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

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

3

4

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22

23 **ABSTRACT**

- 24 1. Climate change and coastal urbanisation are driving the replacement of natural
25 habitats with artificial structures and reclaimed land globally. These novel habitats
26 are often poor surrogates for natural habitats.
- 27 2. The application of integrated greening of grey infrastructure (IGGI) to artificial
28 shorelines demonstrates how multifunctional structures can provide biodiversity
29 benefits whilst simultaneously serving their primary engineering function. IGGI is
30 being embraced globally, despite many knowledge gaps and limitations. It is a
31 management tool to compensate anthropogenic impacts as part of the Mitigation
32 Hierarchy. There is considerable scope for misuse and 'greenwashing' however, by
33 making new developments appear more acceptable, thus facilitating the regulatory
34 process.
- 35 3. We encourage researchers to exercise caution when reporting on small-scale
36 experimental trials. We advocate that greater attention is paid to when experiments
37 'fail' or yield unintended outcomes. We advise revisiting, repeating and expanding
38 on experiments to test responses over broader spatio-temporal scales to improve
39 the evidence base.
- 40 4. *Synthesis and applications*. Where societal and economic demand makes
41 development inevitable, particular attention should be paid to avoiding, minimising
42 and rehabilitating environmental impacts. Integrated greening of grey infrastructure

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43 (IGGI) should be implemented as partial compensation for environmental damage.
44 Mutual benefits for both humans and nature can be achieved when IGGI is
45 implemented retrospectively in previously-developed or degraded environments.
46 We caution however, that any promise of net biodiversity gain from new
47 developments should be scrutinised and any local ecological benefits set in the
48 context of the wider environmental impacts. A 'greened' development will always
49 impinge on natural systems, a reality that is much less recognised in the sea than on
50 land.

51

52 **RESUMEN**

- 53 1. Cambio climático y urbanización costera están causando el reemplazo de hábitats
54 naturales con estructuras artificiales y aprovechamiento del territorio a nivel
55 mundial. Estos nuevos hábitats a menudo son sustitutos pobres de los hábitats
56 naturales.
- 57 2. La aplicación de 'Integrated greening of grey infrastructure' (IGGI) a costas
58 artificiales, demuestra como estructuras multifuncionales pueden proporcionar
59 beneficios a la biodiversidad mientras cumplen simultáneamente su función
60 principal. IGGI está siendo adoptada a nivel mundial, a pesar de un gran deficit en
61 nuestro conocimiento en cuanto a su efectividad. Es una herramienta de gestión para
62 compensar los impactos antropogénicos, usada como parte de la Jerarquía de
63 Mitigación. Sin embargo, existe un margen considerable para que sea usada de

64 forma inapropiada y como 'ecoblanqueamiento', hacienda que los nuevos
65 explotaciones parezcan más aceptables, lo que facilita el proceso de regulación.

66 3. Animamos a los investigadores a tener precaución al informar sobre pruebas
67 experimentales desarrolladas a pequeña-escala. Recomendamos que se preste
68 mayor atención cuando los experimentos 'fallan' o producen resultados no
69 deseados. Recomendamos revisar, repetir y ampliar los experimentos para evaluar
70 las respuestas en escalas espacio-temporales más amplias para mejorar la base
71 empírica.

72 4. *Síntesis y aplicaciones*. Donde la demanda social y económica hace que el desarrollo
73 sea inevitable, se debe prestar especial atención a evitar, minimizar y rehabilitar el
74 impacto ambiental. IGGI debe implementarse como compensación parcial por los
75 daños ambientales. Se pueden lograr beneficios mutuos para los humanos y la
76 naturaleza cuando IGGI se implementa retrospectivamente en entornos
77 previamente-desarrollados o degradados. Sin embargo, advertimos que cualquier
78 promesa de ganancia neta de biodiversidad a partir de nuevos desarrollos debe ser
79 analizada a fondo y cualquier beneficio ecológico local debe establecerse en el
80 contexto de los impactos ambientales más amplios. Un desarrollo 'ecológico'
81 siempre afectará a los ecosistemas naturales, una realidad que es mucho menos
82 reconocida en el mar que en la tierra.

