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Ethics of Assisted Evolution in Marine Conservation

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Climate change is outpacing existing rates of evolution and adaptation for many marine organisms. Human societies are pushing hard to find new solutions to save and protect marine ecosystems, generating research on manipulating genetics of wild organisms for the goal of conservation. This – "assisted evolution" – raises challenging ethical questions because the intention is not to revert to a previous *status quo*, but to modify a community so that it survives better in the conditions we have created. In so doing, our role changes toward "designers" of nature, which requires a rethinking of what is natural, and whether altering or influencing genetics of wild organisms changes the way we conceptualize nature. Assisted evolution could also perpetuate damaging habits and dispositions, such as commodification and technological intervention, which have caused the harm in the first place. Even if we feel morally obliged to repair ecosystems, we still risk further havoc if our attempts to fix our damage are affected by ignorance. Still, from an ethical point of view, we offer cautious support for research on assisted evolution tools. However, we must be clear that we are using these approaches for our own benefit, and should only proceed when they are adequately understood and other options are exhausted. In many cases, we should instead focus our efforts on protecting what we can, minimizing future damage, and understanding future changes. Either way, we need stronger ethical regulations on applying assisted evolution techniques in marine conservation so that there is sufficient deliberation before we use these tools.

Keywords: assisted gene flow, translocation, genetic rescue, intervention, natural, climate change mitigation, adaptation, restoration

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ASSISTED EVOLUTION: A NEW APPROACH TO CONSERVATION

In this era of the Anthropocene, climate change is rapidly altering our oceans and outpacing existing rates of evolution and adaptation for many marine organisms (Doney et al., 2012; Deutsch et al., 2015). Warming sea temperatures are driving the loss of unique polar ecosystems (Kortsch et al., 2012), while creating degraded, or no-analog communities in tropical regions (Hobbs et al., 2011; Filbee-Dexter and Wernberg, 2018). For many, the idea that humans are impacting the ocean to this extent – from remote polar seas (Ramirez-Llodra et al., 2011; Lee et al., 2017) – is a source of anxiety or distress (Lotze et al., 2018). Not to mention, the loss of these ecosystems has serious consequences for coastal societies relying on resources they provide (Costanza, 2000).

The threat to our ocean has triggered a call for immediate and effective conservation action. Existing conservation tools such as establishing MPAs, reducing exploitation, and restoring habitat are effective to some degree (e.g., Halpern and Warner, 2003; Sala and Giakoumi, 2018). However, in other cases, these tools are not being implemented effectively, or are proving inadequate to cope with rapidly changing ocean conditions (Seastedt et al., 2008; Hobbs, 2013; Hughes et al., 2017). This has provoked some researchers to argue for more active interventions to promote recovery or enhance the capacity of ecosystems to tolerate stress from climate-driven impacts (Schlaepfer et al., 2009; Aitken and Whitlock, 2013; van Oppen et al., 2015; Cinner et al., 2016; Anthony et al., 2017; Gattuso et al., 2018).

Assisted evolution is a conservation strategy that involves manipulating the genes of organisms in order to enhance their resilience to climate change and other human impacts. The potential for impacted or vulnerable species to genetically adapt to handle changing environmental conditions depends on the standing genetic variation in the population and how quickly new genetic changes are incorporated (Somero, 2010). Assisted evolution strategies aim to accelerate the rate of naturally occurring evolutionary processes. Such measures include moving resilient individuals to vulnerable margins of their species distribution, or genetically modifying wild species to promote recovery or increase their capacity to resist stressors (Jones and Monaco, 2009; Aitken and Whitlock, 2013; O'Leary et al., 2017). In this paper, we focus on the use of assisted evolution to combat climate change specifically, because we are locked into the effects of such changes, regardless of actions to reduce emissions now (IPCC, 2014). This provides a strong incentive and argument for research into these solutions.

To date, assisted evolution has been almost exclusively discussed in the context of terrestrial systems, namely assisted migration in forests. Its implementation in the place of traditional conservation tools has generated intense debate, which has centered on the trade-off between possible benefits and risk of harm to ecosystems; and there is a lack of consensus on this issue (McLachlan et al., 2007; Ricciardi and Simberloff, 2009; Minteer and Collins, 2010; Hewitt et al., 2011; Marris, 2014). Despite this, governmental agencies, international organizations, and conservation groups are recommending, or even beginning to implement, forms of assisted evolution as climate change adaptation strategies (Foden et al., 2008; Shirey and Lamberti, 2010; Colombo et al., 2018). Managed relocation is already being undertaken for some terrestrial systems (e.g., Marris, 2009; Willis et al., 2009). In the ocean, ecologists are beginning to explore the feasibility, risks and potential of assisted evolution (van Oppen et al., 2015, 2017; Chakravarti and van Oppen, 2018).

