2017-02-10

Ecological responses to environmental change in marine systems

Knights, Antony

<http://hdl.handle.net/10026.1/8026>

10.1016/j.jembe.2017.01.016

Journal of Experimental Marine Biology and Ecology

Elsevier BV

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

Ecological responses to environmental change in marine systems

Antony M. Knights¹, Louise B. Firth², Bayden D. Russell³

¹ School of Marine Science and Engineering, Plymouth University, Plymouth, UK

² School of Geography, Earth and Environmental Science, Plymouth University, UK

³ Swire Institute of Marine Science and School of Biological Sciences, The University of Hong Kong, Hong Kong Special Administrative Region, P. R. China.

Corresponding author: Antony M. Knights, antony.knights@plymouth.ac.uk

Background to volume

Worldwide, the structure of marine communities is being transformed by threats as diverse as climate change, ocean acidification, human introductions of invasive species, and habitat damage, loss or disturbance. Evidence of ecological responses to these threats are increasingly common, manifested in a variety of ways from changes in the behaviour of organisms, to increasing prevalence of disease, changes in the structure, functioning and distribution of species and communities, and efforts to mitigate threats and conserve biodiversity. These responses are occurring across a range of geographic scales, from local, to regional and global, and efforts to understand changes in marine ecosystems are at the forefront of science today. These questions were the focus of the 2015 Aquatic Biodiversity and Ecosystems Conference (ABEC) and this Special Issue presents some of the on-going challenges, solutions and evidence of these responses that emerged from this conference.

Threats to natural systems

There are numerous threats to marine ecosystems originating from a complex web of human activities, occurring at a range of spatial and temporal scales (Halpern et al. 2008; Knights et al. 2015). Whilst many of these threats are largely manageable, perhaps some of the greatest challenges – habitat loss, climate change, invasive species and ocean acidification – are less so, and the impacts of those threats continue to be at the forefront of scientific research today.

Global temperatures continue to increase at unprecedented rates (IPCC 2014) due to historic and continued greenhouse gas emissions, but steps to mitigate impacts are expected to take at least 50 years before effects are seen (Firth & Hawkins, 2011). The impacts of climate change on marine ecosystems are wide and varied (Harley et al., 2006; Rosenzweig et al., 2008): reductions in sea ice (Stocker et al., 2013), increased frequency and intensity of storms (Kossin and Vimont, 2007; Smale et al., 2015), extreme weather events (Crisp, 1964; Firth et al., 2011, 2015; Wetthey et al., 2011; Wernberg et al., 2016) and

37 drought (Diffenbaugh et al., 2015) are particularly obvious examples that have led to catastrophic whole
38 ecosystem changes (Johnson et al., 2011; Russell et al., 2011; Filbee-Dexter and Scheibling, 2014). The
39 implications of global climate change for marine habitats and species are great (Hawkins et al., 2009) but
40 the extent and severity of impacts are yet to be fully revealed (Swart et al., 2015).

41
42 Ocean acidification also continues to pose a significant threat to marine ecosystems. In recent years, there
43 has been a burgeoning literature in this field (Gaylord et al., 2015), many of which focused on impacts on
44 early life-history stages (Byrne, 2011; Findlay et al., 2010a; Findlay et al., 2010b) and to a lesser degree,
45 adults (but see Findlay et al., 2009; Gooding et al., 2009; Rodolfo-Metalpa et al., 2011) of plants and
46 animals. Recent studies have suggested historic ocean acidification linked to the Permian-Triassic mass
47 extinction led to the disappearance of ~90% of marine species (Clarkson et al., 2015). Today, surface ocean
48 hydrogen ion (H^+) concentrations are predicted to increase a further 150 % by 2100 (Stocker et al., 2013).
49 Numerous taxa at first glance appear robust to OA, but when coupled with increased temperature
50 predictions (i.e. ocean acidification-warming scenarios), the persistence of many marine species and
51 associated ecosystem services is less certain (Kroeker et al. 2013).

