Ecological Principles and Biodiversity for Sustainability

Dr. Ankur Awadhiya, IFS

13. Human population growth and requirements

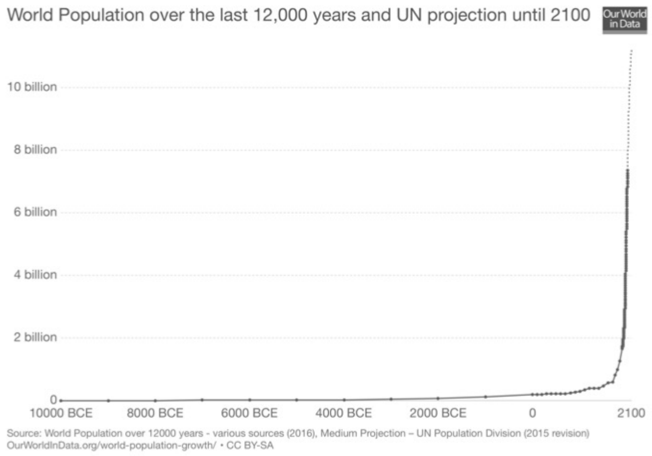
Thomas Robert Malthus

1. English cleric and scholar
2. 13 February 1766 – 23 December 1834
3. 1798 book “An Essay on the Principle of Population”
4. Influenced studies in Population Ecology

Malthusian growth model

1. Population grows in geometric progression, roughly doubling every 25 years: 1 → 2 → 4 → 8 → 16 → 32 ...
2. Food supply increases in arithmetic progression: 1 → 2 → 3 → 4 → 5 → 6 ...
3. Thus population tends to overrun food supply.
4. This imbalance is corrected by positive checks: vice, misery, famine, war, disease, pestilence, floods and other natural calamities
5. The imbalance may also be corrected using preventive checks: foresight, late marriage, celibacy, moral restraint, etc.

World Population does show exponential growth


World Population over the last 12,000 years and UN projection until 2100

Source: World Population over 12000 years - various sources (2016), Medium Projection – UN Population Division (2015 revision)
OurWorldInData.org/world-population-growth/ • CC BY-SA

(https://ourworldindata.org)

Malthusian growth model

If $P(t)$ denotes the population at time t, we can say

$$\frac{dP}{dt} = kP$$

where k is a positive constant. Upon integrating, we get

$$P(t) = P_0 e^{kt}$$

where P_0 denotes the population at time 0.

Doubling time

Doubling time, t_d is defined as the time required to double the population size.

