KELP AND CARBON SEQUESTRATION: EXPORTING TERRESTRIAL GHG ACCOUNTING TO THE DEEP SEA

SEPTEMBER 6, 2018, BY PATRICK CAGE

Recent breakthroughs have elevated algae as a promising biological solution to environmental challenges. Particular species of algae can provide low-impact, non-fossil substitutes for liquid fuel and plastics and can decrease enteric fermentation emissions from cattle. Now, a recent Nature Geoscience paper quantifies the role of kelp and other macroalgae in the global carbon cycle. The peculiarities of seaweed carbon cycling may skirt "permanence" issues that have plagued other biological carbon sinks, such as terrestrial forests. Future research may enable business and government to recruit kelp forest rehabilitation as an additional approach to climate change mitigation.

Permanence and sequestered carbon

Many climate interventions, such as switching from coal to wind energy, reduce and avoid emissions. These interventions deal with gases that *would* have been emitted that year. Given the proper baseline (no easy task), you can credibly state that, thanks to the intervention, a ton of gas was not emitted that year. The non-existence of this emission is permanent.

When reforestation occurs and trees grow by performing photosynthesis, the carbon dioxide removed from the atmosphere is stored ("sequestered") in biomass. Unlike reduced emissions which "no longer exist," the carbon in this biomass is physically vulnerable.

Unplanned deforestation and forest degradation can release this stored carbon back into the atmosphere. These unplanned occurrences reverse the beneficial effects of carbon sequestration. In other words, the sequestration turned out to be temporary. Concerns about "reversals" have long challenged reforestation and afforestation as practical approaches to climate change mitigation. Carbon offset markets (e.g., California's cap-and-trade system) employ technical fixes like "buffer accounts" to reduce the risk of over-crediting, based on the statistical risk of reversal. However, concerns around permanence continue, and surely limit both financial and political investment into restoring ecosystems for climate purposes.

These concerns regarding permanence apply to all "enhancements" of carbon stocks, because of their physical vulnerability. All actions to improve carbon stocks—whether through reforestation, in soils, with coastal blue carbon (e.g., planting mangroves), or through industrial carbon capture and storage—carry real risks of reversal through human or other disturbances.

The macroalgal carbon cycle

One recent study suggests that kelp forests may work differently. Carbon sequestration by kelp forests may be unusually "permanent," due to their specific carbon cycle and the "wild" nature of the deep oceans.

In their Nature Geoscience paper, "Substantial role of macroalgae in marine carbon sequestration," Professors Dorte Krause-Jensen and Carlos M. Duarte synthesize existing data on carbon sequestration by kelp and other macroalgae to develop a "first-order" estimate of kelp sequestration processes, destinations, and quantities. Their initial estimate suggests macroalgae sequesters about 634 million tonnes of carbon dioxide per year (173 TgC), more than twice the net sequestration from China, the country with the greatest net carbon sequestration. While 10% of this is buried in coastal sediments with a risk of anthropogenic reversals, an estimated 90% is exported to the deep sea!