52
53 The introduction of non-native species into new areas, either through intentional (e.g. aquaculture,
54 (Knights et al., 2016; Wetthey et al., 2011; Woodin et al., 2014) or unintentional means (ballast water or hull
55 fouling; Wonham et al., 2005; Drake and Lodge, 2007; Mineur et al. 2007) is of continuing concern,
56 especially given the costs associated with the successful establishment of invasive species to ecosystem
57 services (Costanza et al., 1997; Pimentel et al., 2005). It has been estimated that ~10,000 species are
58 transported globally by these methods alone (Carlton, 1999). The mechanisms of invasion success remain
59 unclear, although evidence suggests the likelihood of establishment may be limited by the existence of
60 intact native species communities (Elton, 1958; Stachowicz et al., 2002; Levine et al., 2004; Arenas et al.
61 2006). Recently, studies have suggested that the traits and functions of invasives are more similar to those
62 of native species than previously suggested (Wilkie et al., 2012; Zwerschke et al., 2016, but see Borsje et al
63 2011 for an example of where the non-native outperforms the native), such that the competitiveness (and
64 likelihood of establishment) of invading species is high (Freestone et al., 2011; Freestone et al., 2013). This
65 competitiveness is also likely to increase into the future, at least in part, because invasive species often
66 have broad tolerance for a range of environmental conditions, such as temperature, and so may have a
67 competitive advantage over local species which are better adapted to the local environment (Zerebecki &
68 Sorte 2011).

69
70 As the human population continues to expand (Gerland et al., 2014) and given the propensity to live by the
71 coast, there has been a significant expansion in the use of artificial structures to protect coastal habitats
72 from climate change impacts such as increased erosion. The introduction of artificial structures has had a

number of impacts including the loss or replacement of natural habitats (Bulleri and Chapman, 2010; Dugan et al., 2011), change in environmental conditions (Airoldi et al., 2005; Wilson and Elliott 2009), breaking down of biogeographic barriers (Dong et al. 2016), and change in community composition including facilitating the establishment and spread of invasive species (Fig. 1, Mineur et al., 2012; Airoldi et al., 2015; Firth et al., 2016).

Ecological Responses

The impact of these threats to marine habitats is great, especially as marine habitats from the intertidal zone out to the continental shelf break (and those under greatest threat) are estimated to provide ~43% of global ecosystem goods (e.g. food, raw materials) and services (e.g. nutrient cycling, carbon sequestration) per year (Costanza et al., 1997). Amelioration of these impacts, in some instances, can be achieved through active management or conservation efforts, or by adaptation by species themselves.

Fig. 1. Proliferation of non-native barnacle (*Austrominius modestus*) and non-native oyster (*Crassostrea gigas*) species interspersed with native barnacles, *Semibalanus balanoides*, on a rocky shore in Plymouth, England. Recruitment has been facilitated by the introduction of artificial substrate on previously open and exposed bedrock. Photo credit: A.M. Knights (unpublished).

The ecological responses of marine organisms to environmental change are highly variable both within and between species depending on the relationship between the organism and its environment (Chevin et al.,

2010; Harley et al., 2006). Moritz and Agudo (2013 and references therein) refer to a combination of exposure (at regional or mesoscales) and intrinsic sensitivity (tolerance) as drivers of species vulnerability. They argue that mediation of vulnerability can be achieved by a range of biological responses, including: reductions in body size (Sheridan and Bickford, 2011), changes in abundance, phenological and range shifts (Parmesan, 2006; Parmesan and Yohe, 2003; Mieszkowska et al., 2005, 2014), altered animal behaviour (Sih, 2013), localised adaption (Hansen et al., 2013; Hof et al., 2011; Muir et al., 2016), but may also be characterised by increased incidence of disease and parasites (Hari et al., 2006; Lindgren and Gustafson, 2001) and local extinction (e.g. Pounds, et al. 2005; Poloczanska et al., 2008; Wetthey et al., 2011). Variability in species performance, community composition or general response to environmental change at local and regional scales (Muir et al., 2014) is increasingly being shown to affect ecosystem functioning, stability, and ecosystem service provision (McCann, 2000; Naeem, 1998; Tilman et al., 2006) and was an important focus of many talks and posters presented at the ABEC Conference.