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85

86 **KEYWORDS**

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

90

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

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

102

103 Integrated Greening of Grey Infrastructure (IGGI) is a new conservation strategy that
104 involves biodiversity enhancement of hard infrastructure that cannot be replaced with
105 green solutions (Naylor et al., 2017). In an effort to promote more sustainable marine built
106 environments, IGGI is being used to improve multifunctionality; in particular the ecological
107 value of hard infrastructure. The field has flourished recently (Strain et al., 2018), with many
108 successful examples emerging (see O'Shaughnessy et al., 2020 for review). It remains a

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109 comparatively young science, however, and has not been subject to the long-term
110 experimentation, implementation and critical evaluation that is necessary before being
111 considered a mainstream solution. Nevertheless, governmental agencies and planning
112 authorities are recommending and implementing IGGI as compensation for environmental
113 damage caused by new developments (Dafforn et al., 2015; Evans et al., 2019).

114

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

125

126 **Arguments for/against IGGI**

127 The very concept of sustainable development demands implementation of IGGI. The
128 *Mitigation Hierarchy* has emerged as a best-practice framework for achieving sustainable
129 development (CSBI, 2015). Practitioners seek to limit negative impacts on biodiversity
130 through a series of steps: avoid, minimise, restore/rehabilitate, and compensate.

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131 Compensation is intended as a last resort for developers seeking to compensate for
132 unavoidable damage, after having applied all other stages. The goal is to achieve no net loss
133 in terms of biodiversity and increasingly, net gain. As developments are typically permanent,
134 the ensuing habitat loss can only be compensated and not mitigated (Elliott & Cutts, 2004).

135

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

145

146 The emerging field of IGGI in the marine environment is producing numerous examples of
147 multifunctional structures yielding multiple biodiversity benefits. This has been achieved
148 through myriad techniques, including manipulating building materials composition, building
149 in topographic complexity and transplanting organisms directly onto substrata (see
150 O’Shaughnessy et al. 2020 for review). To date, much of this has been done by the research
151 community on experimental scales and has typically been applied retrospectively to existing
152 artificial structures. Despite the many possible ecological benefits of IGGI, limitations and

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153 knowledge gaps remain. All experiments have the potential to be oversold, fail, or yield
154 unintended outcomes (Fig. 2, Chapman & Underwood, 2011). IGGI has typically been
155 implemented over limited spatio-temporal scales, with bias towards intertidal and
156 temperate systems (Strain et al., 2018). Often benefits are measured for species, habitats or
157 processes that are not those originally impacted or lost. The goal is typically to encourage
158 colonisation of native species, but responses are unpredictable, particularly under future
159 climate scenarios. 'Success' is typically assessed using ecological metrics (e.g. species
160 richness) or probability tests which have already proven to be inefficient for assessment of
161 restoration success (Palmer & Filoso, 2009). Little is known about the role of multifunctional
162 structures in facilitating the spread of pathogens and non-native species (Firth et al., 2016).
163 Indeed, they may function as ecological traps (reducing fitness of colonising organisms) or
164 environmental filters; leading to biotic and functional homogenisation (McKinney, 2006).
165 There remains a dearth of large demonstration tests that show how interventions will
166 perform when scaled-up operationally in 'real' developments (Evans et al., 2019).

167

168 Seattle, USA and Sydney, Australia have pioneered the implementation of IGGI at
169 ecologically-relevant scales through large-scale urban regeneration (Toft et al., 2013). The
170 incorporation of IGGI in redevelopment/regeneration projects represents a win-win or
171 '*laurel wreath*', with measurable benefits for humans and nature. The promise of making
172 space for nature in new developments that involve breaking ground in natural
173 environments, or through land reclamation is much more limited. Not only could the
174 practice of IGGI be viewed as a '*fig leaf*'; covering up the environmental damage caused by

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175 the development; but if used prospectively to gain consent on the development, it could be
176 viewed as a ‘*Trojan Horse*’; deliberate strategy causing environmental damage.

