HUMAN IMPACTS by the numbers

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ABSTRACT

The greatest experiment of the last 10,000 years is the presence and action of modern human beings on planet Earth. At this point, the consequences of this experiment are being felt on many fronts. Yet, many people still hold the view that because the world is so "huge", humans cannot really make a substantial impact. One way to organize our thinking about what these impacts might be, with tongue in cheek, is to focus on Empedocles's classic elements, earth, air, water and fire, with the idea being to explore how humans have altered the land and its inhabitants, the atmosphere, the oceans and how our quest for cheaper and cheaper energy (fire) from the world around us has altered that world. This snapshot represents a small collection of numbers that summarize the broad reach of human action across the planet, presenting a view of the impact of human presence on Earth.

UNITS OF REFERENCE

human population = $\approx 7\times10^{9}$ mass of a pick-up truck = ≈ 1 t

area of soccer pitch = ≈ 3000 m^2 power of a lightbulb = ≈ 100 W

volume of olympic pool = ≈ 2000 m^3

A MELT WATER

glacial melt volume $\approx 3\times10^{11}$ m^3/yr $\approx$ 150 million × /yr

arctic sea-ice melt volume $\approx 3\times10^{11}$ m^3/yr $\approx$ 150 million × /yr

ice-sheet melt volume $\approx 4\times10^{11}$ m^3/yr $\approx$ 200 million × /yr

total melt volume $\approx 10^{12}$ m^3/yr $\approx$ 500 million × /yr

B POWER DERIVED FROM RENEWABLES

wind $\approx$ 360 GW $\approx$ 4 billion ×

solar $\approx$ 200 GW $\approx$ 2 billion ×

biofuels $\approx$ 150 GW $\approx$ 1.5 billion ×

total $\approx$ 875 GW $\approx$ 9 billion ×

C SEA LEVEL RISE

rise from melt-water $\approx$ 1.6 mm / yr

rise from thermal expansion $\approx$ 1.2 mm / yr

total annual sea-level rise $\approx$ 3 mm / yr

D NITROGEN FIXATION

reactive nitrogen produced via Haber-Bosch $\approx 2\times10^{8}$ t/yr $\approx$ 200 million × /yr

E RIVER FRAGMENTATION

global volume of dammed and fragmented rivers $\approx 10^{12}$ m^3 $\approx$ 500 million ×