107

108 **Structure of the volume**

109 This Special Issue volume of *the Journal of Experimental Marine Biology and Ecology* is a compilation of
110 articles emerging from the Aquatic Biodiversity and Ecosystems Conference (ABEC) held at the University of
111 Liverpool in September 2015. Originally conceived as a follow-up and review of the 1990 Conference *Plant-
112 Animal Interactions in the Marine Benthos*, ABEC addressed eight themes falling under the broad banner of
113 “Evolution, Interactions and Global change”. The themes were: (i) Evolutionary Biology, (ii) Fisheries and
114 Aquaculture, (iii) Dispersal and Connectivity, (iv) General Aquatic Biology, (v) Global Environmental Change,
115 (vi) Food webs and trophic dynamics, (vii) Conservation, Management and Policy, and (viii) Biodiversity,
116 Ecosystem Functioning and Services.

117

118 This Special Issue is a compilation of reviews and research articles, each of which, fall under one of these
119 themes. Reviews include the effect of ocean sprawl on ecological connectivity (Bishop et al. 2016) and soft
120 sediment habitats (Heery et al. this issue), ocean acidification impacts on ecosystem service provision in
121 oysters (Lemasson et al. this issue), nutrient flux across the land-sea interface (Moss, this issue) and a
122 global analysis of the role of kelp forests as biogenic habitat formers (Teagle et al. this issue). Research
123 articles include environmental factors affecting host-parasite interactions (Firth et al. this issue), habitat
124 complexity of artificial structures affecting biodiversity (Lavender et al. this issue, Loke et al. this issue),
125 impacts of climate change on intertidal ectotherm behaviour (Ng et al. this issue) and larval metamorphosis
126 in response to biofilm cues (Simith et al. this issue).

127

128 Finally, we dedicate and open this volume with a tribute to Professor Roger Hughes, formerly Editor-in-
129 Chief of the *Journal of Experimental Marine Biology and Ecology*. Thanks to Professor Bob Elner for

agreeing to write this fitting tribute and especially to Helen Hughes for providing much of the information and long-time Roger's right-hand 'man' – she is deserving of tributes of her own!

Acknowledgments

Compiling this special edition has been a rewarding challenge that couldn't have been achieved without the efforts of all of those who were involved in its preparation and production. We must firstly thank Professor Sandra Shumway, Editor-in-Chief of the Journal of Experimental Marine Biology and Ecology, for giving us the opportunity to produce this special issue. We are also extremely grateful to all the authors for submitting papers to make this exciting issue covering a broad range of topics, and to all the peer-reviewers who helped to draw the contributions together. Without your donated time, we would not have been able to complete this volume. We also wish to thank the staff at the Journal of Experimental Marine Biology and Ecology for their help in the production of this special volume. But finally, we wish to acknowledge the legacy and contribution of two great scientists, one who this volume is dedicated to, and another who sadly passed away during the production of this volume. To Professor Roger Hughes and Professor Brian Moss – you are missed.