Assisted evolution raises complex ethical questions. Not only does it create conflicting conservation objectives (e.g., where benefits to particular species are prioritized over risks to others), but it transforms the role of humans from being primarily protectors to designers or engineers of natural systems. Here, we discuss how these approaches differ ethically from other intervention-based conservation techniques and address the ethics of assisted evolution as they apply to marine conservation. Specifically we explore three topics central to this debate: (1) What is our target?; (2) What is our motivation?; and (3) Should we be ethically for or against these approaches?

THE ONGOING DEBATE ON ASSISTED EVOLUTION IN ECOLOGY

To properly tackle these questions, we first outline some of these tools and current debates on their use. Opinions on assisted evolution in ecology range from cautious approval to serious skepticism. Approaches such as assisted gene flow (AGF), which enhances the spread of existing beneficial genes *within* a current species distribution, has tentative support, with the main negative consequence or risk being outbreeding depression (Edmands, 2006; Frankham et al., 2011). In a similar way, assisted translocation, where organisms are moved from their native range to more favorable regions, has been argued for in some cases (Thomas, 2011; van Oppen et al., 2015). Laboratory selection experiments to increase the tolerance of algal symbionts (Chakravarti and van Oppen, 2018) and pilot projects involving transplantation of warm-adapted corals to cooler reefs that are projected to warm have already been conducted (Aswani et al., 2015). These translocations could occur across ocean scales, such as moving the algae symbiont *Symbiodinium* spp., which survives at 36°C in corals in the Gulf of Aqaba (D'Angelo et al., 2015; Hume et al., 2015), to bleached reefs in other seas. However, there are potentially serious negative consequences of this strategy, mainly that the translocated species could become invasive in the new location and adversely impact other ecosystems.

The more controversial suggestion of releasing artificially selected or genetically modified species into wild populations to achieve conservation goals has not been undertaken and the idea has drawn heavy criticism, with fear that these modified species may have novel traits that give them competitive advantage over native populations, or that they may reduce overall genetic diversity and increase disease (Laikre et al., 2010). Despite this, artificial selection on wild populations have already been explored, such as artificial manipulations of sea turtle hatchlings to balance feminized sex ratios in Japan (Kobayashi et al., 2018).

Implementing techniques such as AGF and translocation may be a gateway to employing far more drastic measures, such as manipulating genetics of wild species using CRISPR or other gene editing tools. This could be a slippery slope, and as Ricciardi and Simberloff (2009) described, akin to "playing ecological roulette". Worries about risks, feasibility, and uncertainties dominate the debate (Hewitt et al., 2011). But an equally important question is not what are the risks, but whether humans should even cross this line?

WHAT IS OUR TARGET AND SHOULD DESIGNED NATURAL SYSTEMS BE THE GOAL OF CONSERVATION?

There is a strong possibility that our efforts to reduce threats to our oceans might be too little and too late in more heavily disturbed regions (Hobbs et al., 2011; Rinkevich, 2014). In this context assisted evolution solutions seem to offer new ways forward. Given that it works by actively enhancing or creating ecosystems, it is a departure from the traditional conservation goal of maintaining ecosystems in their current state, or restoring them to a historical “pristine” state. The prospect of recovering this baseline is becoming more of a fantasy. Pristine conditions are unknown for many marine ecosystems (Jackson et al., 2001), and there is a growing consensus that recreating past communities will be difficult in light of persistent changes in ocean conditions (Hobbs, 2007; Thomas, 2011) (**Figure 1**). This is illustrated by the shift in management interventions away from restoration and toward rehabilitation or rewilding, which aims to repair ecosystem processes and maximize services without restoring the pre-existing ecosystem (Lorimer et al., 2015). It also coincides with an ongoing shift in ecology from describing and understanding ecosystems to altering them (Hobbs et al., 2011). Accordingly, rather than focusing on attempts to recover what is more or less unattainable, it may seem that new techniques such as assisted evolution are warranted.

Yet the application of assisted evolution in marine conservation comes with a unique set of challenges. First, while human-mediated movement of species, ecosystem manipulations and other interventions have been undertaken for millennia on land, such measures are rare in the sea, and mostly limited to coasts (Halpern et al., 2015; Mccauley et al., 2015). Thus, we lack critical historic knowledge and experience to understand the consequences of some types of interventions in marine systems. This makes cost/benefit analyses and frameworks from terrestrial ecosystems difficult to apply to marine ecosystems. Second, keeping purposely modified systems isolated from natural ones is a peculiarly fraught endeavor in the ocean due to the more or less constant flow of some organisms, nutrients, or resources.

