Submission in response to

Draft Great Barrier Reef Interventions Policy

Animal agriculture's devastating impacts

Paul Mahony

Submission in response to Draft Great Barrier Reef Interventions Policy: Animal agriculture's disastrous impacts.

Author:

Paul Mahony

Issued 31 July 2020

> *"At least thirty, perhaps anything up to eighty, per cent of all marine species have some part of their life cycle in a coral reef."*
>
> Dr. John "Charlie" Veron, former Chief Scientist of the Australian Institute of Marine Science[1]

Table of Contents

1. INTRODUCTION

This submission has been prepared for the Great Barrier Reef Marine Park Authority's consultation on the Draft Great Barrier Reef Interventions Policy.

It focuses on the historical and ongoing impact on the reef of animal-based food production. This aspect is largely ignored by major environmental and climate change campaign organisations, which otherwise generally have much to say about the reef.

The submission initially highlights the loss of coral since 1960, the extent of which is far greater than is generally reported.

It then considers the impact of farmed animal grazing in the form of sediment and nutrient discharge to the reef's waters.

The submission also considers impacts on seagrass, with adverse climate change and biodiversity outcomes.

The draft interventions paper notes that the Authority "considers restoration and adaptation interventions likely to be an integral part of its work on protection and conservation of the Great Barrier Reef (GBR) into the future".

It also notes that some interventions being considered are unprecedented, complex and potentially harmful, and that a wide range of actions or processes, engineering concepts and delivery methods are likely to be required.

A general transition away from animals as a food source, as proposed by this submission, would avoid the technical complexities and concerns involved in other measures under consideration. It would, however, require society to consider approaches required to ensure that such a transition was fair and equitable.

The author thanks the Great Barrier Reef Marine Park Authority for the opportunity to submit.

2. THE FULL EXTENT OF CORAL LOSS SINCE 1960

Much of the media reporting following two massive bleaching events in 2016 and 2017 indicated that around half the Great Barrier Reef's corals had been lost as a result of those events.[2] However, that estimate was based on measurements from a low base, as much of the coral had already disappeared before the bleaching events occurred.

Similar reporting had occurred following the release of a research paper in 2012, which indicated that around half had been lost since 1985, with the coverage extent falling from 28 to 13.8 per cent. [3]

If we go back further still, we find that the coverage extent was around 50 per cent in 1960, meaning it had reduced 22 percentage points in absolute terms (or 44 per cent in relative terms) between that date and 1985.[4]

The reductions are depicted in Figure 1. It also refers to causes, which are elaborated on in the next section. It does not incorporate a major bleaching event which occurred in early 2020.

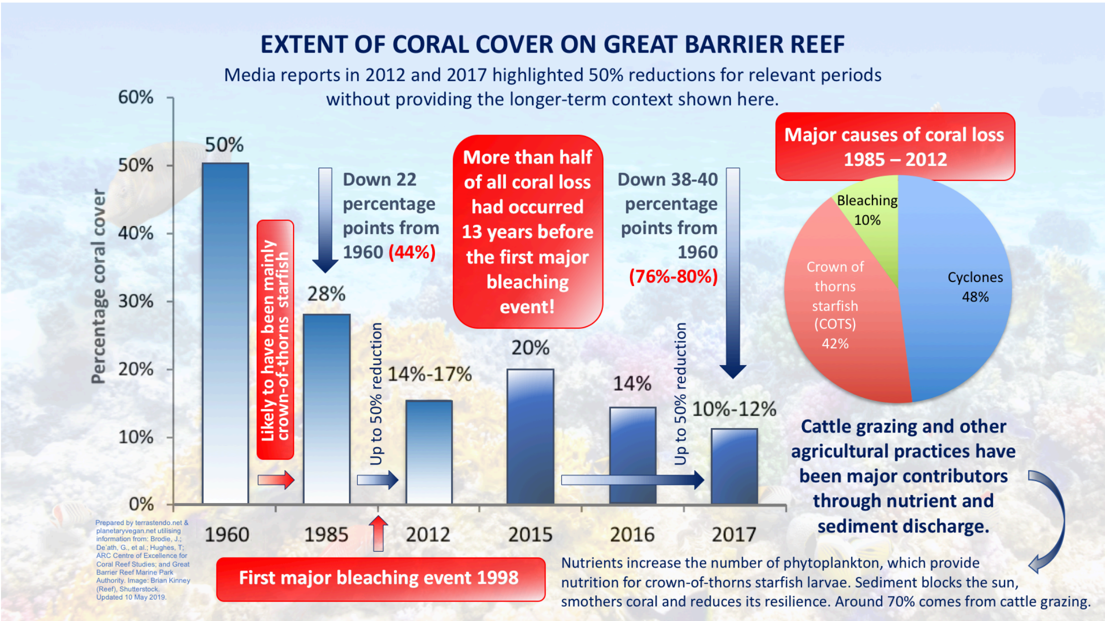

Figure 1: Extent of coral cover on Great Barrier Reef

3. MAJOR CAUSES OF CORAL LOSS

Although coral bleaching from warming waters is currently a critical threat, more than half of all coral loss between 1960 and 2017 had occurred thirteen years before the first major bleaching event in 1998.