References

- Airoidi, L., Abbiati, M., Beck, M.W., Hawkins, S.J., Jonsson, P.R., Martin, D., Moschella, P.S., Sundelöf, A., Thompson, R.C. Åberg, P. 2005. An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. *Coast. Engineer.*, 52(10), 1073-1087.
- Arenas, F., Sánchez, I., Hawkins, S.J. Jenkins, S.R. 2006. The invasibility of marine algal assemblages: role of functional diversity and identity. *Ecology*, 87(11), 2851-2861.
- Bishop, M.J., Mayer-Pinto, M., Airoidi, L., Firth, L.B., Morris, R.L., Loke, L.H.L., Hawkins, S.J., Naylor, L.A., Coleman, R.A., Chee, S.Y., Dafforn, K.A. XXXX. Effects of ocean sprawl on ecological connectivity: impacts and solutions. *J. Exp. Mar. Biol. Ecol.*, THIS ISSUE
- Borsje, B.W., van Wesenbeeck, B.K., Dekker, F., Paalvast, P., Bouma, T.J., van Katwijk, M.M. de Vries, M.B. 2011. How ecological engineering can serve in coastal protection. *Ecol. Engineer.*, 37(2), 113-122.
- Bulleri, F., Chapman, M.G. 2010. The introduction of coastal infrastructure as a driver of change in marine environments. *J. Appl. Ecol.*, 47(1), 26-35.
- Byrne, M. 2011. Impact of ocean warming and ocean acidification on marine invertebrate life history stages: Vulnerabilities and potential for persistence in a changing ocean. *Oceanogr. Mar. Biol. Ann. Rev.*, 49, 1-42.
- Carlton, J.T. 1999. The scale and ecological consequences of biological invasions in the World's oceans, In: Sandlund, O.T., Schei, P.J., Viken, A. (Eds.). Kluwer Academic Publishers, 195-212.
- Chevin, L.M., Lande, R., Mace, G.M. 2010. Adaptation, plasticity, and extinction in a changing environment: towards a predictive theory. *PLoS Biol*, 8(4), p.e1000357.
- Clarkson, M.O., Kasemann, S.A., Wood, R.A., Lenton, T.M., Daines, S.J., Richoz, S., Ohnemuehler, F., Meixner, A., Poulton, S.W., Tipper, E.T. 2015. Ocean acidification and the Permo-Triassic mass extinction. *Science*, 348(6231), 229-232.

170 Costanza, R., d'Arge, R., De Groot, R., Faber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V.,
171 Paruelo, J., Raskin, R.G. 1997. The value of the world's ecosystem services and natural capital. *Nature*,
172 387, 253-260.

173 Crisp, D.J. 1964. The effects of the severe winter of 1962-63 on marine life in Britain. *Journal of Animal*
174 *Ecology*, 33(1), 165-210.

175 Diffenbaugh, N.S., Swain, D.L., Touma, D., 2015. Anthropogenic warming has increased drought risk in
176 California. *Proc. Nat. Acad. Sci.*, 112(13), 3931-3936.

177 Dong, Y.W., Huang, X.W., Wang, W., Li, Y., Wang, J., 2016. The marine 'great wall' of China: local- and
178 broad-scale ecological impacts of coastal infrastructure on intertidal macrobenthic communities. *Diversity*
179 *and Distributions* 22(7), 731-744.

180 Drake, J.M., Lodge, D.M. 2007. Hull fouling is a risk factor for intercontinental species exchange in aquatic
181 ecosystems. *Aquatic Invasions*, 2(2), 121-131.

182 Dugan, J.E., Airolidi, L., Chapman, M.G., Walker, S.J., Schlacher, T., Wolanski, E., McLusky, D. 2011. Estuarine
183 and coastal structures: environmental effects, a focus on shore and nearshore structures. *Treatise on*
184 *estuarine and coastal science*, 8, 17-41.

185 Elton, C.S. 1958. *The ecology of invasions by animals and plants*. Methuen, London.

186 Filbee-Dexter, K., Scheibling, R.E. 2014. Sea urchin barrens as alternative stable states of collapsed kelp
187 ecosystems. *Mar. Ecol. Prog. Ser.* 495, 1-25.

188 Findlay, H.S., Burrows, M.T., Kendall, M.A., Spicer, J.I., Widdicombe, S. 2010a. Can ocean acidification affect
189 population dynamics of the barnacle *Semibalanus balanoides* at its southern range edge?. *Ecology*,
190 91(10), pp.2931-2940.

191 Findlay, H.S., Kendall, M.A., Spicer, J.I., Widdicombe, S., 2009. Future high CO₂ in the intertidal may
192 compromise adult barnacle *Semibalanus balanoides* survival and embryonic development rate. *Mar. Ecol.*
193 *Prog. Ser.*, 389, 193-202.