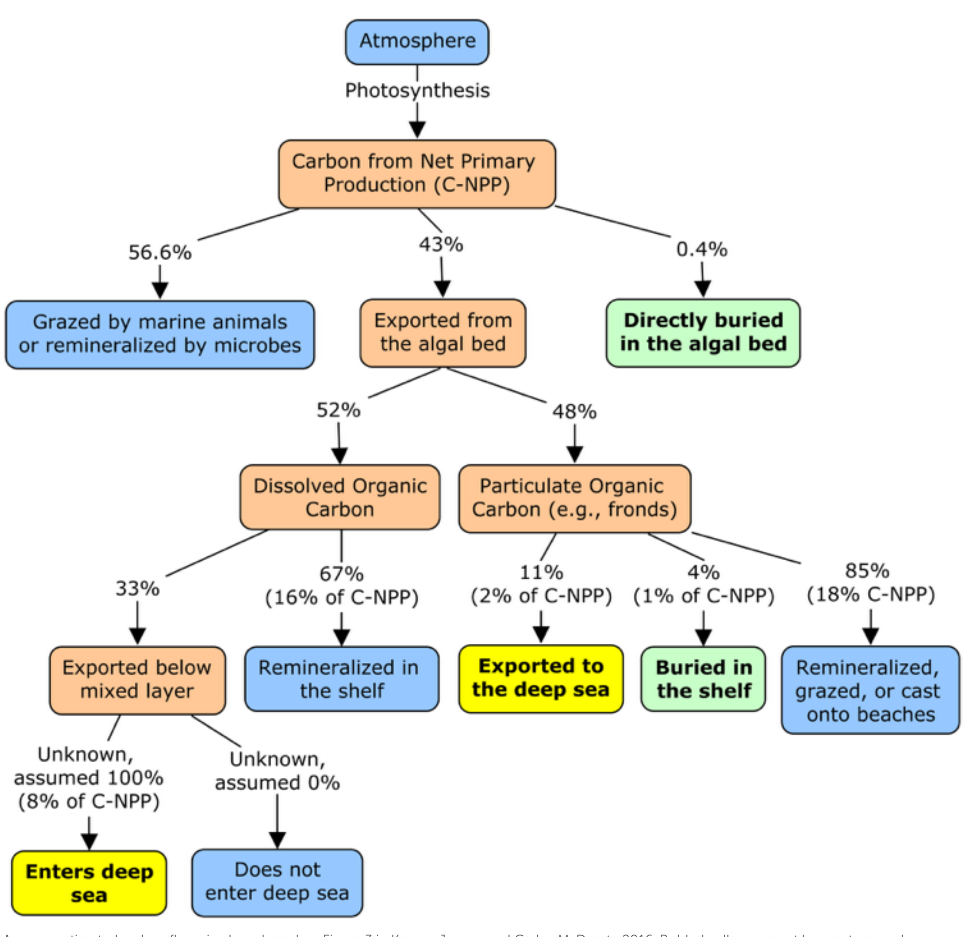
Despite the name, kelp forests have more in common with grasslands than with terrestrial forests in terms of their carbon cycle. Like terrestrial grasslands, kelp forests can be perennial (in warmer seas) or annual (in colder ocean regions). Whereas most forest types concentrate carbon in living biomass, grasslands and kelp forests have relatively short life cycles and rapidly "donate" carbon from living biomass to other carbon pools.

Most immediately, carbon moves from seaweed biomass to the Dissolved Organic Carbon (DOC) and the Particulate Organic Carbon (POC) pools. DOC refers broadly to organic molecules dissolved in water. Seaweeds and other marine photosynthesizers continually release organic material that readily dissolves in water. This material can settle in place, travel to other parts of the ocean, or be rapidly consumed by microbes.

POC refers to drifting pieces of biomass, such as kelp fronds, which can gather in enormous rafts. This detritus can float hundreds of kilometers, kept buoyant by air bladders and protected by chemical compounds that render kelp unpalatable to most animal species. This process of drift occurs with other macroalgae such as *Sargassum* and Desmarestiales as well. Combined with ocean circulation patterns, the carbon sequestered by macroalgae arrives in the deep sea, especially submarine canyons. Storms rip fronds and whole plants from the ground to accelerate the export of material and sequestration of carbon into the deep sea.

Moving carbon from the atmosphere to the deep sea

For those interested in the numbers, the authors of the Nature Geoscience paper estimate the following average carbon fluxes (flows), synthesizing existing data sources and studies:



Average estimated carbon flows in algae, based on Figure 3 in Krause-Jensen and Carlos M. Duarte 2016. Bolded cells represent longer-term carbon storage. Yellow cells represent carbon sequestered in the deep sea, which is unlikely to be reversed. Green cells represent carbon sequestered in shallower regions, with a possibility of reversal. Blue cells are "destinations" that will rapidly cycle carbon back into the atmosphere. Orange cells are intermediate stages. Percentages are rounded.