In researching the causes of coral decline between 1985 and 2012, Dr Glenn De'ath and his co-authors from the Australian Institute of Marine Science (AIMS) and the University of Wollongong assessed the relative contributions of tropical cyclones, crown-of-thorns starfish (COTS) and coral bleaching. Their results are shown in Figure 2, which has been extracted from Figure 1. It shows the relative shares as: cyclones 48 per cent; COTS 42 per cent; and bleaching 10 per cent.

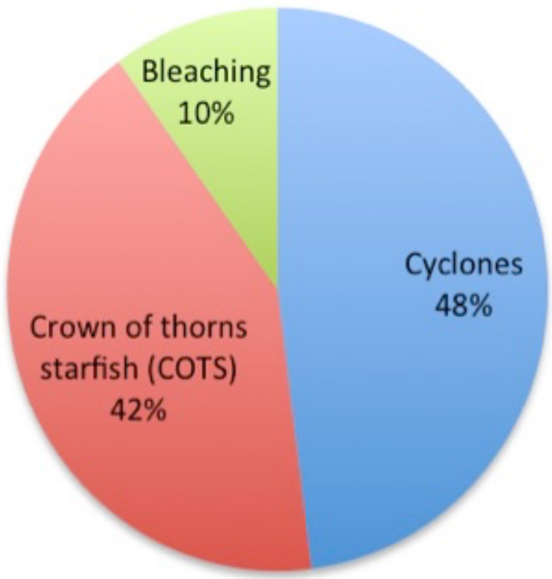

Figure 2: Causes of Great Barrier Reef coral decline 1985 – 2012

In a profound indication of the relative impact of COTS predation, the researchers estimated that there would have been a net increase in average coral cover if such predation had not occurred, rather than their estimated 50 per cent reduction.

Findings from Kate Osborne and fellow AIMS researchers in 2011 indicated there was no overall loss for the period 1995-2009, with loss in some areas and species offset by expansion in others.[5] However, in respect of those corals that did decline, they reported COTS as the major cause at 36.7 per cent compared to cyclones at 33.8 per cent, disease at 6.5 per cent, bleaching at 5.6 per cent, with the remainder comprising multiple or unknown causes.

Dr Jon Brodie of the ARC Centre of Excellence for Coral Reef Studies at James Cook University reported in 2012 that COTS were probably the major cause of coral mortality in the period from 1960 to 1985 but pointed out that available data for the period was incomplete.[6]

Water quality has also been a major factor, as it affects the frequency of COTS outbreaks in the central and southern GBR.

The comments that follow elaborate on the impact of coral bleaching and COTS.

Coral bleaching

Many types of coral have a symbiotic relationship with marine algae known as zooxanthellae that live inside their tissue. The zooxanthellae are efficient food producers that provide up to 90 per cent of the energy corals require to grow and reproduce. They also give coral much of its colour.[7, 8]

When the relationship becomes stressed due to factors such as ocean temperature or pollution, the zooxanthellae leave the coral's tissue. Without the zooxanthellae, the tissue of the coral animal appears transparent and its bright white skeleton is revealed.

Without the zooxanthellae as a food source, corals generally begin to starve.

If conditions return to normal, corals can regain their zooxanthellae, return to their normal colour and survive. However, this stress is likely to cause decreased coral growth and reproduction, and increased susceptibility to disease. Bleached corals often die if the stress persists.

Rising sea temperature is the main cause of coral bleaching. Other stressors can also contribute to it but generally to a smaller extent. They include: tropical cyclones; freshwater inflows from flooding events (with low salinity); sedimentation; pollution from urban or agricultural run-off; over-exposure to sunlight; and disease.[9, 10]

Major bleaching events have occurred on the GBR in 1998, 2002, 2016, 2017 and 2020.

Reefs can often recover from such events if given enough time, but two in quick succession in 2016 and 2017, along with the 2020 event, may have caused permanent loss of large sections of the reef.

There is no doubt that coral bleaching is a critical, perhaps catastrophic, issue. Although De'ath et. al. highlighted the need to improve water quality and develop relevant control measures, they stressed that such measures would only succeed if climatic conditions were stabilised, as losses from bleaching and cyclones will otherwise increase.

As a result, given the lack of meaningful response from so-called world leaders to the climate change threat, and taking into account the impact of other stressors that have destroyed much of the reef and weakened the resilience of much of the remaining coral, we may have lost the opportunity to save the reef's corals.[11]

Crown-of-thorns-starfish (COTS)

COTS are marine invertebrates that occur naturally on reefs throughout the Indo-Pacific region, feeding exclusively on coral. Certain conditions enable them to reach plague proportions and devastate hard coral communities.

Figure 3: Crown-of-thorns starfish devouring coral off northern Queensland Crown-of-Thorns Starfish (Acanthaster planci), Lizard Island

The long-term monitoring program conducted by AIMS has shown that outbreaks have begun in the north and migrated southward, generally over periods of around 15 years, with ocean currents transporting larvae between reefs. There have been four major outbreaks on the Great Barrier Reef since 1960: in that decade itself; the late 1970s; the early 1990s; and 2010 (which is still under way).[12, 13]

De'ath et. al. have reported that COTS were likely to have occurred every 50-80 years before European agricultural nutrient runoff commenced.