194 Findlay, H.S., Kendall, M.A., Spicer, J.I., Widdicombe, S. 2010. Post-larval development of two intertidal
195 barnacles at elevated CO₂ and temperature. *Mar. Biol.*, 157(4), 725-735.

196 Firth, L.B., Knights, A.M., Bell, S.S. 2011. Air temperature and winter mortality: implications for the
197 persistence of the invasive mussel, *Perna viridis* in the intertidal zone of the south-eastern United States.
198 *J. Exp. Mar. Biol. Ecol.*, 400(1), 250-256.

199 Firth, L.B., Mieszkowska, N., Grant, L.M., Bush, L.E., Davies, A.J., Frost, M.T., Moschella, P.S., Burrows, M.T.,
200 Cunningham, P.N., Dye, S.R., Hawkins, S.J. 2015. Historical comparisons reveal multiple drivers of decadal
201 change of an ecosystem engineer at the range edge. *Ecol. Evol.*, 5(15), 3210-3222.

202 Firth, L.B., Knights, A.M., Thompson, R.C., Mieszkowska, N., Bridger, D., Evans, A., Moore, P.J., O'Connor,
203 N.E., Sheehan, E.V., Hawkins, S.J. 2016. Ocean sprawl: challenges and opportunities for biodiversity
204 management in a changing world. *Oceanography and Mar. Biol. Ann. Rev.* 54, 193-269.

205 Firth, L.B., Grant, L.M., Crowe, T.P., Ellis, J.S., Wiler, C., Convery, C., O'Connor, N.E., XXXX. Factors affecting
206 the prevalence of the trematide parasite *Echinostephila patellae* (Lebour, 1911) in the limpet *Patella*
207 *vulgata* (L.). *J. Exp. Mar. Biol. Ecol.* THIS ISSUE.

208 Freestone, A.L., Osman, R.W., Ruiz, G.M., Torchin, M.E., 2011. Stronger predation in the tropics shapes
209 species richness patterns in marine communities. *Ecology*, 92(4), 983-993.

210 Freestone, A.L., Ruiz, G.M., Torchin, M.E., 2013. Stronger biotic resistance in tropics relative to temperate
211 zone: effects of predation on marine invasion dynamics. *Ecology*, 94(6), 1370-1377.

212 Gaylord, B., Kroeker, K.J., Sunday, J.M., Anderson, K.M., Barry, J.P., Brown, N.E., Connell, S.D., Dupont, S.,
213 Fabricius, K.E., Hall-Spencer, J.M., Klinger, T., Milazzo, M., Munday, P.L., Russell, B.D., Sanford, E.,
214 Schreiber, S.J., Thiyagarajan, V., Vaughan, M.L.H., Widdicombe, S., Harley, C.D.G., 2015. Ocean
215 acidification through the lens of ecological theory. *Ecology* 96(1), 3-15.

216 Gerland, P., Raftery, A.E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B.K., Chunn, J.,
217 Lalic, N., Bay, G. 2014. World population stabilization unlikely this century. *Science*, 346(6206), 234-237.

218 Gooding, R.A., Harley, C.D., Tang, E. 2009. Elevated water temperature and carbon dioxide concentration
219 increase the growth of a keystone echinoderm. *Proc. Nat. Acad. Sci.*, 106(23), 9316-9321.

220 Hansen, G.J., Ives, A.R., Vander Zanden, M.J., Carpenter, S.R. 2013. Are rapid transitions between invasive
221 and native species caused by alternative stable states, and does it matter?. *Ecology*, 94(10), 2207-2219.

222 Hari, R.E., Livingstone, D.M., Siber, R., Burkhardt-Holm, P., Guettinger, H. 2006. Consequences of climatic
223 change for water temperature and brown trout populations in Alpine rivers and streams. *Glob. Change*
224 *Biol.*, 12(1), 10-26.

225 Harley, C.D., Randall Hughes, A., Hultgren, K.M., Miner, B.G., Sorte, C.J., Thornber, C.S., Rodriguez, L.F.,
226 Tomanek, L., Williams, S.L. 2006. The impacts of climate change in coastal marine systems. *Ecology*
227 *letters*, 9(2), 228-241.

