Quantifying Greenhouse Gas (GHG) Emissions Associated with Global Seafood Production

Proposers & Clients:

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Objective:

This project aims to quantify greenhouse gas (GHG) emissions associated with global seafood production. In collaboration with the Environmental Markets Lab (emLab) and Global Fishing Watch (GFW), we will create a reproducible, extensible, and open-source data processing pipeline to connect GFW fishing vessel emissions data with species-specific FAO seafood production data. Time permitting, we will also incorporate Aquatic Resource Trade in Species (ARTIS) data to assess emissions associated with the consumption of seafood species. This first-of-its-kind dataset would unlock novel research and publication opportunities, as well as unlock potential new policy and market-based interventions for reducing fisheries-related emissions.

Environmental motivation:

Climate change is undeniably one of the most pressing challenges facing this generation, and it affects virtually every aspect of life from health to food security to natural disasters (IPCC, 2023). Rising temperatures and shifting weather patterns are being driven by anthropogenic activities that emit large concentrations of GHGs (IPCC, 2023), including carbon dioxide (CO_2) and methane (CH_4), as well as smaller concentrations of nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride (EPA, 2024). The rise in global CO_2 concentrations have been primarily attributed to the combustion of fossil fuels (EPA, 2024), and nearly a quarter of global GHG emissions are the result of food production (Parker, 2018).

Global fisheries are heavily dependent on fossil fuels, with varied fuel use based on factors such as vessel size, target species, and gear type (Parker et al., 2018). Despite the footprint of marine fisheries covering more than four times the spatial extent of agriculture, satellite technology has been employed to monitor land-based emissions while ocean-based emissions have largely been generalized by a few case studies (Parker et al., 2018; Halpern et al., 2022). As a result, both total CO_2 emission calculations and carbon-intensity assessments associated with global fisheries have been simplified in previous studies, largely due to a lack of high-resolution fishing vessel emissions data (Greer et al., 2019).

Greenhouse gas emissions associated with fishing are not evenly distributed across areas or demographics. As such, the overarching goal of this project is to help identify areas for improved regulation and market-based interventions. By leveraging multiple new datasets, this project aims to provide precise insights to GHG emissions associated with global fisheries production of specific species (and potentially consumption), resulting in actionable data to identify key GHG contributors and highlight opportunities to reduce emissions. Improved understanding of emissions contributions can hold large emitters accountable for their role in climate change. The dataset resulting from this project could be leveraged in additional analyses to assess the

relationship between emissions and overfishing and evaluate the potential co-benefits of sustainable fisheries management and reduced emissions.

Data Science Need:

Recent advances in satellite technology and machine learning (Kroodsma et al., 2018; Paolo et al. 2024) have allowed for high-resolution spatiotemporal emissions data to be measured at scale. Many large industrial ships, including fishing vessels, are required to share location information via an automatic identification system (AIS; GFW, 2024). Harnessing these data, GFW and emLab have created an AIS-based model to estimate emissions associated with over 150,000 industrial fishing vessels across seven different pollutants (CO2, CH4, N2O, NOX, SOX, CO, and PM) (GFW & emLab, 2024). Additionally, there exists a fleet of vessels that do not broadcast AIS signals. Using Sentinel-1 Synthetic Aperture Radar (SAR) data, GFW and emLab have been able to estimate spatiotemporal emissions associated with the non-broadcasting fleet for the first time (GFW & emLab, 2024).

We are now uniquely positioned to join these two emissions datasets with FAO species-specific fisheries production data, allowing for the analysis of GHG emissions associated with global seafood production of specific species. A data processing pipeline is essential to effectively link these large datasets, but difficulties may extend from mismatched taxonomic classifications, spatial distribution, and allocation by gear use. We plan to develop a dashboard with interactive maps and plots to visualize emissions associated by flag, species, gear type, and region. If possible, the project will also incorporate Aquatic Resource Trade in Species (ARTIS) data to quantify the emissions associated with the consumption of marine species in particular countries.

Deliverables:

1. Reproducible, extensible, and open-source data processing pipeline to assess emissions associated with seafood production (and potentially seafood consumption)
2. Interactive public dashboard to visualize the relationships between GHG emissions and fishing vessel flag, species, gear type, and region (and potentially seafood commodity and consuming country)
3. Comparison of results (i.e., emissions of CO2 per kilogram of catch) to other published estimates (e.g., Parker et al., 2018; Halpern et al., 2022; Seafood Carbon Emissions Tool)

As open-source products, our deliverables can be viewed and utilized by the public, research communities, and other working groups who may wish to build upon our findings. The dashboard is designed as an exploratory tool for policymakers and regulators interested in developing emissions reductions strategies as well as for consumers concerned with investing in more sustainable seafood products. Seafood certification or labeling bodies may be interested in

using our findings to incorporate emissions standards into their programs. emLab and GFW hope to eventually publish one or more peer-reviewed publications based on this work, and would be excited to collaborate on this with any or all of the students if they are interested.