The absence of a clearly articulated baseline and target heightens some of the challenges involved in its implementation. Assisted evolution aims to modify a community so that it survives better in the conditions we have created, which makes it harder to specify what an intervention’s aims are, and whether they have been met. And since these targets are new in the ecological context, the lack of clear data on the impacts and long-term outcomes of these techniques exacerbate the degree of uncertainty surrounding these interventions. In this context, it is not surprising some have advanced concerns about the use of assisted evolution at all.

From an ethical perspective, the transition from traditional conservation or restoration to assisted evolution strategies is significant. This is not simply a matter of creating artificial ecosystems or populations. These already exist in the ocean (e.g., artificial coastlines, aquaculture pens). What differs here is that the goal of other genetic interventions in nature, such as use of GM crops or artificially selected livestock, has been human benefit. Accordingly, the question of whether or not such interventions are implemented has been determined on the basis of the trade-offs between benefit to societies and costs to the ecosystem. Further, even though past conservation efforts might indirectly have resulted in genetic changes to some species,

FIGURE 1 | Examples of ocean ecosystems threatened by widespread loss due to climate change. **(A)** Seagrass bed in Australia (T. Wernberg), **(B)** kelp forest in Norway (K. Filbee-Dexter), and **(C)** coral reef in Honduras (A. Pinder).

current attempts to ‘assist evolution’ are different because they are not retrospective or accidental, but forward-looking and deliberate.

With this forward-looking perspective, we can design ecosystems for conservation purposes, aiming to increase or preserve their “naturalness” or biodiversity. But in moving species or ecosystems toward states that they have never been in before, we are in some senses newly defining what we deem to be valuable and using the tools of assisted evolution to *create* value. The conservation value of species and ecosystems is no longer clearly based purely on their naturalness, but on the degree to which they match our ideals of how things should be.

This raises the question of whether an ecosystem heavily degraded by human activity is more natural than a more intact ecosystem that has been genetically manipulated to resist environmental stress. It seems plausible that there could be arguments on both sides. But what is clear is that any certainty we have that it is *nature per se* being valued and preserved, has become far less tenable. We need to understand what precisely it is that is being sought and why.

THE MOTIVATION FOR ASSISTING EVOLUTION

To look at a species, and confidently state what its goal should be, and to change its genetic makeup in order that it fulfill this human-identified goal, is a hugely bold undertaking. In “assisting” evolution, we are essentially taking steps toward deciding the winners and losers of the Anthropocene, and in so doing, designing and creating the world around us *as we want it to be.* There are two possible motivations here, and they have implications for how we decide to use these tools. If our motivation is to ensure the continued supply of services and benefits that the ocean provides us, then our decision to assist evolution depends on the capacity of these tools to benefit human beings. This makes an ethical discussion relatively straightforward, because we can apply similar frameworks or protocols that are currently used for research on genetically modified organisms or artificial selection in agriculture (Siipi, 2015; Hartley et al., 2016; Nuffield Council on Bioethics, 2016). The justification for using assisted evolution can be determined mathematically based on the value of the services provided to society in dollars (e.g., Lorimer et al., 2015; Bennett et al., 2016). Such value judgments regarding what we should conserve with assisted evolution are already in operation. Baums (2008) argues that coral reefs "deserve" active solutions because they provide valuable services to society. Aitken and Whitlock (2013) assert that AGF efforts and research should be targeted on: (a) foundation species, (b) species that provide economic value to humans, and (c) species at risk of extirpation.

If it works well, assisting evolution on this basis may enable us to overcome the problems we have caused through failure to moderate our consumption. In this case, we do not lose through having caused damage to the environment; we simply find new ways to ensure that our needs are met. Yet this may seem morally troubling. The use of assisted evolution could serve to perpetuate the habits and dispositions we currently display, and which have caused the damage in the first place. Rather than changing our resource-hungry approach to nature, assisted evolution confirms and facilitates our relationship with nature as one of consumption and commodification. We view the world on the basis of its potential to profit us, and attempt to control it to yield more value (Honneth et al., 2007). Many conservationists and environmental ethicists believe this is precisely what is wrong about our relationship with nature (Sandler, 2013).