228 Hawkins, S.J., Sugden, H.E., Mieszkowska, N., Moore, P.J., Poloczanska, E., Leaper, R., Herbert, R.J., Genner,
229 M.J., Moschella, P.S., Thompson, R.C. Jenkins, S.R. 2009. Consequences of climate-driven biodiversity
230 changes for ecosystem functioning of North European rocky shores. *Marine Ecology Progress Series*, 396,
231 245-259.

232 Heery, E., Bishop, M.J., Critchley, L., Bugnot, A.B., Airoidi, L., Mayer-Pinto, M., Sheehan, E.V., Coleman, R.A.,
233 Loke, L.H.L., Johnston, E.L., Komyakova, V., Morris, R.L., Strain, E., Naylor, L.A., Dafforn, K.A. XXXX.
234 Identifying the consequences of ocean sprawl for sedimentary habitats. *J. Exp. Mar. Biol. Ecol.*, THIS ISSUE

235 Hof, C., Levinsky, I., Araujo, M.B., Rahbek, C. 2011. Rethinking species' ability to cope with rapid climate
236 change. *Glob. Change Biol.*, 17(9), 2987-2990.

237 Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Frusher, S.D., Gardner, C.,
238 Haddon, M., Helidoniotis, F., Hill, K.L. 2011. Climate change cascades: Shifts in oceanography, species'
239 ranges and subtidal marine community dynamics in eastern Tasmania. *J. Exp. Mar. Biol. Ecol.*, 400(1), 17-
240 32.

241 Knights, A.M., Firth, L.B., Thompson, R.C., Yunnice, A.L., Hiscock, K., Hawkins, S.J. 2016. Regional Studies in
242 Marine Science. In Press

243 Kossin, J.P., Vimont, D.J. 2007. A more general framework for understanding Atlantic hurricane variability
244 and trends. *B Am Meteorol Soc* 88, 1767.

245 Kroeker, K.J., Kordas, R.L., Crim, R., Hendriks, I.E., Ramajo, L., Singh, G.S., Duarte, C.M., Gattuso, J.P., 2013.
246 Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with
247 warming. *Global Change Biology* 19(6), 1884-1896.

248 Lavender, J.T., Dafforn, K.A., Bishop, M.J., Johnston, E.L. XXXX. Negative interactions between ecosystem
249 engineers lead to the formation of habitat mosaics at small scales. *J. Exp. Mar. Biol. Ecol.* THIS ISSUE

250 Lemasson, A.J., Fletcher, S., Hall-Spencer, J.M., Knights, A.M. Linking the biological impacts of ocean
251 acification on oysters to changes in ecosystem services: a review. *J. Exp. Mar Biol. Ecol.* THIS ISSUE

252 Levine, J.M., Adler, P.B., Yelenik, S.G. 2004. A metaanalysis of biotic resistance to exotic plant invasions.
253 *Ecol. lett.*, 7(10), 975-989.

254 Lindgren, E., Gustafson, R. 2001. Tick-borne encephalitis in Sweden and climate change. *Lancet* 358, 16-18.

255 Loke, L.J.L, Bouma, T.J., Todd, P.A. XXXX. The effects of manipulating microhabitat size and variability on
256 tropical seawall biodiversity: field and flume experiments. *J. Exp. Mar Biol. Ecol.* THIS ISSUE

257 McCann, K.S. 2000. The diversity-stability debate. *Nature* 405, 228-233.

258 Mieszkowska, N., Kendall, M.A., Hawkins, S.J., Leaper, R., Williamson, P., Hardman-Mountford, N.J.,
259 Southward, A.J. 2006. Changes in the range of some common rocky shore species in Britain—a response to
260 climate change?. *Hydrobiologia*, 555(1), 241-251.

261 Mieszkowska, N., Sugden, H., Firth, L.B., Hawkins, S.J., 2014. The role of sustained observations in tracking
 262 impacts of environmental change on marine biodiversity and ecosystems. *Phil. Trans. R. Soc. Lond. A.*,
 263 372(2025), 20130339.