hydroelectric power consumption $\approx$ 1 TW $\approx$ 10 billion ×

F POPULATION OF LIVESTOCK

chicken population $\approx 2\times10^{10} \approx 3$ ×

cattle population $\approx 2\times10^{9} \approx 0.3$ ×

pig population $\approx 1\times10^{9} \approx 0.1$ ×

total livestock population $\approx$ 30 billion ≈ 4 ×

G EXTENT OF TERRESTRIAL LAND USAGE

agriculture $\approx 5\times10^{13}$ m^2 $\approx$ 15 billion ×

urban $\approx 4\times10^{12}$ m^2 $\approx$ 1 billion ×

H DEFORESTATION AND FOREST DISRUPTION

commodity driven $\approx 5\times10^{10}$ m^2 $\approx$ 16 million × /yr

shifting agriculture $\approx 4\times10^{10}$ m^2 $\approx$ 10 million × /yr

forestry $\approx 6\times10^{10}$ m^2 $\approx$ 20 million × /yr

urbanization $\approx 2\times10^{9}$ m^2 $\approx$ 600,000 × /yr

total $\approx 2\times10^{11}$ m^2 $\approx$ 60 million × /yr

I MATERIAL OF HUMAN ORIGIN

concrete production $\approx 3\times10^{10}$ t/yr $\approx$ 30 billion × /yr

steel production $\approx 2\times10^{9}$ t/yr $\approx$ 2 billion × /yr

plastic production $\approx 4\times10^{6}$ t/yr $\approx$ 4 million × /yr

J OCEAN pH

% increase in H^+ concentration $\approx$ 0.2% / yr

K HUMAN WATER USE

agriculture $\approx 1.5\times10^{12}$ m^3/yr $\approx$ 750 million × /yr

power generation $\approx 3\times10^{11}$ m^3/yr $\approx$ 150 million × /yr

domestic $\approx 6\times10^{10}$ m^3/yr $\approx$ 30 million × /yr

total water use $\approx 2\times10^{12}$ m^3 /yr $\approx$ 1 billion × /yr

L GLOBAL POWER CONSUMPTION

global power usage $\approx$ 20 TW/yr $\approx$ 200 billion × /yr

M OCEAN WARMING

power deposited into oceans $\approx$160 TW $\approx$1.5 trillion ×

change in surface temperature $\approx$ 0.03 ° C / yr

N GREENHOUSE GAS PRODUCTION

anthropogenic CO_2 release $\approx 42\times10^{9}$ t $\approx$ 42 billion × /yr

anthropogenic CH_4 release $\approx 4\times10^{8}$ t $\approx$ 400 million × /yr

O OIL & NATURAL GAS EXTRACTION

volume of natural gas extracted $\approx 4\times10^{12}$ m^3 /yr $\approx$ 2 billion ×

volume of oil extracted $\approx 5.5\times10^{9}$ ^{mv} $\approx$ 3 million ×

power derived from natural gas $\approx$ 4 TW $\approx$ 40 billion ×

power derived from oil $\approx$ 6 TW $\approx$ 60 billion ×

P HUMAN-CAUSED EXTINCTION

animal species > 800

plant species > 150

Q CORAL REEF LOSS

Great Barrier Reef coral coverage decrease in 2016 $\approx$ 30%

R EROSION

intentional soil movement $\approx 4\times10^{10}$ t/yr $\approx$ 40 billion × /yr