177

178 **What is the scope for greenwashing?**

179 We are increasingly hearing consultants, developers and local authorities discussing how
180 implementing IGGI can expedite, facilitate and reduce costs of regulatory processes.

181 Through implementation of the Mitigation Hierarchy there is a clear incentive for
182 implementing IGGI. Artificial reefs (analogous to IGGI), have long been deployed as
183 compensation for habitat loss associated with coastal development. Unlike IGGI, artificial
184 reefs have been subject to criticism (Baine, 2001). Here, we draw on the lessons learnt from
185 artificial reefs to illustrate how IGGI could potentially be misused for greenwashing.

186

187 All artificial structures have the capacity to function as ‘artificial reefs’ as they inevitably
188 provide habitat and refuge for marine life. The word “reef” often conjures up images of
189 healthy, diverse biological communities; and may be more acceptable or appealing to
190 developers than sedimentary habitats that may be perceived as “barren”. For instance, the
191 developers of the *Palm Jumeirah* artificial island, Dubai claim that not only is this the
192 ‘world’s largest artificial reef’, but that the construction of *The World* artificial island
193 development actually ‘improved the quality of the seawater surrounding the islands’ in
194 comparison to that tested along the shoreline of Dubai (Nakheel, 2018). Although the
195 breakwaters do support diverse marine life, the new communities differ greatly from
196 natural reefs (Burt et al., 2013). We view this example as a *fig leaf*; covering up the damage

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197 caused by the construction of the island on sedimentary and coral reef habitats (Burt et al.,
198 2008). Some planned artificial reefs are even more pernicious. Whilst some proponents
199 argue that artificial reefs are prudent recycling projects creating valuable fisheries for
200 recreation, many artificial reefs are merely disguised ocean dumping (Fig. 1b). We view such
201 examples as *Trojan Horses* which may be the result of either wilful or misguided intent to
202 dispose of material at sea.

203

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

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219 nonetheless, obvious potential for misrepresentation by the media and misuse by the
220 industry (Macura et al., 2019).

221

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

228

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

238

239 **Where do the opportunities lie?**

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

248

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

257

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

259 Over the last 30 years, Asia and the Middle East have experienced the greatest population
260 and urban growth (United Nations, 2017). Coincidentally, many of these (e.g. United Arab
261 Emirates, Qatar) have constructed some of the most ambitious and iconic land reclamation

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262 projects (Fig. 3), yet few have biodiversity offsetting policies (Biodiversity Consultancy,
263 2017). While controversial, the implementation of offsetting at least gives some indication
264 of willingness to compensate environmental damage. Of the top 50 countries expected to
265 experience the fastest population growth from 2020-2100, 86% are African; 72% of which
266 are coastal (United Nations, 2017). Many of these countries are characterised by some of
267 the largest remaining stretches of 'unaltered' coastlines (Firth et al., 2016), but with limited
268 environmental protection policies (Biodiversity Consultancy, 2017). Whilst
269 megadevelopments continue apace in Asia and the Middle East, arguably, these African
270 countries are the most vulnerable to future habitat loss and megadevelopment.

271

272 **Moving forward, what can be done?**

273 Whilst it is impossible for scientists to prevent their science being used for harm, there are a
274 number of things that they can do to improve the science and to reduce the risk of such
275 practice. The majority of IGGI projects have been conducted in few locations, under
276 particular environmental conditions and over short timescales. These experiments should
277 be revisited, repeated and expanded on (e.g. Hsiung et al. 2020) to improve the evidence
278 base for policy development. The rise of the global research network (e.g.
279 www.worldharbourproject.org) represents a great platform for implementation of large-
280 scale experiments and information sharing. Furthermore, the research and practice should
281 move together in tandem. New developments and redevelopments should trial and
282 implement IGGI. Such projects will provide essential insight into how biological communities
283 will respond at anthropogenically and ecologically relevant scales. The information gathered

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284 from such experiments should be collated in an evidence-based catalogue (Evans et al.,
285 2019) that is constantly updated and made available to policy makers and practitioners in a
286 globally available and accessible format such as Conservation Evidence
287 (www.conservationevidence.com).