264 Mineur, F., Johnson, M.P., Maggs, C.A., Stegenga, H. 2007. Hull fouling on commercial ships as a vector of
 265 macroalgal introduction. *Mar. Biol.*, 151(4), 1299-1307.

266 Mineur, F., Cook, E.J., Minchin, D., Bohn, K., MacLeod, A., Maggs, C.A., 2012. Changing coasts: marine aliens
 267 and artificial structures. *Oceanogr. Mar. Biol. Ann. Rev.*, 50, 189-234.

268 Moritz, C., Agudo, R. 2013. The future of species under climate change: resilience or decline? *Science* 341,
 269 504-508.

270 Moss, B. XXXX. Marine reptiles, birds and mammals and nutrient transfers among the seas and the land: an
 271 appraisal of current knowledge. *J. Exp. Mar. Biol. Ecol.* THIS ISSUE

272 Muir, A.P., Biek, R., Thomas, R., Mable, B.K. 2014. Local adaptation with high gene flow: temperature
 273 parameters drive adaptation to altitude in the common frog (*Rana temporaria*). *Molec. Ecol.*, 23(3), 561-
 274 574.

275 Muir, A.P., Nunes, F.L., Dubois, S.F., Pernet, F. 2016. Lipid remodelling in the reef-building honeycomb
 276 worm, *Sabellaria alveolata*, reflects acclimation and local adaptation to temperature. *Sci. Rep.*, 6.

277 Naeem, S. 1998. Species redundancy and ecosystem reliability. *Conserv. Biol.* 12, 39-45.

278 Ng, T.P.T., Lau, S.L.Y., Seuront, L., Daves, M.S., Stafford, R., Marshall, D.J., Williams, G.A., XXXX. Linking
 279 behaviour and climate change in intertidal ectotherms: insights from littorinid snails. *J. Exp. Mar. Biol.*
 280 *Ecol.* THIS ISSUE

281 Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annu Rev Ecol Evol S*
 282 37, 637-669.

283 Parmesan, C., Yohe, C. 2003. A globally coherent fingerprint of climate change impacts across natural
 284 systems. *Nature* 421, 37-42.

285 Pimentel, D., Zuniga, R., Morrison, D. 2005. Update on the environmental and economic costs associated
 286 with alien-invasive species in the United States. *Ecol. Econ.*, 52(3), 273-288.

287 Poloczanska, E.S., Hawkins, S.J., Southward, A.J., Burrows, M.T. 2008. Modeling the response of populations
 288 of competing species to climate change. *Ecology*, 89(11), 3138-3149.

289 Pounds JA, Fogden MPL, Masters KL (2005) Responses of natural communities to climate change in a
 290 highland tropical forest. A Case Study. In: Hannah, Lovejoy & Schneider, "Biodiversity and climate change
 291 in context" pp. 70-74. Yale University Press, New Haven.

292 Rodolfo-Metalpa, R., Houlbrèque, F., Tambutté, É., Boisson, F., Baggini, C., Patti, F.P., Jeffree, R., Fine, M.,
 293 Foggo, A., Gattuso, J.P., Hall-Spencer, J.M. 2011. Coral and mollusc resistance to ocean acidification
 294 adversely affected by warming. *Nat. Clim. Change*, 1(6), 308-312.

295 Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T.L., Estrella, N.,
 296 Seguin, B., Tryjanowski, P. 2008. Attributing physical and biological impacts to anthropogenic climate
 297 change. *Nature*, 453(7193), 353-357.

298 Russell, B.D., Harley, C.D., Wernberg, T., Mieszkowska, N., Widdicombe, S., Hall-Spencer, J.M., Connell, S.D.
 299 2011. Predicting ecosystem shifts requires new approaches that integrate the effects of climate change
 300 across entire systems. *Biol. Lett.*, p.rsbl20110779.

301 Sheridan, J.A., Bickford, D. 2011. Shrinking body size as an ecological response to climate change. *Nat. Clim.*
 302 *Change* 1, 401-406.

