreline. Ecological Engineering, 57, 97-108. doi:10.1016/j.ecoleng.2013.04.022

United Nations, (2017). https://population.un.org/wpp/) 2/02/20

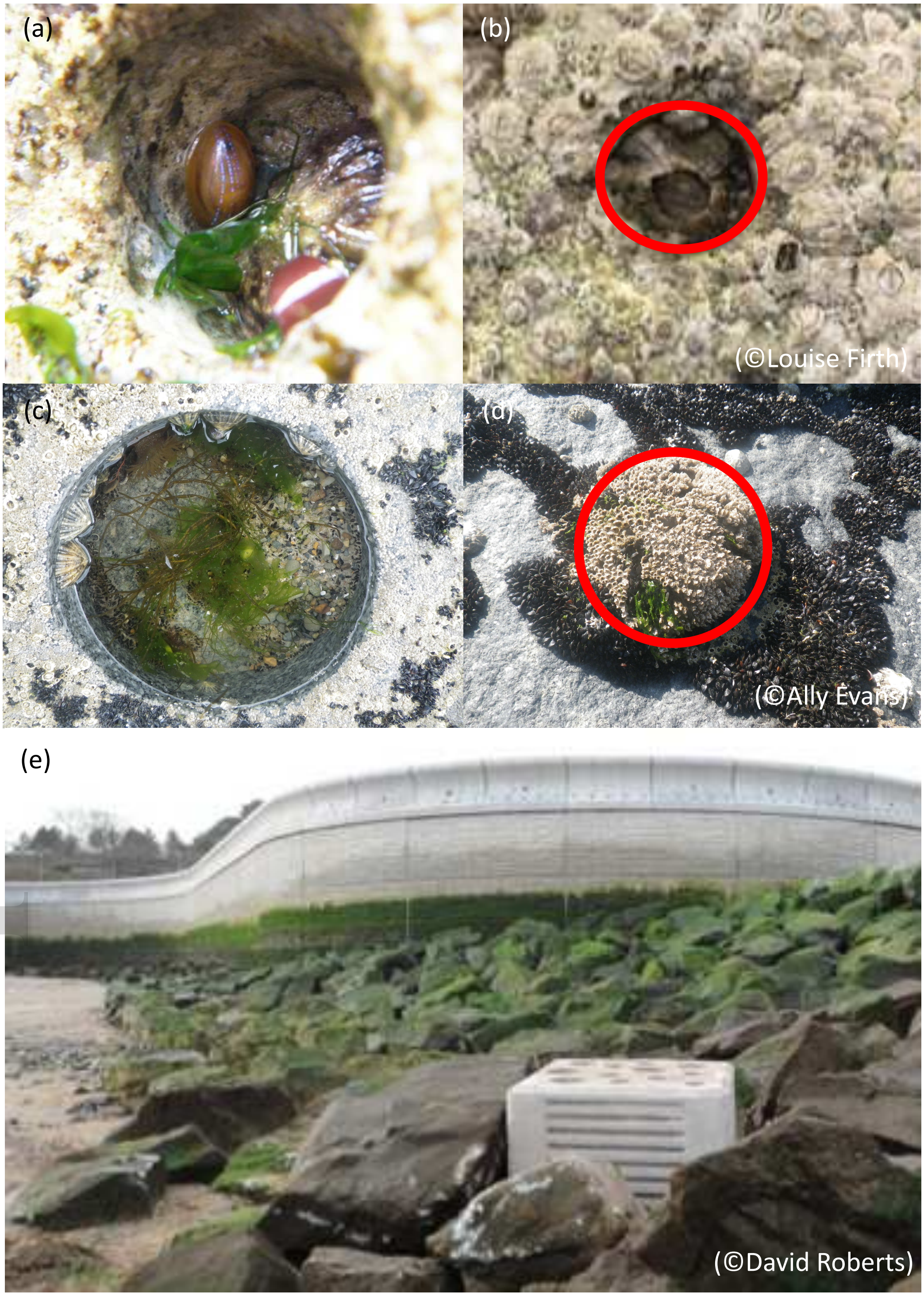
van Elden, S., Meeuwig, J., Hemmi, J.M., & Hobbs, R. (2019). Offshore oil and gas platforms as novel ecosystems: A global perspective. Frontiers in Marine Science, 6, p.548. doi:10.3389/fmars.2019.00548

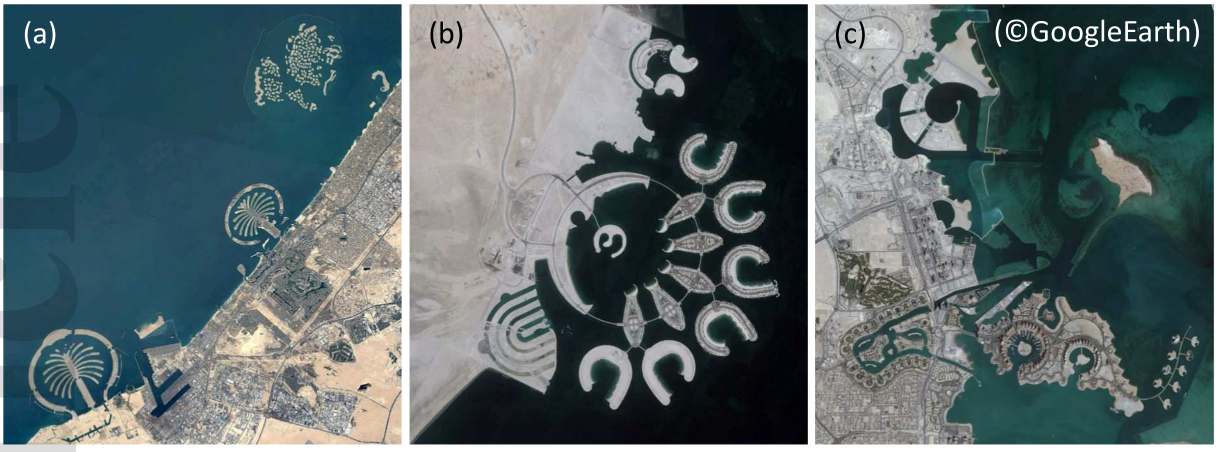
Figure 1. Coastal artificialisation. (a) Hong Kong condensed into narrow coastal strip. (b) Treadmill dumped as part of artificial reef, Malaysia. (c) Artificial structures in industrialised landscape, UK.

Figure 2. Unintended outcomes from IGGI experiments. Drilled pits after five (a) and nine years (b); longer-term observations revealed that many (red circle indicates outline) had become dominated by individual barnacles. (c) Drilled rockpools after 1.5 (c) and five years (d); longer-term observations revealed that some rockpools filled up with the worm *Sabellaria alveolata*. (e) The BIOBLOCK is a habitat-enhancement unit. Following 2013/14 storms the BIOBLOCK become covered by sand; it was still buried in 2019. All examples from Firth et al. (2014).

Figure 3. Artificial island construction in (a) Dubai; (b) Bahrain; (c) Qatar.


(a)
(©Laura Airoldi)
(b)
(©Alvin Cheillah)
(c)
(©Louise Firth)


(a)
(b)
(©Louise Firth)
(c)
(d)
(©Ally Evans)
(e)
(©David Roberts)


(a)
(b)
(c)
(©GoogleEarth)