- Sequestration of carbon dioxide from the atmosphere begins with Net Primary Production – algal growth, driven by photosynthesis.
- On average, an estimated 43% of the carbon sequestered through photosynthesis is exported from the algal bed, the immediate area where the algae are anchored. Most of the remainder is grazed by marine animals or remineralized into its simplest elements by microbes, recycling it through the ecosystem. Only about **4% is directly buried in the algal bed.**
- This carbon exported from the algal bed travels in two carbon pools: about half moves as DOC and about half as POC.
- About **one-third of the DOC is exported below the top mixed layer of the ocean**, of which some fraction enters the deep sea (this study assumes 100%). The rest is remineralized in the shelf, transformed into inorganic material for use as nutrients by other organisms.
- About **11% of the POC is exported to the deep sea** and **4% is buried in the shelf**. The remainder is remineralized, grazed, or cast onto beaches.
- Together, long-term carbon sequestration by macroalgae occurs through four processes: carbon directly buried in the algal bed, DOC exported below the mixed layer, POC exported to the deep sea, and POC buried in the shelf. Ultimately, about 11% of the carbon involved in biomass growth (Net Primary Production) is sequestered into four carbon pools for longer-term storage and the remainder is quickly recycled through the ecosystem.

The carbon buried in the algal bed and buried in the shelf is vulnerable to reversal due to human influence on coastal sediments. This sequestered carbon is conceptually similar to the carbon sequestered in other blue carbon ecosystems.

The carbon from the export of DOC and POC, however, largely ends up in the deep sea, where it faces minimal risk of reversal.

This "deep sea sequestration" represents an estimated 88% of the net carbon sequestration by macroalgae, or about 10% of biomass growth.[1] And it suggests that this carbon may avoid the permanence issues that complicate sequestration for forests, other terrestrial ecosystems, and other blue carbon ecosystems. Unlike these other ecosystems, the deep sea has few direct land-uses, such as farms, urbanization, industry, or coastal resorts. Because the sediments of the deep sea have so little human contact, carbon that enters the deep sea is theoretically insulated against the risks of reversals that affect other biological carbon.

Next steps and policy mechanisms

Until now, kelp forests and other seaweeds have received almost no attention in terms of climate change mitigation policy discussions. Even other blue carbon ecosystems (seagrass meadows, tidal marshes, and mangroves) are a relatively new field. Why is this research into seaweed carbon sequestration important?

First, this paper raises the profile of carbon sequestration by seaweeds. Better understanding the role of macroalgae in the global carbon cycle is inherently important as a scientific pursuit. This paper is only a "first order estimate," as there is significant uncertainty in the authors' numbers. Much more scientific work will be required to increase the resolution and improve these estimates. For example, future studies will need to confirm that there are no other natural or anthropogenic processes that cause this carbon to cycle away from the deep sea and back into the atmosphere.

Second, increased focus on seaweed sequestration highlights the potential for kelp forest "afforestation" as a novel climate change mitigation strategy. Policy interventions can encourage kelp production and the carbon sequestration it brings:

1. Governments could directly implement kelp reforestation and protection programs, which have substantial benefits for marine ecosystems and can spur dive tourism.
2. Carbon offset standards could develop kelp offset methodologies, inside or outside a government context (compliance or voluntary offset markets, respectively). Where kelp is allowed to fully grow and is not used commercially, kelp cultivation efforts should theoretically be additional, and therefore a credible source of offsets. Managing natural kelp beds, which face numerous existential threats, could also be a credible offset type.
3. Another option is for governments to promote kelp cultivation through economic incentives for the private sector. Kelp has various commercial uses: as a gel (e.g., in the hypercolloid industry), as an energy source, in pharmaceuticals, in fertilizers, and for invertebrate aquaculture (e.g., abalone, shrimp, sea urchins).[2] Tax breaks for kelp cultivation could provide a "discount" to match the unmonetized social good that cultivation brings through carbon sequestration.[3]

Third, if further research confirms reduced reversal risk for kelp, this insight could impact and accelerate the creation of kelp reforestation methodologies on the offset markets. Under California's cap-and-trade system, to address permanence concerns, forestry projects sign 100-year contracts and place a share of their credits into a buffer account to protect against the risk of unintentional reversals (e.g., wildfires). Low-risk kelp projects could potentially skirt these requirements, making oceanic sequestration projects more profitable to project developers.