Data:

The following datasets are needed for the project:

1. GFW/emLab AIS-based emissions data for emissions of AIS-tracked fishing vessels
2. GFW/emLab Sentinel-1 based emissions data for emissions of non-broadcasting fishing vessels
3. Marine Gazetteer Placedetails (FAO Region shapefile) to assign FAO region
4. FAO seafood production data for analysis of seafood production data

The following datasets are additional resources:

5. ARTIS data for analysis of seafood consumption/commodities data
6. Global Fisheries Landings for assigning gear type by flag and species
7. RAM legacy stock assessment data for analysis by fisheries stock assessment

Project Requirements:

There are no predefined approaches for the implementation of the project, but emLab has suggested a general guiding workflow (see supporting materials). Spatiotemporal aggregation of emissions data at a monthly scale within 1x1 degree grid cells allows for each datapoint to be assigned to an FAO region using a shapefile (data resource # 3), providing a crucial link between the datasets. ARTIS data can later be incorporated at the year, flag, and species level.

While there are no strict technical requirements, we anticipate that most programming will occur in R. Data is hosted on Nextcloud and accessible by password. As for the dashboard, emLab has offered to use their shinyapps.io account, but a simple data exploration/visualization tool could be done using an html flexdashboard hosted using GitHub pages. For code version control, emLab recommends using GitHub; for package dependency management, emLab recommends using the renv R package; and for workflow management, emLab recommends using the targets R package.

Supporting Materials

References:

Environmental Protection Agency (EPA), 2024. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000. EPA 430-R-24-004.

Global Fishing Watch (GFW), 2024. What is AIS?. https://globalfishingwatch.org/faqs/what-is-ais/

GFW and Environmental Markets Lab, 2024. Quantifying Ocean-based Greenhouse Gas Emissions. https://emlab-ucsb.github.io/ocean-ghg/

Greer, K., Zeller, D., Woroniak, J., Coulter, A., Winchester, M., Deng Palomares, M.L., and Pauly, D., 2019. Global trends in carbon dioxide (CO2) emissions from fuel combustion in marine fisheries from 1950 to 2016. *Marine Policy*, 107(103382), pp. 1-9.

Intergovernmental Panel on Climate Change (IPCC), 2023. Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, pp. 1-34.

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A. and Woods, P., 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), pp.904-908.

Parker, R.W.R., Blanchard, J.L., Gardner, C., Green, B.S., Hartmann, K., Tyedmers, P.H., and Watson, R.A., 2018. Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, 8, pp. 333–337.

Halpern, B.S., Frazier, M., Verstaen, J., Rayner, P., Clawson, G., Blanchard, J.L., Cottrell, R.S., Froehlich, H.E., Gephart, J.A., Jacobsen, N.S., Kuempel, C.D., McIntyre, P.B., Metain, M., Moran, D., Nash, K.L., Tobben, J., and Williams, D.R., 2022. The environmental footprint of global food production. *Nature Sustainability* 5, pp. 1027–1039.

Paolo, F.S., Kroodsma, D., Raynor, J., Hochberg, T., Davis, P., Cleary, J., Marsaglia, L., Orofino, S., Thomas, C., and Halpin, P., 2024. Satellite mapping reveals extensive industrial activity at sea. *Nature* 625, pp. 85–9.

Max, L., Parker, R., Tyedmers, P., nd. Seafood Carbon Eimssions Tool. http://seafoodco2.dal.ca/

Budget and justification:

No additional funding requirements are anticipated for this project as all data are freely available and analysis can be executed with open-source software. The $250 allocated by the Bren School should be more than sufficient.

Client letter of support:

MEDS Capstone Project Selection Committee
Bren School of Environmental Science & Management
2400 Bren Hall, UCSB, Santa Barbara CA 93106

Dear MEDS Capstone Project Selection Committee,

We are thrilled to enthusiastically endorse the MEDS Capstone project proposal, "Quantifying greenhouse gas emissions associated with wild caught fisheries". I am writing this letter on behalf of the entire client team here at UCSB's Environmental Markets Lab (emLab), which includes myself, data scientist Pol Carbó Mestre, and project scientist Echelle Burns.

emLab is a research group based at the Bren School. We are a "think and do" tank composed of an interdisciplinary research team that develops innovative science to address complex natural resource management challenges. In collaboration with our close partner Global Fishing Watch (GFW), we have developed a dataset of high-resolution greenhouse gas emissions for every vessel in the ocean that uses the satellite-based Automatic identification system (AIS). The dataset covers over 150,000 fishing vessels, and an additional 550,000 non-fishing vessels. Additionally, leveraging Sentinel-1 Synthetic Aperture Radar, we have developed a first-of-its kind dataset of emissions from non-broadcasting vessels that do not use AIS. Combined, these datasets provide a comprehensive and unprecedented picture of ocean-based emissions (read more on these datasets here).