Healthy reefs generally recover between outbreaks, taking 10 to 20 years to do so. However, recovery takes longer on reefs that are affected by additional stresses, such as coral bleaching, cyclones or poor water quality, so the coral may not fully recover before the next wave of outbreaks occurs.[14]

Jon Brodie has stated "it is now well established" that the major COTS outbreaks since 1962 were most likely caused by nutrient enrichment associated with increased discharge of nitrogen and phosphorus from the land due to soil erosion and large-scale fertiliser use. The nutrients promote phytoplankton growth suitable to COTS larvae.[15]

Stanford University researchers have stated:[16]

"Low numbers of this starfish increase reef diversity, but large numbers can destroy reefs. Avoiding human activities that increase starfish numbers is more effective than trying to control Crown-of-Thorns outbreaks once they happen."

Fishing's impact on COTS outbreaks

Dr Hugh Sweatman of the Australian Institute of Marine Science has reported on the frequency of COTS outbreaks in areas where fishing occurs. He has found that, in the mid-shelf region of the GBR where most outbreaks occur, the frequency of outbreaks as of 2008 on reefs that were open to fishing had been 3.75 times higher than on those where it was prohibited. The frequency was seven times higher on open reefs when all reefs were included in the analysis.[17]

Although exploited fish species are unlikely to prey on COTS directly, he has indicated that the difference may have resulted from changes in interactions between species at different positions in the food web. This would provide an additional argument for establishment of effective marine protected areas across the geographic range of COTS.

The issue of food web interactions is considered in more detail in Section 5, dealing with seagrass.

4. ANIMAL AGRICULTURE'S CONTRIBUTION TO CORAL LOSS

The Queensland government's "Frequently Asked Questions" (FAQs) supporting its 2017 Scientific Consensus Statement and the Reef 2050 Reef Water Quality Improvement Plan stated (with this author's underlines but original bold formatting):[18,19,20]

> *"The current poor state of Great Barrier Reef ecosystems is from the combined impacts of land run-off from development in the catchment now and in the past, coastal development, extreme weather events, and climate change impacts such as coral bleaching events.*
>
> *The environment is changing with more extreme weather events occurring, and ocean warming and ocean acidification predicted to intensify.*
>
> *This means it is **even more important** to increase and accelerate efforts to mitigate local stressors such as land-based sources of pollution, coastal development and the management of direct uses including fishing."*

The extract highlights the detrimental role of land-based pollution sources and the need to address them.

Of those pollution sources, farmed animal grazing (the largest single land use in the reef's catchment area) is a major contributor but is rarely mentioned by prominent environmental groups that otherwise have much to say about the reef. Such groups almost invariably focus on coral bleaching caused primarily by warming oceans. However, as indicated earlier, the impact of bleaching is relatively recent.

Farmed animal grazing's contribution to sediment

Sediment blocks the sun, smothers coral and promotes the excessive development of algae, making the coral less resilient than it would otherwise have been to the impacts of other stressors, such as warming and more acidic waters.

Modeling indicates that fine sediment loads from rivers to the Great Barrier Reef's waters have increased around 5-fold since the beginning of European settlement.

In the FAQs referred to earlier, the Queensland government reported that farmed animal grazing (49 per cent) and streambank erosion (34 per cent) were the main sources of anthropogenic fine sediment (under 16 micrometres) in the reef's waters. Fine sediment is the type most likely to reach the reef's waters.

Streambank erosion caused by farmed animal grazing has not been directly attributed to that activity within the latest Scientific Consensus Statement. However, after allowing for its role in such erosion, grazing's overall contribution to fine sediment load may be close to its contribution to sediment as a whole, at around 70 per cent.

Such a possibility is supported by the fact that the 2013 statement indicated (similarly to the more recent statement) that grazing land's share of total sediment was 75 per cent, while its share from gully and hillslope erosion was 45 per cent, with streambank erosion from all causes accounting for 39 per cent.[21]

It is also consistent with feedback from Dr Jon Brodie, who co-authored the 2013 and 2017 consensus statements. He has indicated that relevant estimates are unlikely to have changed significantly between the two.[22]

it is estimated that expenditure ranging from $5.3 billion to $18.4 billion (most likely $7.8 billion) would be required to reduce sediment flow by 50 per cent, which is a target established under the Australian and Queensland governments' Reef 2050 Long-Term Sustainability Plan.[23]

Farmed animal grazing's contribution to nutrients

Of the various nutrient types, dissolved inorganic nitrogen and dissolved inorganic phosphorus are of greatest concern because they are immediately and completely available for uptake by marine organisms.

However, particulate nutrients, of which the main source is grazing land, are also a major problem. They are mostly deposited close to river mouths from where they can be broken down for years by bacteria into dissolved inorganic nutrients. The dissolved nutrients may then travel further into the reef's waters, where they are consumed by phytoplankton, algae and bacteria. As mentioned earlier, phytoplankton are a key source of nutrition for crown-of-thorns starfish larvae.