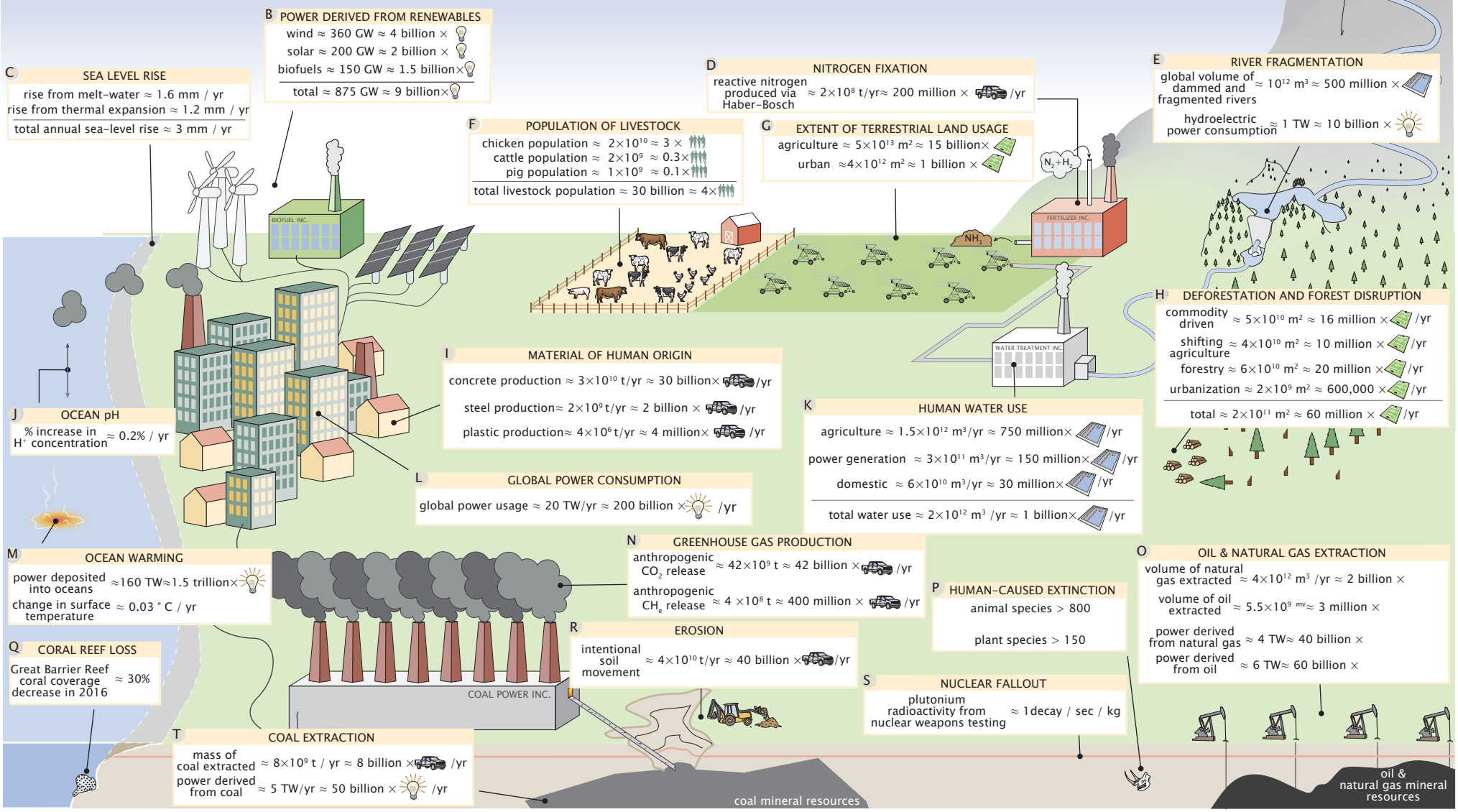
S NUCLEAR FALLOUT

plutonium radioactivity from nuclear weapons testing $\approx$ 1decay / sec / kg

T COAL EXTRACTION

mass of coal extracted $\approx 8\times10^{9}$ t / yr $\approx$ 8 billion × /yr

power derived from coal $\approx$ 5 TW/yr $\approx$ 50 billion × /yr



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SUPPORTING INFORMATION

A MELTWATER

glacial melt rate	HuID: 32459

Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 2.A.1 on pp. 199–202 **Notes:** Value corresponds to the trend of annual mass loss from major glacierized regions (2006–2015). Volume loss was calculated from mass loss.

ice-sheet melt rate	HuID: 44746; 88530

Data Source(s): NASA JPL Physical Oceanography Distributed Active Archive Center. **Notes:** Value corresponds to the trend of annual mass loss from the Greenland and Antarctic Ice Sheets (2002–2020). Volume loss was calculated from mass loss.

arctic sea ice melt rate	HuID: 89520

Data Source(s): PIOMAS Arctic Sea Ice Volume Reanalysis, original method source: Schweiger et al. 2011 DOI: 10.1029/2011JC007084 **Notes:** Value reported corresponds to the trend of decadal volume loss from Arctic sea ice (1979–2020) which was converted to annual volume loss.

total melt rate	HuID: 89075

Data Source(s): Sum of glacial, ice sheet, and sea ice melt rate. **Notes:** Antarctic sea ice loss is not included due to data sparsity. The periods of analysis are not the same, therefore this rate represents an approximation rather than an exact calculation.

B POWER DERIVED FROM RENEWABLES

wind	HuID: 30581
solar	HuID: 99885
biofuels	HuID: 89570
total	HuID: 20246

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Reported values correspond to estimates for the 2019 calendar year. Renewable resources are defined as wind, geothermal, solar, biomass and waste, and does not include hydroelectric power generation.

C SEA LEVEL RISE

rise due to meltwater	HuID: 97108
rise due to thermal expansion	HuID: 97688
total annual sea-level rise	HuID: 81373

Data Source(s): Table 1 of Frederikse et al. 2020. DOI:10/d689. **Notes:** Values correspond to the average global sea level rise of the years 1993 – 2018. Meltwater is defined as the global annual sea level rise due to melt of glaciers, the Greenland ice sheet, and antarctic ice sheet.