Not only this, but the ascription of value to nature on the basis of its economic importance to human beings can create perverse incentives. To the extent that assisted evolution aims to enhance how ecosystems function, it is likely to become prey to these problems. Assisted evolution, within this view, even if not wrong in itself, is complicit with a worldview that is inherently materialistic, and harmful to our oceans. It does nothing to change the behaviors that caused environmental damage, and it makes us dependent on biotechnological intervention to meet our ongoing demands into the future. Nevertheless, for those who do believe it is morally acceptable to value nature primarily for its potential to benefit us, the use of assisted evolution techniques to achieve these benefits seems reasonable. Of course, the risks/benefits need to be carefully weighed, and this may rule in favor of less invasive methods. But there is no intrinsic reason to think that assisted evolution is morally problematic. It simply accelerates processes which are already being undertaken in slower, incremental, and perhaps less effective ways.

The use of assisted evolution specifically for conservation purposes, however, raises a different set of moral questions. Initially it may seem more morally commendable to intervene for the sake of protecting or preserving nature for its own sake. In other words, recognizing and acting to protect its intrinsic value instead of applying the instrumental approach described above (e.g., Boldt, 2013). Further, since we have caused the damage, it might seem that we have a moral obligation to compensate for this. This moves away from a purely outcome-based or economic position, to think about our relationship with nature directly in terms of moral responsibilities. There are *moral* reasons to reduce habitat loss, cut emissions, rebuild fisheries, and continue rigorous scientific research on oceans, because these are commendable ways of redressing the wrongs that humans have already perpetrated on the natural environment. In this light, assisted evolution strategies may be valuable (or even the only) conservation tools to achieve these goals, and at least some of them could justifiably be explored.

However, there is a risk that when people try to respond to moral obligations by atoning for past mistakes, they may make things worse. If environmental damage has come about through our failure to understand adequately the effects of our actions, we may *still* lack the necessary wisdom in attempting to reverse what we have done. From a duty-based view of moral obligation, it might appear that the best approach is to halt the actions that caused the damage, and recognize that we may lack the knowledge to be able to repair it, however, guilty we might feel about this. Of course, we mean well. But regardless of good intentions, we risk making further mistakes and we may still get it horribly wrong. Or we may inescapably be driven by our own preoccupations.

FOR OR AGAINST ASSISTED EVOLUTION

The debate on the ethics of using genetic approaches to conserve natural systems centers on the fundamental question of whether we should *act* to conserve ecosystems by all available tools or not. It seems that there is a strong compulsion to take some active measure that either protects or repairs damage to our oceans, and this makes these new tools attractive. Past measures have not worked, so why not try something else. But, not all environmental damage occurs through ignorance or lack of tools. Some occurs through straightforward self-interest. That is, we have placed our own short-term needs above those of other species. For many ecosystems, we *do* have the knowledge and wisdom required to improve things – we just have lacked the motivation to do so. In these cases, it is difficult to justify the use of genetic manipulations until other options have been exhausted. Many harmful impacts on the ocean can and should be curbed. There is no need to intervene in the genetics of organisms threatened by pollution if the same outcomes could be achieved by passing stricter pollution regulations.

Nevertheless, if a situation is so dire that a dramatic level of intervention is warranted, then these tools should be understood and even available. From an ethical standpoint, we offer cautious support for research on some of these practices, provided other solutions have been exhausted. Although using genetic tools to conserve marine ecosystems seems drastic, these practices are consistent with a long history of modifying the natural environment to achieve anthropogenically valuable outcomes. We are implementing similar genetic approaches for food production, disease control, and medicine, and there seems little need to shy away from them in management of natural systems. Yet, we must be clear that we are deciding to use assisted evolution as a way to actively and aggressively intervene for the sake of our own interests and *not* to "protect" or "help" nature. Despite our tentative support, in many cases, instead of using these tools, perhaps it is better to say we messed up, and as a result the marine environment is going to change in persistent and unavoidable ways and we must adapt to this new normal.

CONCLUSION

The pervasive influence of humans on the oceans has been starkly illustrated in the last couple of decades, resulting in a hard push to find new solutions. Although we find no strong ethical argument against research on assisted evolution. There is a strong case to be made that we should focus our efforts on minimizing future damage, protecting what we can, and understanding future changes; and not risk further havoc by playing with the genetic code of life. Alternatively, we can embrace the new Anthropocene, explore these new tools, and start playing God in earnest. Regardless, the debate needs to properly begin about whether, when, and how we might disrupt the genetics of ecosystems for the sake of conservation.

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KF-D and AS conceived and designed the manuscript. Both authors contributed to manuscript revision, read and approved the submitted version.

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