The latest consensus statement indicates that particulate nitrogen contributes 45 per cent of total nitrogen, and particulate phosphorus 76 per cent of total phosphorus, in the reef's waters, with rangeland grazing dominating overall particulate nutrient loads. (p. 11)

It also indicates that "erosion processes (hillslope, gully and streambank) in grazing lands are likely to be contributing higher bioavailable nutrient loads than currently estimated using models". (p. 4)

The ABC may have been incorrect in reporting nutrient sources

It appears the Australian Broadcasting Corporation (ABC) may have been incorrect in relation to comments made in a special report hosted by journalist Peter Greste in August 2018.[24] Contrary to those comments, sugarcane farming is responsible for 78 per cent of dissolved inorganic nitrogen, not 78 per cent of total nutrients, in the reef's waters.[25]

Report Cards

The Queensland government's FAQ document that was referred to earlier highlighted the need to increase and accelerate efforts to mitigate local stressors on the Great Barrier Reef's waters, including land-based sources of pollution.[26, 27, 28]

Of those pollution sources, farmed animal grazing (covering 73 per cent of the reef's catchment area as referred to below) is a major contributor of sediment and nutrients, with extremely adverse consequences.

The government issues report cards which measure progress towards the improvement plan's goal and targets. The most recent report card, issued in August 2019 (and showing the status as at June 2018) rated overall grazing management as "D", indicating "poor".[29, 30]

That result reflected 35.8 per cent of grazing lands being subject to best management practice (BMP) systems, representing an improvement of only 0.5 per cent since 2016. Specific results were: gully management 24.7 per cent; pasture management 31.1 per cent; and streambank management 51.1 per cent.

Despite the red meat industry highlighting the grazing BMP program in its 2018 Beef Sustainability Update, in practice the results have been tragically inadequate for the reef itself and the many marine species and Australian livelihoods outside the agriculture sector that depend on it.[31]

Figure 5 on page 12 shows an example of gully erosion which can be initiated by cattle grazing, leading to major increases in sediment load.

Grazing on cleared and uncleared land

Grazing of farmed animals is the dominant land use in the GBR catchment, responsible for nearly three times the area of all other activities combined. The comparison to other uses of the land is shown in Figure 4 on the following page.

This enormous area reflects the gross and inherent inefficiency of animals as a food source. Such inefficiency is reflected in the fact that farmed animal grazing occupies 54 per cent of Australia's total land mass.[32]

In terms of global impacts, in a paper in the journal Science from June 2018, researchers Joseph Poore and Thomas Nemecek indicated that a general transition to an animal-free diet would reduce food production's land use by 76 per cent or 3.1 billion hectares (31 million square kilometres).[33] That is an area slightly larger than Africa or four times Australia.

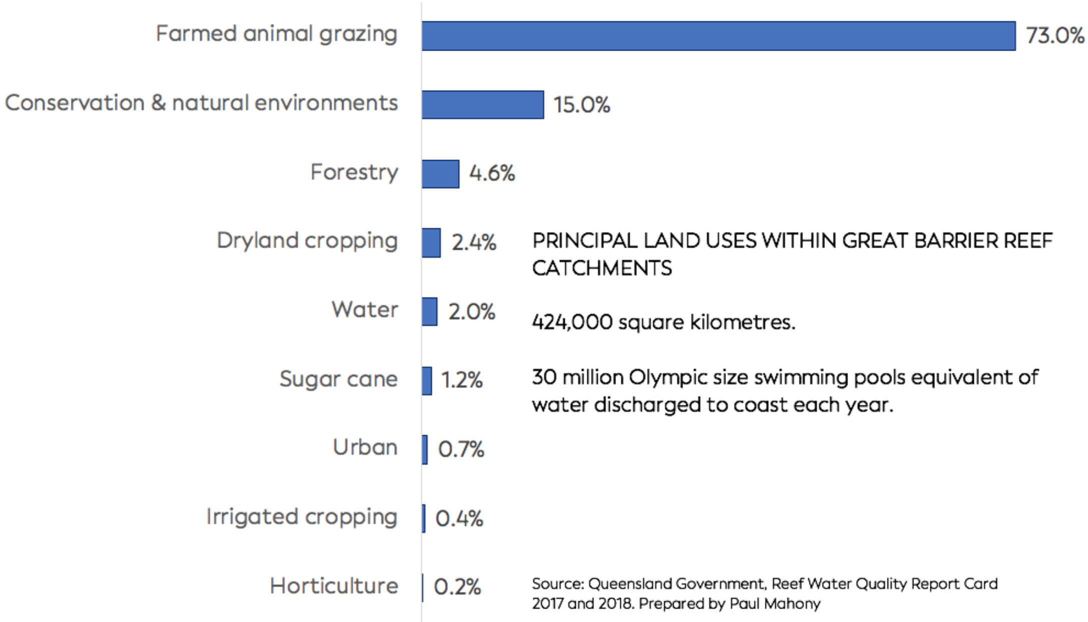

Figure 4: Principal land uses within Great Barrier Reef catchment

The Wilderness Society has reported that 94 per cent of land clearing in the reef's catchment areas between 2013 and 2018 had been for cattle grazing. It has cited the Great Barrier Reef Marine Park Authority as noting that land clearing in the reef's catchments leads to erosion and sediment run-off into the GBR World Heritage Area.[34]

In Queensland as a whole, farmed animal-related land clearing has been responsible for 91 per cent of clearing since 1988.[35]

Extensive erosion and resultant sediment release have also resulted from cattle grazing in uncleared areas.

The Victorian government has highlighted the role of cattle grazing in gully erosion:[36]

"Under natural conditions, run-off is moderated by vegetation which generally holds the soil together, protecting it from excessive run-off and direct rainfall."