D NITROGEN FIXATION

fixed mass of nitrogen	HuID: 60580; 30310; 78152

Data Source(s): USGS Mineral Commodities Summaries (Fixed Nitrogen), January 2020; Table 2 of "World fertilizer trends and outlook to 2022" Food and Agricultural Organization of the United Nations, 2019, ISBN: 978-92-5-131894-2. Smith et al. 2020, DOI:10.1039/c9ee02873k. **Notes:** The approximate mass of contained nitrogen in salient ammonia produced globally in 2018 as reported by the USGS is ≈ 144 Mt. This value is in moderate agreement with the forecast of ≈ 160 Mt of nitrogen-contained ammonia as forecast for 2018 by the FAO. Approximately all of this mass is produced by the Haber-Bosch process (>96%, Smith et al. 2020).

E RIVER FRAGMENTATION

fragmented river volume	HuID: 000000

Data Source(s): CSV dataset: DOI: 10.5281/zenodo.3875115, original data source: Grill et al. 2019 DOI: 10.1038/s41586-019-1111-9. **Notes:**

hydroelectric power	HuID: 27945

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Value corresponds to the reported value of global hydroelectricity consumption for 2019.

F LIVESTOCK POPULATION

chicken	HuID: 94934
cattle	HuID: 92006
pig	HuID: 21368
total	HuID: 15765

Data Source(s): Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT). **Notes:** Counts correspond to the approximate average of the standing populations reported between 2010 – 2018. Values are reported directly by countries, yet the FAO uses non-governmental statistical sources to address uncertainty and missing (non-reported) data.

G EXTENT OF TERRESTRIAL LAND USAGE

agriculture	HuID: 29582

Data Source(s): Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT) **Notes:** "Agriculture" land is defined as all land that is under agricultural management including pastures, meadows, permanent crops, temporary crops, land under fallow, and land under agricultural structures. Reported value corresponds to 2017 measurements by FAO.

urban	HuID: 00000

Data Source(s): World Bank and Center for International Earth Science Information Network (CIESIN)/-Columbia University. 2013. **Notes:** Urban land area is determined from satellite imagery. An area is determined to be "urban" if the total population is greater than 5,000. Value corresponds to the most recent estimate from 2010.

H DEFORESTATION AND DISRUPTION

commodity-driven	HuID: 96098
shifting agriculture	HuID: 24388
forestry	HuID: 38352
urbanization	HuID: 19429
total	HuID: 78576

Data Source(s): Table 1 and Figure 3 of Curtis et al. 2018 DOI:10.1126/science.aau3445. Hansen et al. 2013 DOI:10.1126/science.1244693. Global Forest Watch, 2020. **Notes:** Commodity-driven deforestation is defined as "long-term, permanent, conversion of forest and shurbland toa nonforest land use such as agriculture, mining, or energy infrastructure." Forest area loss due to shifting agriculture is defined as "smal-to-medium-scale forest and shrubland conversion for agriculture that is later abandoned and followed by subsequent forest regrowth." Forest area disruption due to forestry is defined as... "large-scale forestry operations occurring within managed forests and tree plantations with evidence of forest regrowth in subsequent years." Forest land disruption due to urbanization is defined as "forest and shrubland conversion for the expansion and intensification of existing urban centers." Total value of deforested and disrupted forest land includes wildfires of both human and natural causes. Values correspond to calendar year 2015 and are calculated from the statistic that ≈ 25% of total deforested and disrupted forest land sums to ≈ 5 MHa/yr. See Table 1 and Figure 3 of Curtis et al. 2018.