The MEDS Capstone Project would leverage these datasets, along with publicly available global datasets of fisheries catch, to quantify the greenhouse gas emissions associated with wild caught fisheries. This would unlock novel research and publication opportunities, such as being able to quantify the relationship between overfishing and emissions, and being able to assess the potential co-benefits of sustainable fisheries management and emissions mitigation. This would also unlock novel market-based and consumer-facing interventions, such as certifications and eco-labels that would be able to list the emissions associated with specific seafood products.

As the project's clients, we can fully commit to supporting the students with supervision throughout the project, regular meetings at least every other week, timely review of project

documents and deliverables, professional mentorship, and any other support as-needed. We do not anticipate needing any additional funding to complete this project. If the students choose to use R Shiny for creating a visualization dashboard, they could use emLab's paid shinyapps.io account. All data necessary to successfully complete the project are currently available, either publicly or directly from emLab. There are no publication restrictions related to our data; in fact, we would be excited to eventually collaborate on peer-reviewed publications with any of the students that may be interested.

We greatly appreciate your consideration of our project proposal. We would be thrilled to work with the students. We look forward to hearing back from you, and would be happy to answer any questions you may have.

Sincerely,

Gavin McDonald
Senior Project Scientist
Environmental Markets Lab (emLab)
University of California, Santa Barbara
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404-787-7993

Additional letter of support from Global Fishing Watch:

MEDS Capstone Project Selection Committee
Bren School of Environmental Science & Management
2400 Bren Hall, UCSB, Santa Barbara CA 93106

Dear MEDS Capstone Project Selection Committee,

This letter is written to communicate Global Fishing Watch's (GFW) strong endorsement of the MEDS Capstone project proposal, "Quantifying greenhouse gas emissions associated with wild caught fisheries". Our Mission at GFW is to advance ocean governance through increased transparency of human activity at sea, which we strive to accomplish through creating and publicly sharing data and analysis tools that enable scientific research. This proposal perfectly encapsulates that theory of change and is a natural extension of our longstanding partnership with UCSB's Environmental Markets Lab (emLab).

As climate change poses a significant threat to our world, an understanding of how much greenhouse gas (GHG) emissions such as carbon dioxide are produced as a result of ocean based activities may provide important information for better monitoring and management of these

emissions. Together, GFW and emLab synthesized numerous satellite and remote sensing datasets and deployed a sophisticated model of vessel-based emissions. The new datasets resulting from this work may be an important building block for understanding emissions at sea but have yet to be explored across different ocean sectors. The proposed project will help unlock and inform various types of policy and/or market-based solutions that could aid in the reduction of at-sea GHG emissions from the fisheries sector, GFW's core focus.

Global Fishing Watch is very enthusiastic about this project as we believe it will help MEDS students develop strong technical skills while advancing our ambitions to enable novel insights of human activity at sea with our datasets. As a Senior Data Scientist on GFW's Research and Innovation Team and a Bren MESM alumni, I am further excited to supporting the project with technical guidance, data access, and general mentorship. We look forward to your decision and are available to answer any questions.

Best,

Tyler Clavelle, MESM 2014
Senior Data Scientist, Research and Innovation
Global Fishing Watch
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(802) 578-8701

Recommended workflow:

1. Start with GFW/emLab AIS-based emissions estimates (data resource #1), which are aggregated by flag, gear, vessel size class, month, and 1x1 degree pixel (**meds_capstone_ais_emissions_data.csv**).
2. Next, take the GFW/emLab non-broadcasting emissions estimates (data resource #2), which are aggregated by vessel size class, month, and 1x1 degree pixel (**meds_capstone_non_broadcasting_emissions_data.csv**).
3. Join the tables from step #1 and step #2 so that we can assign non-broadcasting fleet emissions by flag, gear, month, and 1x1 degree pixel. This will give us a table that has both AIS-based and non-broadcasting fleet emissions by flag, gear, month, and 1x1 degree pixel.
4. Assign all of the pixels for the table in step #3 to an FAO region (using Marine Gazetteer Placedetails (FAO Region shapefile, data resource #3). Then we can aggregate the data up to the level of flag, gear, year, and FAO region.
5. Investigate the Watson (2006) database (data resource #6) to see if it could be used to make a lookup table of which gears are used by which flags to catch which species. We should be looking for whether or not we could use this to readily match up the GFW

flag-by-gear by effort data to the FAO flag-by-species catch data. If it seems feasible, build this gear-by-flag-by-species lookup table.