"Excessive clearing, inappropriate land use and compaction of the soil caused by grazing often means the soil is left exposed and unable to absorb excess water. Surface run-off then increases and concentrates in drainage lines, allowing gully erosion to develop in susceptible areas."

Soils with dispersible subsoils are very common in Queensland and are vulnerable to gully erosion when the shallow layer of relatively stable topsoil is disturbed. As water penetrates through early-stage erosion (referred to as rill erosion up to 30 centimetres deep), the subsoil is dispersed, leaving the topsoil unsupported. The topsoil then collapses, and the process is repeated.

Figure 5: Gully erosion in Queensland, Australia

From that stage, even with little or no surface flow, the gully walls can become saturated, causing them to slump and the gully to expand. The Queensland government has likened the process at that point to digging a hole to the depth of the water table at the beach, with the hole expanding as the sides slump away.[37]

The underlying rock will often limit gully depth to around two metres, but they can be as deep as fifteen metres in alluvial and colluvial soils.

In an effort to reduce erosion run-off from uncleared lands, the Queensland government purchased the 56,000-hectare Springvale cattle station on Cape York Peninsula in 2016 with the intention of removing the cattle and rehabilitating the station's stream and riverbanks and gullies.[38]

Although the current Queensland government has tightened land clearing laws, there is the potential to revert to the previous arrangements with any future change in government, as occurred in 2013.

Climate Change

Given the impacts of warming waters and ocean acidification, climate change is a critical issue for the GBR. As mentioned earlier, warming waters contribute to coral bleaching, while increased acidity (resulting from increased carbon dioxide emissions) slows the rate at which corals generate calcium carbonate, thereby slowing the growth of coral skeletons.[39]

A 2014 land use discussion paper from climate change campaign group Beyond Zero Emissions and the University of Melbourne's Melbourne Sustainable Society Institute considered the climate change impacts of animal agriculture in Australia. It was followed by a journal paper on the same subject, with two co-authors in common.[40, 41]

In estimating that animal agriculture is responsible for around 50 per cent of Australia's greenhouse gas emissions, the researchers allowed for various factors ignored or attributed to other sectors in official estimates, including land clearing for farmed animal production, related loss of soil carbon, tropospheric ozone from savanna fires, and the shorter-term impacts of methane emissions.

5. SEAGRASS

A 2015 paper in Nature Climate Change highlighted critical impacts of excessive fishing on vegetated coastal habitats, comprising seagrass meadows, mangroves and salt marshes.[42] Fifteen species of seagrass occur within the GBR World Heritage Area.[43]

Excessive fishing disturbs food webs, changing the way ecosystems function, and altering the ecological balance of the oceans in dangerous ways. The paper focused on the phenomenon of "trophic downgrading", the disproportionate loss of species high in the food web.

The process involves the loss of ocean predators, such as large carnivorous fish, sharks, crabs, lobsters, seals and sea lions, and the resultant impact on carbon rich vegetation and sediment on the ocean floor. It cited earlier research indicating that the overall predator population had reduced by up to 90 per cent from natural levels.[44]

Based on the research findings, the reduction is likely to have adversely affected the ability of vegetated coastal habitats to absorb or sequester atmospheric carbon. It would also have released massive amounts of carbon (unaccounted for in any official emissions figures) in the form of CO2 re-mineralised from carbon that had been stored in the vegetation and underlying sediment.

The problem arises when the loss of high-level predators causes an unnatural increase in the population levels of their prey, who may be herbivores (such as dugongs and sea turtles) or bioturbators (creatures who disturb ocean sediment including certain crabs). With reduced predator numbers, the former prey have a far greater impact than previously on their own food sources in vegetated coastal habitats.

Those habitats are the most carbon-rich ecosystems in the world, capturing carbon forty times faster than tropical rainforests. Most of the carbon stored in them is in the form of organic matter trapped in the underlying sediment. The sediment contains little or no oxygen, allowing the organic material to last for millennia.

Despite their relatively small overall area, they represent fifty per cent of the carbon buried in ocean sediments.

Release of carbon stores

Vegetated coastal habitats are estimated to store up to 25 billion tonnes of carbon globally. If it was released in the form of CO2, it would equate to 2.5 times the emissions from fossil fuels globally in 2018 (92 vs 37 billion tonnes).[45]

Figure 6: Green turtle swimming over seagrass

Estimates of the areas affected are unavailable, but if only 1 per cent of vegetated coastal habitats were affected to a depth of 1 metre in a year, around 460 million tonnes of CO2 could be released. That is around the same level of emissions from all motor vehicles in Britain, France and Spain combined in 2010, and not far below Australia's annual CO2-equivalent greenhouse gas emissions.[46]

Loss of ongoing carbon sequestration

The other key problem is a reduction in the ocean's ability to sequester (or absorb) carbon from the atmosphere.

If sequestration capability were reduced by 20 per cent in only 10 per cent of vegetated coastal habitats, it would equate to a loss of forested area the size of Belgium.

Adverse impacts of recreational fishing

With their close proximity to land, vegetated coastal habitats are vulnerable to the impacts of recreational fishing.