I MATERIAL OF HUMAN ORIGIN

concrete production	HuID: 25488
steel production	HuID: 51453

Data Source(s): USGS 2020, Mineral commodities. DOI:10.3133/mcs2020; Monteiro et al. 2017, DOI:10.138/nmat4930 **Notes:** Concrete production value corresponds to approximate value from multiple sources. USGS 2020 Mineral Commodities Survey reports mass of cement produced in 2019. This is converted to concrete using a multiplicative conversion factor of ≈ 7 as described in Monteiro et al. 2017. Steel production corresponds to the USGS 2019 value.

plastic production	HuID: 97241

Data Source(s): Table S2 of Geyer et al. 2017. DOI:10.1126/sciadv.1700782. **Notes:** Value represents the sum total global production of plastic fibers and plastic resin during calendar year 2015.

J OCEAN pH

yearly change in $[H^+]$	HuID: 19394

Data Source(s): Figure 2 of European Environment Agency report CLIM 043 (2020). Original data source of report is "Global Mean Sea Water pH" from Copernicus Marine Environment Monitoring Service. **Notes:** Reported value is calculated from the average annual change in pH over years 1985–2018. Annual change in pH is ≈ 0.001 pH units, corresponding to a change in $[H^+]$ of ≈ 0.2 % / yr.

K HUMAN WATER USE

agriculture	HuID: 43593
power generation	HuID: 78784
domestic	HuID: 69424
total	HuID: 27342

Data Source(s): Figure 1 of Qin et al. 2019. DOI:10.1038/s41893-019-0294-2. **Notes:** "Agricultural use" is defined as water used for irrigation, maintenance of livestock, and water used in the management of irrigation via damming. "Power generation" is defined as water used for thermal power generation (coal, nuclear, gas, biomass, oil, and other/waste) and hydroelectric generation. "Domestic" is defined as water directly used by humans and water used in the maintenance of municipal water supply. "Total" water use includes the above categories as well as other uses of water in reservoir management including flood control and other unannotated uses. All values pertain to estimates for 2016.

L GLOBAL POWER CONSUMPTION

global power consumption	HuID: 31373

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Reported values correspond to estimates for the 2019 calendar year. Represents the sum total consumed energy from oil, natural gas, coal, nuclear energy, hydroelectric, and renewables.

M OCEAN WARMING

power deposition	HuID: 59201
ocean surface warming	HuID: 87228

Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 5.1 on pp. 458 and footnote 4 on pp. 457. **Notes:** Value is calculated from the reported annual heat uptake of ≈ 5 ZJ/yr over the time period of 2005 – 2017. This assumes a constant value for deposition into the ocean surface (0 – 700 m depth) and deep ocean (700 – 2000 m depth) where heat deposition is lower. Ocean surface temperature change is calculated from ≈ 5 ZJ/yr heat uptake by noting that deposition of ≈ 144 ZJ/yr raises the temperature of the top 100 m of ocean by ≈ 1° C. See the complete report or section 5.2.2.2 of the source material for more information.

N GREENHOUSE GAS EMISSIONS

yearly CO_2 released	HuID: 47200; 98043

Data Source(s): Friedlingstein et al. 2019, DOI: 10.5194/essd-11-1783-2019. Original data sources relevant to this study compiled in Friedlingstein et al.: 1) Gilfillan et al. https://energy.appstate.edu/CDIAC 2) Average of two bookkeeping models: Houghton and Nassikas 2017 DOI: 10.1002/2016GB005546; Hansis et al. 2015 DOI:10.1002/2014GB004997 3) Dlugokencky and Tans, NOAA/GML https://www.esrl.noaa.gov/gmd/ccgg/trends/. **Notes:** Value corresponds to CO_2 emissions from fossil fuel combustion, industrial emissions (predominantly cement production), and land-use change during calendar year 2018. CO_2 was added to the atmosphere at a rate of ≈ 18.8 Gt / yr in 2018 (HuID: 98043); most of the remainder is taken up by the land sink and ocean sink.