Finally, kelp-based offsets may command a higher quality status, given reduced reversal risk. Although the carbon offset is theoretically a fungible commodity, in practice, the characteristics of offset projects do affect offset price in the voluntary market.[4] Factors such as project charisma and co-benefits can lead to higher prices. Risks of low additionality or reversal can depress prices. Lower risk of reversal could place kelp sequestration on a higher footing than other sequestration projects.

For now, carbon sequestration by kelp is still in the early stages of research science. At present, the Nature Geoscience paper is an interesting publication that provides an initial estimate of carbon fluxes by macroalgae. As research expands over the next several years, the seaweed aquaculture sector may provide new, creative options for conservation and climate change mitigation that can be amplified by incentivizing policies and the offset markets.

---

[1] This is about 70% through the Dissolved Organic Carbon pool and about 30% through the Particulate Organic Carbon pool.

[2] https://oar.marine.ie/bitstream/handle/10793/702/Quantitative%20Assessment%20Methodology%20fo sequence=1&isAllowed=y

[3] To be economically efficient, research would need to quantify how cultivation methods and harvest timing affect carbon release compared to a natural growth baseline. Typically, we would expect reduced carbon released in cultivated systems, since commercial users want to maximize their take of kelp biomass. This may be partially or entirely offset by the increased productivity of complex aquaculture techniques.

[4] "Unlocking Potential: State of the Voluntary Carbon Markets 2017," https://www.forest-trends.org/wp-content/uploads/2017/09/doc_5591.pdf

VIEW BY CATEGORY

- Inside the Institute
- Events
- News
- From the Journal
- Webinar Series
- Featured
- Podcasts
- Uncategorized

4 responses to "Kelp and carbon sequestration: exporting terrestrial GHG accounting to the deep sea"

1. *Ann Ruddy* says:
   April 23, 2019 at 11:10 pm

   Redrose Developments Ltd. County Mayo Ireland holds two recently acquired licenses for seaweed cultivation and would very much like to focus on carbon sequestration and to join the discussion.

   Reply

   - *Patrick Cage* says:
     May 20, 2019 at 1:51 pm

     Greetings Ann, pardon my delay responding to your comment. It is great to hear that Redrose is moving forward with seaweed cultivation in Ireland. Happy to connect further to discuss the state and outstanding questions around seaweed carbon sequestration: patrick.cage@ghginstitute.org

     Reply

2. *Robert CAPRIOLA* says:
   January 7, 2020 at 8:57 pm

   I am interested in whether anyone has attempted to quantify the net carbon export in grams per carbon ton equivalent per square meter per year for kelp forest…I know it probably depends on many factors, including total biomass of kelp per square meter of ocean floor. I am trying to get to a market value for restoring kelp forest in a denuded area.

   Reply

   - *Patrick Cage* says:
     May 13, 2020 at 1:39 pm

     Hi Robert, thanks for reading. I hope your efforts are going well. Probably the best place to start is with Froehlich et al. 2019 – "Blue Growth Potential to Mitigate Climate Change through Seaweed Offsetting." This paper looks at the cost of cultivation in the existing literature, as well as areas available for seaweed and kelp cultivation globally. What they find is that the cost of kelp restoration is orders of magnitude higher than the market price of carbon offsets. Comparing the price of cultivation against more conventional emissions reductions approaches is also very far from favorable. These estimates do not take into account the estimated export fraction directly, but that can be accomplished roughly with the material in the paper discussed above. I'd also emphasize the importance of not overestimating the scientific certain from the results in the paper above. Long story short, though there are many benefits to restoring kelp forests, the carbon benefits are neither certain nor cost-effective. (Note: In some sense this paper itself attempts to do what you are asking for at an extremely coarse resolution and the units you are looking for could be translated from the units provided. Again this is extremely rough, but would give you an approximate sense of scale.)

     Reply

Leave a Reply

Your email address will not be published. Required fields are marked *

COMMENT

NAME *

EMAIL *

WEBSITE

SAVE MY NAME, EMAIL, AND WEBSITE IN THIS BROWSER FOR THE NEXT TIME I COMMENT.

POST COMMENT