Estimating the consequences of a new coal mine (and its associated emissions) on the Great Barrier Reef World Heritage Area.

Summary

For each gigatonne of carbon dioxide (equivalent) generated by a coal mine in Australia, the Great Barrier Reef would be expected to lose approximately 1,000 hectares of coral habitat.

The mechanism that links a new coal mine with damage to the ecosystems of the Great Barrier Reef operates as follows.

- Coal mining and export generate emissions that increase the atmospheric concentration of CO_2.
- Increased atmospheric CO_2 increases global temperatures
- Increased global temperature create extreme heatwaves that cause mass coral mortality on coral reefs
- Increased coral mortality places coral reef ecosystems like the GBRWHA at risk.

We propose a simple and transparent estimate of how a particular quantity of greenhouse gas emissions will affect coral cover on the Great Barrier Reef.

Using coal increases atmospheric CO_2, which increases global temperatures

When coal is used for energy generation or industrial production, carbon dioxide is released into the atmosphere, as well as other greenhouse gases (GHG), particularly methane which has a greenhouse effect 80 times stronger than CO_2 (Sadavarte *et al*. 2021; Saint-Amand *et al*. 2022). These GHG cause an increase in the global temperature via the greenhouse effect, and a concomitant increase in heatwaves in the tropics.

The impacts of increasing GHG concentrations on global mean temperatures is estimated using “climate sensitivity”. In broad terms, a doubling of GHG concentration in the atmosphere will lead to an increase in mean temperature of approximately 3.25 degrees (Solomon *et al*. 2007). The relationship between the emissions e of additional carbon dioxide into the atmosphere (in gigatonnes), and the global mean temperature T, can thus be stated as:

$$T(e) = 287 + 3.25\frac{e}{418 \cdot 7.28}.$$

Equation 1

Increased global temperatures cause more mass bleaching events

When summer maximum sea surface temperatures increase above long-term averages, the mutualism between reef-building *Scleractinian* corals and their dinoflagellate symbionts breaks down. If temperatures remain elevated by a single degree Celsius for more than 4–6 weeks, mass coral bleaching can result. Marine heatwaves can last from weeks to years (Holbrook *et al*. 2020).

Increases in the global mean temperature are responsible for the more frequent mass bleaching events currently being experienced worldwide, including on the Great Barrier Reef. However, the relationship is not simple because (i) mass bleaching events are typically caused by extreme marine heatwaves under particular meteorological and oceanographic conditions (e.g., low wind, clear water, reduced current speeds), and (ii) the mortality response of the coral community is nonlinear, often occurs in multiple stages (e.g., direct mortality from heat stress in the days following the heat wave, followed by elevated levels of disease, predation, and starvation in the months that follow), and depends on bleaching return frequency, rather than any single mass bleaching event (Holbrook *et al*. 2020; Hughes *et al*. 2017).

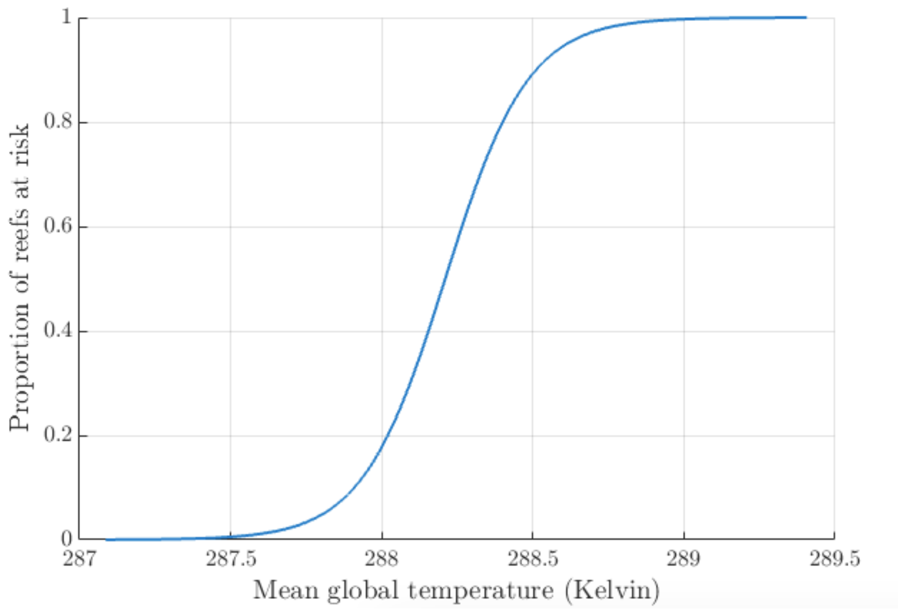

Figure 1*: Risk of degradation for a given cell of reef habitat, as a function of global mean temperature.*