An example involved salt marshes in Cape Cod, USA. Recreational overharvesting of predatory fish and crabs resulted in marsh die-off and significant erosion. Carbon stocks that had accumulated over hundreds of years were released, and sequestration capacity was reduced by around 17,000 tonnes of CO2 per year, which is equivalent to emissions from more than 3,000 cars.

Species-level protection required

Because of the extensive geographical range of many large predators, the authors argue that species-level protection on a broad scale is required, in addition to protection within the area of any particular vegetated coastal habitat.

The key problem is that the ecosystems have been losing their natural balance. The role of herbivores in helping to maintain vigorous plant growth through moderate grazing and cropping, and that of bioturbators through sediment aeration, has been transformed to a more destructive presence due to changes in behaviour (reflecting reduced threat from predators) and increasing numbers.

Seagrass condition on the Great Barrier Reef

In its most recent report card on the Great Barrier Reef, the Queensland government has rated the condition of most inshore seagrasses as poor, with the remainder being moderate or very poor.[47]

Region (inshore)	Year	Abundance	Reproduction	Nutrient status	Seagrass score
Great Barrier Reef	2016-2017	46	15	46	36
	2017-2018	42	12	32	29
Cape York	2016-2017	46	10	47	34
	2017-2018	40	6	30	25
Wet Tropics	2016-2017	28	2	35	22
	2017-2018	40	33	35	36
Burdekin	2016-2017	70	38	54	54
	2017-2018	62	33	45	47
Mackay Whitsunday	2016-2017	32	33	34	33
	2017-2018	29	9	25	21
Fitzroy	2016-2017	27	0	44	24
	2017-2018	35	0	30	22
Burnett Mary	2016-2017	29	0	33	21
	2017-2018	33	0	24	19

Note: The Great Barrier Reef inshore seagrass score is the average of scores for three indicators. Values are indexed scores scaled from 0-100; ■ = very good (81-100), ■ = good (61-80), ■ = moderate (41-60), = poor (21-40), ■ = very poor (0-20). NB: Scores are unitless. (McKenzie et al. 2019).

Figure 7: Seagrass scores for the inshore Great Barrier Reef and natural resource management regions in 2016-2017 and 2017-2018 (Attribution CC by 4.0)

The Great Barrier Reef Marine Park Authority has previously recognised poor water quality from catchment runoff as one of the major pressures facing the seagrass.[48]

Action in relation to farmed animal grazing (and resultant sediment discharge) and fishing regimes may play a key role in improving the quality of this critically important marine vegetation.

6. CONCLUSION

It is difficult to overstate the negative impact of animal agriculture on Australia's environment since European settlement. The effects are ongoing and dramatic, with the sector's strategic marketing approach seeking to portray a vastly different image to the general community.

If we are to protect and maintain our precious natural assets, we must honestly and directly address the critical problems we have created. Government support for powerful animal agriculture industry forces would contribute to long-term adverse outcomes for the Great Barrier Reef and Australia as a nation.

It is important that domestic and international consumers be informed of the impacts of their food choices, and that producers' costs include a component that reflects (as far as possible) the adverse environmental outcomes they create.

Image Credits

Front cover: © Paul Mahony, Daintree Rainforest and Great Barrier Reef, All rights reserved

V_E, “Wonderful and beautiful underwater world with corals and tropical fish”, Image ID 260385482, Shutterstock

Ryan McMinds, Crown-of-Thorns Starfish (Acanthaster planci), Lizard Island, Flickr, Creative Commons, Attribution CC BY 2.0, https://creativecommons.org/licenses/by/2.0/

Queensland Government, Types of erosion - Gully erosion, https://www.qld.gov.au/environment/land/management/soil/erosion/types, Attribution CC BY 4.0, https://creativecommons.org/licenses/by/4.0/

Caan2gobelow, Adult male Green turtle swimming over seagrass, Dreamstime.com

Figure 7: Queensland Government (Department of Environment and Science), Attribution CC BY 4.0, https://creativecommons.org/licenses/by/4.0/

References

1 National Climate Emergency Summit 2020, "Ecoystems in collapse", 14th February 2020 [38.40], https://omny.fm/shows/ncesummit2020/ecosystems-in-collapse?in_playlist=ncesummit2020!podcast

2 Chang, C. and AAP, "Half the Great Barrier Reef may have died in last two years", 23 May 2017, http://www.news.com.au/technology/environment/climate-change/half-the-great-barrier-reef-may-have-died-in-last-two-years/news-story/d1a7e2974597f40d04700d7313c9f713

3 De'ath, G., Katharina Fabricius, K.E., Sweatman, H., Puotinen, M., "The 27–year decline of coral cover on the Great Barrier Reef and its causes", PNAS 2012 109 (44) 17995-17999; published ahead of print October 1, 2012, doi:10.1073/pnas.1208909109, http://www.pnas.org/citmgr?gca=pnas%3B109%2F44%2F17995

4 Brodie, J., "Great Barrier Reef dying beneath its crown of thorns", The Conversation, 16th April, 2012, http://theconversation.com/great-barrier-reef-dying-beneath-its-crown-of-thorns-6383

5 Osborne, K., Dolman, A. M., Burgess, S. C., & Johns, K. A. (2011). Disturbance and the Dynamics of Coral Cover on the Great Barrier Reef (1995–2009). *PLoS ONE*, *6*(3), e17516. http://doi.org/10.1371/journal.pone.0017516, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3053361/ and https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3053361/pdf/pone.0017516.pdf