288

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

294

295 Finally, we advocate that greater attention is given to when experiments ‘fail’ or yield
296 unintended outcomes. Researchers should not be afraid to point out shortcomings and
297 limitations to ensure broader progress; and should be careful not to oversell short-term,
298 localised experimental trials. In an age of Open Science, research ‘impact’, and “perverse
299 incentives and hypercompetition” in academia (Edwards & Roy 2017), now more than ever,
300 researchers must maintain standards and scientific integrity. It is important that researchers
301 exercise nuance in the manner in which they communicate their findings, and that
302 developers, planners and decision-makers responsibly use the research-based knowledge
303 available to them. Furthermore, the point above about failure and unintended outcomes
304 could also be extended to funders and publishers in particular. Publication bias, whereby
305 studies reporting positive outcomes are more likely to be published and cited more, is

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306 particularly prevalent in the applied and biological sciences with implications for scientific
307 and social agendas (Fanelli, 2013). We urge that publishers actively encourage and promote
308 null and negative results in an effort to reduce the risk from this potentially harmful
309 practice.

310

311 **Conclusions**

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

317

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328 **Authors' contributions**

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

331 **Data availability statement**

332 This article does not use data.

333

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488 Figure 1. Coastal artificialisation. (a) Hong Kong condensed into narrow coastal strip. (b)

489 Treadmill dumped as part of artificial reef, Malaysia. (c) Artificial structures in industrialised

490 landscape, UK.

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492 Figure 2. Unintended outcomes from IGGI experiments. Drilled pits after five (a) and nine

493 years (b); longer-term observations revealed that many (red circle indicates outline) had

494 become dominated by individual barnacles. (c) Drilled rockpools after 1.5 (c) and five years

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495 (d); longer-term observations revealed that some rockpools filled up with the worm
496 *Sabellaria alveolata*. (e) The BIOBLOCK is a habitat-enhancement unit. Following 2013/14
497 storms the BIOBLOCK become covered by sand; it was still buried in 2019. All examples from
498 Firth et al. (2014).

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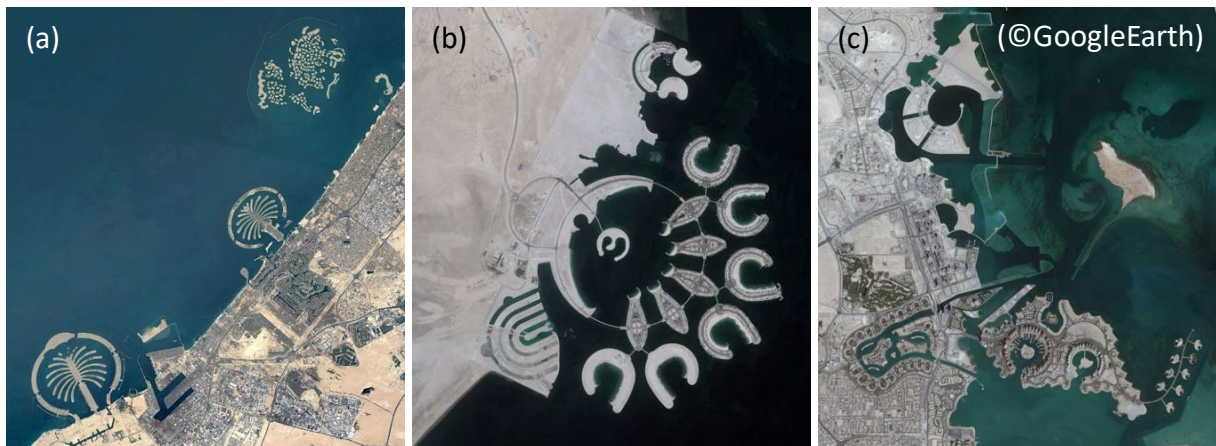
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509 Figure 3. Artificial island construction in (a) Dubai; (b) Bahrain; (c) Qatar.

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