Analyses that include these factors, and that are driven by general circulation models, can predict this relationship (Frieler *et al*. 2012). Specifically, they can predict how a particular increase in the global mean temperature T (Equation 1), determines the proportion of reef habitat P that is at risk of long-term degradation:

$$P(T) = (1 + \exp[-c(T + s)])^{-1},$$

Equation 2

where $c = 7.3$, and -288.21 are statistical fit, calibrated to the outputs of biophysical simulations. Note that the effects of a given increase in temperature are currently low (given that the mean global temperature is approximately 287K), but that it rapidly increases after 288K. As a consequence, the effects of emitting a gigatonne of CO_2 will also vary through the near future.

Coupled predictions

Equations 1 and 2 can be integrated to predict how increased emissions will affect the risk profile of the Great Barrier Reef. Specifically:

$$P(e) = (1 + \exp[f - ge])^{-1},$$

Equation 3

where $f = 1.53$ and $g = 0.0073$ are composite parameters.

Using these two parameters and an estimate of the total shallow-water reef habitat of the Great Barrier Reef (i.e., shallow offshore water with hard substrate suitable for coral growth) of 1,060,000 hectares, we can estimate the amount A of GBR coral reef habitat that will be placed at risk by increased emissions from any Australian source (Figure 2).

Effectively, we estimate that an additional 1 Gt of carbon dioxide emissions would remove over 1,000 hectares of suitable reef habitat from the Great Barrier Reef.

For context, global net anthropogenic GHG emissions are estimated at 59 ± 6.6 Gt CO_2 in 2019 .

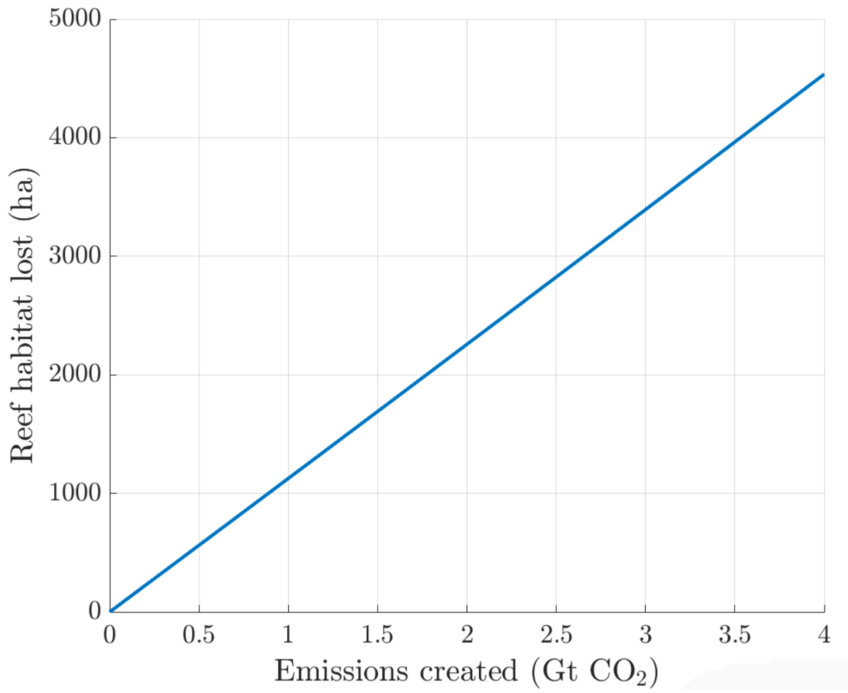

***Figure 2**: Estimate of reef habitat lost (in hectares) as a consequence of additional CO_2-equivalent emissions.*

Literature cited

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Author biography

Dr Michael Bode is a Professor of Applied and Computational Mathematics at the Queensland University of Technology. Professor Bode has written over 150 peer-reviewed research articles, in journals including Nature, Science, and *PNAS*, focusing on applying mathematics to conservation science. See Google Scholar for a full list. A considerable number of his research outputs focus on the management of coral reef ecosystems in the face of escalating anthropogenic disturbances, including mass bleaching events driven by climate change.

Since completing his PhD in Mathematics at the University of Queensland in 2008, Professor Bode has held three Australian Research Council (ARC) Fellowships, working at the ARC Centre of Excellence for Coral Reef Studies at James Cook University, the ARC Centre of Excellence for Environmental Decisions at the University of Melbourne, and at the ARC Special Research Initiative Securing Antarctica's Environmental Future. He has secured over $100 million in research grants, from sources ranging from the ARC to the Bill & Melinda Gates Foundation.