303 Sih, A. 2013. Understanding variation in behavioural responses to human-induced rapid environmental
 304 change: a conceptual overview. *Anim. Behav.* 85, 1077-1088.

305 Simith, D.J.B., Abrunhosa, F.A., Diele, K. XXXX. Metamorphosis of the edible mangrove crab *Ucides cordatus*
306 (*Ucididae*) in response to benthic microbial films. *J. Exp. Mar. Biol. Ecol.* THIS ISSUE

307 Smale, D.A., Yunnice, A.L., Vance, T., Widdicombe, S., 2015. Disentangling the impacts of heat wave
308 magnitude, duration and timing on the structure and diversity of sessile marine assemblages. *PeerJ*, 3,
309 p.e863.

310 Stachowicz, J.J., Fried, H., Osman, R.W., Whitlatch, R.B., 2002. Biodiversity, invasion resistance, and marine
311 ecosystem function: reconciling pattern and process. *Ecology*, 83(9), 2575-2590.

312 Stocker, T., et al., 2013. IPCC, 2013: climate change 2013: the physical science basis. Contribution of
313 working group I to the fifth assessment report of the intergovernmental panel on climate change.

314 Swart, N.C., Fyfe, J.C., Hawkins, E., Kay, J.E., Jahn, A. 2015. Influence of internal variability on Arctic sea-ice
315 trends. *Nat. Clim. Change*, 5(2), 86-89.

316 Teagle, H., Hawkins S.J., Moore, P.J., Smale, D.A., XXXX. The role of kelp species as biogenic habitat formers
317 in coastal marine ecosystems. *J. Exp. Mar. Biol. Ecol.* THIS ISSUE

318 Tilman, D., Reich, P.B., Knops, J.M. 2006. Biodiversity and ecosystem stability in a decade-long grassland
319 experiment. *Nature*, 441(7093), 629-632.

320 Wernberg, T., Bennett, S., Babcock, R.C., de Bettignies, T., Cure, K., Depczynski, M., Dufois, F., Fromont, J.,
321 Fulton, C.J., Hovey, R.K., Harvey, E.S. 2016. Climate-driven regime shift of a temperate marine ecosystem.
322 *Science*, 353(6295), pp.169-172.

323 Wethey, D.S., Woodin, S.A., Hilbish, T.J., Jones, S.J., Lima, F.P., Brannock, P.M. 2011. Response of intertidal
324 populations to climate: effects of extreme events versus long term change. *J. Exp. Mar. Biol. Ecol.*, 400(1),
325 132-144.

326 Wilkie, E.M., Bishop, M.J., O'Connor, W.A. 2012. Are native *Saccostrea glomerata* and invasive *Crassostrea*
327 *gigas* oysters' habitat equivalents for epibenthic communities in south-eastern Australia?. *J. Exp. Mar.*
328 *Biol. Ecol.*, 420, 16-25.

329 Wilson, J.C., Elliott, M. 2009. The habitat - creation potential of offshore wind farms. *Wind Energy*, 12(2),
330 203-212.

331 Wonham, M.J., Lewis, M.A., MacIsaac, H.J. 2005. Minimizing invasion risk by reducing propagule pressure: a
332 model for ballast - water exchange. *Front. Ecol. Envir.*, 3(9), 473-478.

333 Woodin, S.A., Wethey, D.S., Dubois, S.F. 2014. Population structure and spread of the polychaete *Diopatra*
334 *biscayensis* along the French Atlantic coast: Human-assisted transport by-passes larval dispersal. *Mar.*
335 *Envir. Res.*, 102, 110-121.

336 Zerebecki, R.A. and Sorte, C.J., 2011. Temperature tolerance and stress proteins as mechanisms of invasive
337 species success. *PLoS One*, 6(4), p.e14806.

338 Zwerschke, N., Emmerson, M.C., Roberts, D., O'Connor, N.E. 2016. Benthic assemblages associated with
339 native and non-native oysters are similar. *Mar. Poll. Bull.*, 111(1), 305-310.