yearly CH_4 released	HuID: 96837; 56405; 30725

Data Source(s): Table 2 of Saunois, et al. 2020. DOI: 10.5194/essd-12-1561-2020. **Notes:** Value corresponds to CH_4 emissions from anthropogenic sources in the calendar year 2017. Represents emissions from agriculture and waste, fossil fuels, and biomass and biofuel burning. Value is not simply the sum of these sources but is based on a full anthropogenic inventory of emissions. Natural emissions amount to ≈ 0.3 Gt / yr in 2017. CH_4 was added to the atmosphere at a rate of ≈ 17 Mt/yr in 2017; most of the remainder is taken up by chemical loss sink and soil sink.

O OIL & NATURAL GAS EXTRACTION

power derived from nat. gas	HuID: 49947
power derived from oil	HuID: 42121
volume of nat. gas extraction	HuID: 11468
volume of oil extraction	HuID: 66789

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Values pertain to 2019 estimates only. Oil volume includes crude oil, shale oil, oil sands, condensates, and natural gas liquids separate from specific natural gas mining. Natural gas value excludes gas flared or recycled and includes natural gas produced for gas-to-liquids transformation.

P HUMAN CAUSED EXTINCTION

animal species recently extinct	HuID: 44641
plant species recently extinct	HuID: 86866

Data Source(s): The IUCN Red List of Threatened Species. Version 2020-2. **Notes:** Values correspond to absolute lower-bound measurements of extinctions caused over the past ≈ 500 years. Of the predicted ≈ 8 million animal species, The IUCN databases catalogues only ≈ 900,000 with only ≈ 75,000 being assigned a conservation status. Representation of plants and fungi is even more sparse with only ≈40,000 and ≈285 being assigned a conservation status, respectively.... The number of extinct animal species is undoubtedly higher than these reported values, as signified by an inequality symbol (>).

Q CORAL REEF LOSS

2016 GBR cover loss	HuID: 90720

Data Source(s): Figures 1A, S1, and S2 of Hughes et al. 2018, DOI:10.1038/s41586-018-0041-2. **Notes:** Value corresponds to measured loss in coral coverage on members of the Great Barrier Reef using field measurements and satellite imaging. Time period considers the total area loss of coral between March and November of 2016. See methods section "Longer Term Mortality" of source publication.

R EROSION

soil moved	HuID: 59841

Data Source(s): Table 1 and Figure 4 of Hooke 2000, DOI:10/bdnqv9. K-Tec Earthmovers Inc. March 2018 Newsletter. Grand View Research Construction Industry Analysis, April 2020. **Notes:** Hooke 2000 estimates ≈ 35 Gt of soil moved annually in latter years of 20th century. This is in agreement with reported soil volume moved by industry member (K-Tec) and total revenue of soil movement and construction industry as reported by Grand View Research in April 2020. This value accounts for intentional soil movement only (such as mining and construction) and does not include agricultural soil movement.

S NUCLEAR FALLOUT

$^{239+240}Pu$ activity	HuID: 38748; 91171

Data Source(s): Figure 4 and Figure 5 in Hancock et al. 2014, DOI:10.1144/SP395.15. Figure 3 (col. 2, rows 3 – 5) of Ciszewski and Łokas, 2019, DOI:10.1515/geochr-2015-0111. **Notes:** Value corresponds to current-day detectable combined radioactivity of ^{239}Pu and ^{240}Pu present in cores of stratified soil with estimated date of ≈ 1963 CE during the peak of atmospheric nuclear weapons testing. Reported is approximate average activity from sediment samples in SE Australia (Hancock et al.) and Polish river basins (Ciszewski and Łokas).

T COAL EXTRACTION

mass of coal extracted	HuID: 78435
power derived from coal	HuID: 10400

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Values includes 2019 value exclusively for solid commercial fuels such as bituminous coal and anthracite, lignite and sub-bituminous coal, and other solid fuels. This includes coal used directly in power production as well as coal used in coal-to-liquids and coal-to-gas transformations.