6 Brodie, J., op. cit.

7 National Oceanic and Atmospheric Administration, National Ocean Service, "What is coral bleaching?", revised 17 March 2016, http://oceanservice.noaa.gov/facts/coral_bleach.html

8 Australian Government, Great Barrier Reef Marine Park Authority, "Managing the reef – Coral bleaching" (undated), http://www.gbrmpa.gov.au/managing-the-reef/threats-to-the-reef/climate-change/what-does-this-mean-for-species/corals/what-is-coral-bleaching

9 Australian Government, Bureau of Meteorology (undated), http://www.bom.gov.au/oceanography/oceantemp/GBR_Coral.shtml

10 The Nature Conservancy, Ocean and Coasts, "Coral bleaching: What you need to know" (undated), https://www.nature.org/ourinitiatives/habitats/coralreefs/coral-reefs-coral-bleaching-what-you-need-to-know.xml

11 Dunlop, I., "Time for honesty on climate and energy policy", The Sydney Morning Herald, 12 December 2016, http://www.smh.com.au/comment/time-for-honesty-on-climate-and-energy-policy-20161208-gt7g1k.html

12 Edwards, A., "Winning the war on Great Barrier Reef crown-of-thorns starfish", CSIROscope, 21 July 2020, https://blog.csiro.au/crown-of-thorns-starfish-great-barrier-reef/

13 Great Barrier Reef Marine Park Authority, "History of crown-of-thorns outbreaks on the Great Barrier Reef", http://www.gbrmpa.gov.au/about-the-reef/animals/crown-of-thorns-starfish/history-of-outbreaks

14 Australian Institute of Marine Science, "Crown-of-thorns starfish" (undated), http://www.aims.gov.au/docs/research/biodiversity-ecology/threats/cots.html

15 Brodie, J., op. cit.

16 Stanford University, Microdocs Project, "Crown-of-thorns starfish", https://www.youtube.com/watch?v=_SpLgzPqCV8

17 Sweatman, H., "No-take reserves protect coral reefs from predatory starfish", Current Biology, Volume 18, Issue 14, pR598–R599, 22 July 2008, http://www.cell.com/current-biology/fulltext/S0960-9822(08)00671-4 and http://www.cell.com/current-biology/pdf/S0960-9822(08)00671-4.pdf

18 Frequently Asked Questions: Reef 2050 Water Quality Improvement Plan and 2017 Scientific Consensus Statement, State of Queensland, pp. 7 – 8, https://www.reefplan.qld.gov.au/about/assets/faqs-reef-2050wqip-2017scs.pdf

19 Bartley, R., Waters, D., Turner, R., Kroon, F., Wilkinson, S., Garzon-Garcia, A., Kuhnert, P., Lewis, S., Smith, R., Bainbridge, Z., Olley, J., Brooks, A., Burton, J., Brodie, J., Waterhouse, J., 2017. Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. State of Queensland, 2017, https://www.reefplan.qld.gov.au/about/reef-science/scientific-consensus-statement/

20 Queensland Government, Reef 2050 Reef Water Quality Improvement Plan 2017-2022, https://www.reefplan.qld.gov.au/about/

[21] Kroon, F., Turner, R., Smith, R., Warne, M., Hunter, H., Bartley, R., Wilkinson, S., Lewis, S., Waters, D., Caroll, C., 2013 "Scientific Consensus Statement: Sources of sediment, nutrients, pesticides and other pollutants in the Great Barrier Reef Catchment", The State of Queensland, Reef Water Quality Protection Plan Secretariat, July, 2013, Ch. 4, http://www.reefplan.qld.gov.au/about/scientific-consensus-statement/sources-of-pollutants.aspx

[22] Email correspondence of 2nd October 2018

[23] Australian Government, Department of Environment and Energy, Reef 2050 Long-Term Sustainability Plan – Progress on Implementation Review by Great Barrier Reef Independent Review Group, February 2017, p. 50, http://www.environment.gov.au/marine/gbr/long-term-sustainability-plan

[24] Australian Broadcasting Corporation, 7.30 special, Part 2: "Could a change in farming practices help save the Great Barrier Reef?", 21st August 2018, https://www.abc.net.au/7.30/could-a-change-in-farming-practices-help-save-the/10149466

[25] Frequently Asked Questions, op. cit., p. 6

[26] Frequently Asked Questions: Reef 2050 Water Quality Improvement Plan and 2017 Scientific Consensus Statement, State of Queensland, pp. 7 – 8, https://www.reefplan.qld.gov.au/about/assets/faqs-reef-2050wqip-2017scs.pdf

[27] Bartley, R., Waters, D., Turner, R., Kroon, F., Wilkinson, S., Garzon-Garcia, A., Kuhnert, P., Lewis, S., Smith, R., Bainbridge, Z., Olley, J., Brooks, A., Burton, J., Brodie, J., Waterhouse, J., 2017. Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. State of Queensland, 2017, https://www.reefplan.qld.gov.au/about/reef-science/scientific-consensus-statement/

[28] Queensland Government, Reef 2050 Reef Water Quality Improvement Plan 2017-2022, https://www.reefplan.qld.gov.au/about/