6. Now join the table from step #4 with the FAO data (data resource #4). If we're able to build the gear lookup from step #5, we will join the datasets based on year, flag, gear, and FAO region. If we're not able to build the gear lookup table, we will simply join the datasets based on year, flag, and FAO region. This will ultimately give us a table of year, flag, (maybe gear), species, catch, and emissions. So at this point, we'll have an incredibly awesome, first of its kind dataset! The dataset itself would be the first major deliverable.
7. With the dataset from step #6, the second major deliverable would be some really exciting data visualizations, comparative statistics, etc. looking at emissions (and emissions-per-unit catch) across the production of different species, different flags, etc.
8. Alongside the visualizations, the third deliverable would be a comparison of our results to some other published work in this space (like this paper). Even if we only got to this point, the project would be a success!
9. If there is still time, the next step would be to link the dataset from step #6 to the ARTIS database (data resource #5). This would be done at the year, flag, and species level. If we're able to make this link, then we would be able to determine the emissions associated with the trade of different species, and really importantly the emissions associated with the apparent consumption of different species. So at this point, we'd not only be able to quantify the emissions (and emissions-per-unit catch) of production, but now also the emissions (and emissions-per-unit-catch) of consumption of different species in different countries. This could be huge in terms of consumer information and market-based interventions! So this dataset would be a fourth "reach" deliverable.
10. If we can do step #8, another set of really exciting data visualizations, comparative statistics, etc. looking at emissions (and emissions-per-unit catch) across the consumption of different species in different countries. This would be a fifth "reach" deliverable. This is probably the furthest we might make it in the project timeline.

11. Additional reach goal: As we think about eventual potential publications, we'll eventually want to link the production emissions data to fisheries stock assessments (i.e., from the RAM Legacy Stock Assessment Database, data resource #7)). So in the chance there is still time left during the MEDS capstone, we could explore making this connection between our year-by-flag-by-species production emissions with year-by-flag-by-species stock assessments. This would allow us to start exploring questions like whether there is a relationship between emissions and overfishing, and whether there could be co-benefits between more sustainable fisheries management and reduced emissions! This could be a fifth "super reach" deliverable that we eventually hope to do in future research.

Emissions datasets descriptions and schemas:

Beside the publically available datasets, emLab is providing the following two emissions datasets, which can both be downloaded at the following public link: https://nextcloud.grit.ucsb.edu/index.php/s/QrFpsExrwrtNyeW:

`meds_capstone_ais_emissions_data.csv`:

This dataset summarizes AIS-based emissions aggregated by flag, vessel class, fishing activity, vessel size group, and spatiotemporally aggregated at a monthly scale within 1x1 degree grid cells.

- **time:** From 2015-01 to 2022-01 (monthly)
- **lon_bin:** Longitude of the pixel (spatial aggregation of 1x1 degree)
- **lat_bin:** Latitude of the pixel
- **length_size_class_percentile:** Vessels are divided into large (2) and small (1)
- **flag:** Vessel flag (ISO alpha-3)
- **vessel_class:** GFW vessel classes (note: this may include some non-fishing vessels due to discrepancies between models determining fishing/non-fishing activity. Unwanted classes can be filtered out later)
- **fishing:** Distinguishes between fishing activity (TRUE) and navigation (FALSE)
- **hours:** Cumulative hours
- **emissions_{pollutant}_mt:** Seven variables corresponding to the seven pollutants (CO2, CH4, N2O, NOX, SOX, CO, and PM), with emissions in metric tons.

`meds_capstone_non_broadcasting_emissions_data.csv`:

This dataset summarizes non-broadcasting fleet emissions aggregated by vessel size group at a monthly scale within 1x1 degree grid cells.

- **time:** From 2016-01 to 2022-12 (Monthly)
- **lon_bin:** Longitude of the pixel (spatial aggregation of 1x1 degree)
- **lat_bin:** Latitude of the pixel
- **length_size_class_percentile:** Vessels are divided into large (2) and small (1)
- **emissions_{pollutant}_non_broadcasting_mt:** Seven variables corresponding to the seven pollutants (CO2, CH4, N2O, NOX, SOX, CO, and PM), with emissions in metric tons.