[29] Queensland Government (Department of Environment and Science), Reef 2050 Water Quality Improvement Plan, Reef Water Quality Report Card 2017 and 2018, https://reportcard.reefplan.qld.gov.au/ and https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0022/82903/report-card-2017-2018-results-combined.pdf

[30] Queensland Government (Department of Environment and Science), Reef 2050 Water Quality Improvement Plan, Reef Water Quality Report Card 2017 and 2018, Grazing, Great Barrier Reef Wide, https://reportcard.reefplan.qld.gov.au/home?report=target&measure=GZ&area=GBR

[31] Red Meat Advisory Council, Sustainability Steering Group, 2018 Australian Beef Sustainability Annual Update, pp. 29 & 33, https://www.sustainableaustralianbeef.com.au/annual-update and https://www.sustainableaustralianbeef.com.au/58735/widgets/299337/documents/172551

[32] Australian Government, Department of Agriculture and Water Resources, ABARES National scale land use (based on Land Use of Australia 2010-11, Version 5, ABARES 2016) Last reviewed 5th March 2018, http://www.agriculture.gov.au/abares/aclump/land-use

[33] Poore, J., and Nemecek, ,T., "Reducing food's environmental impacts through producers and consumers", *Science,* 01 Jun 2018, Vol. 360, Issue 6392, pp. 987-992 DOI: 10.1126/science.aaq0216, http://science.sciencemag.org/content/360/6392/987

[34] Cox, L., "Beef industry linked to 94% of land clearing in Great Barrier Reef catchments", The Guardian, 8 August 2019, https://www.theguardian.com/australia-news/2019/aug/08/beef-industry-linked-to-94-of-land-clearing-in-great-barrier-reef-catchments

[35] Queensland Government Department of Natural Resources, Mines and Energy, Statewide Landcover and Trees Study (SLATS), https://www.qld.gov.au/environment/land/vegetation/mapping/slats8

[36] Agriculture Victoria, "Gully Erosion", Nov 1999, http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/erosion/gully-erosion

[37] Carey, B., Queensland Government, Natural Resources and Water, "Gully Erosion", March 2006, https://www.qld.gov.au/dsiti/assets/soil/gully-erosion.pdf

[38] Willacy, M., "Great Barrier Reef: Queensland Government buys $7m cattle station in 'unprecedented' protection bid", ABC News, 22 June 2016 (updated 28 June 2016), https://www.abc.net.au/news/2016-06-22/great-barrier-reef-government-buys-cattle-station-protection-bid/7533216

[39] National Oceanic and Atmospheric Administration, Florida Keys National Marine Sanctuary, Coral bleaching and ocean acidification are two climate-related impacts to coral reefs, https://floridakeys.noaa.gov/corals/climatethreat.html

[40] Longmire, A., Taylor, C., Wedderburn-Bisshop, G., "Zero Carbon Australia – Land Use: Agriculture and Forestry – Discussion Paper", Beyond Zero Emissions and Melbourne Sustainable Society Institute of The University of Melbourne, October, 2014, https://bze.org.au/research/agriculture-farming-land-use/

[41] Wedderburn-Bisshop, G., Longmire, A., Rickards, L., "Neglected Transformational Responses: Implications of Excluding Short Lived Emissions and Near Term Projections in Greenhouse Gas Accounting", International Journal of Climate Change: Impacts and Responses, Volume 7, Issue 3, September 2015, pp.11-27. Article: Print (Spiral Bound). Published Online: August 17, 2015, http://ijc.cgpublisher.com/product/pub.185/prod.269

[42] Atwood, T.B., Connolly, R.M., Ritchie, E.G., Lovelock, C.E., Heithaus, M.R., Hays, G.C., Fourqurean, J.W., Macreadie, P.I., "Predators help protect carbon stocks in blue carbon ecosystems", published online 28 September 2015, http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2763.html

[43] Great Barrier Reef Marine Park Authority, A Vulnerability Assessment for the Great Barrier Reef: Sea Grass, Feb 2012, http://www.gbrmpa.gov.au/__data/assets/pdf_file/0017/21743/VA-Seagrass-31-7-12.pdf

[44] Myers, R. A. & Worm, B., "Rapid worldwide depletion of predatory fish communities", Nature 423, 280–283 (2003), cited in Atwood, T.B., et al., ibid.

[45] Garthwaite, J., Stanford News Service, "Global fossil fuel emissions have climbed upward for a second straight year, driven by growing energy use", 5 Dec 2018, https://news.stanford.edu/press-releases/2018/12/05/global-carbon-dioxide-emissions-rise-even-coal-wanes-renewables-boom/

[46] Hannam, P., "Australia's greenhouse gas emissions up for four years in a row", Sydney Morning Herald, 29 May 2019, https://www.smh.com.au/environment/climate-change/australia-s-greenhouse-gas-emissions-up-for-four-years-in-a-row-20190529-p51s6u.html

[47] Queensland Government (Department of Environment and Science), Reef 2050 Water Quality Improvement Plan, Reef Water Quality Report Card 2017 and 2018, op. cit., Marine Monitoring Program Summary: Inshore Great Barrier Reef Ecosystem Health, Table 3, p. 15

[48] Great Barrier Reef Marine Park Authority, A Vulnerability Assessment for the Great Barrier Reef: Sea Grass, op. cit.