Thus, $P(t_d) = 2P_0$

Hence,

$$2P_0 = P_0 e^{kt_d}$$

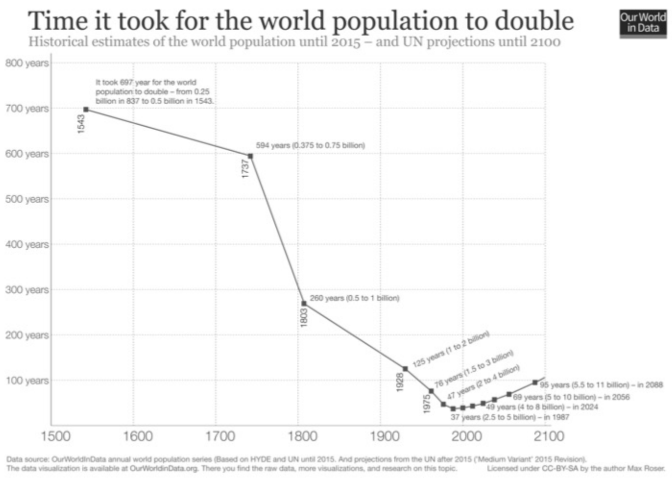
$$\implies 2 = e^{kt_d}$$

$$\implies ln2 = kt_d$$

$$\implies t_d = \frac{1}{k} ln2$$

Criticism 1: Population growth is not as suggested

The observed doubling time



Time it took for the world population to double

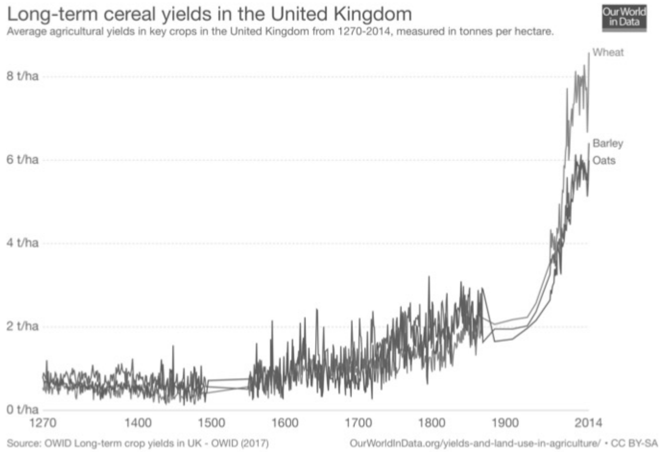
Historical estimates of the world population until 2015 – and UN projections until 2100

Data source: OurWorldInData annual world population series (Based on HYDE and UN until 2015. And projections from the UN after 2015 ('Medium Variant' 2015 Revision).
The data visualization is available at OurWorldinData.org. There you find the raw data, more visualizations, and research on this topic. Licensed under CC-BY-SA by the author Max Roser.

(https://ourworldindata.org)

Criticism 2: Agricultural growth is not as suggested

Exponential increase in yields



Long-term cereal yields in the United Kingdom

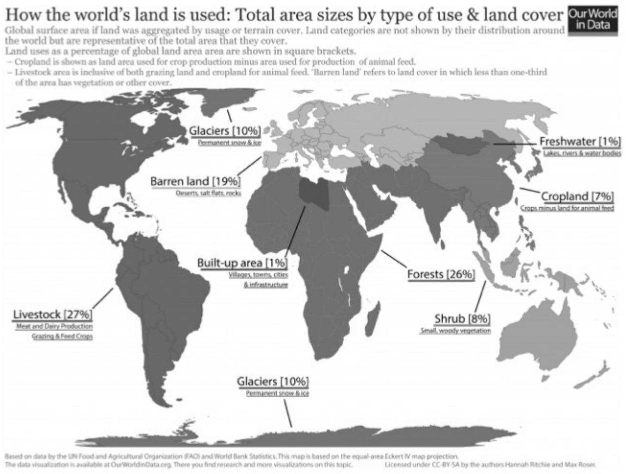
Average agricultural yields in key crops in the United Kingdom from 1270-2014, measured in tonnes per hectare.

Source: OWID Long-term crop yields in UK - OWID (2017)
OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA

(https://ourworldindata.org)

Criticism 3: Does not incorporate new land that becomes available

World land usage



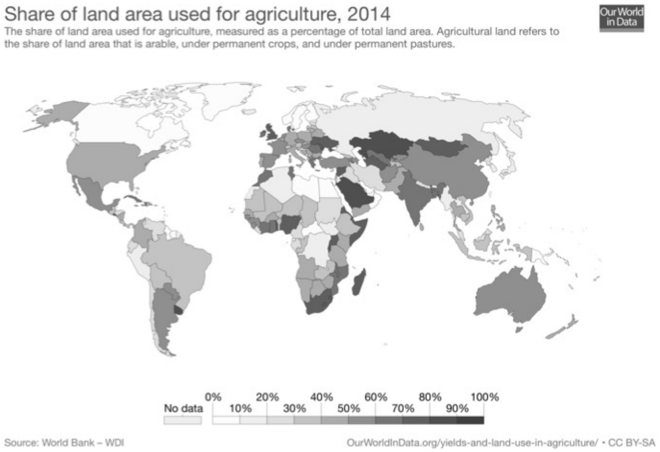
How the world's land is used: Total area sizes by type of use & land cover

Global surface area if land was aggregated by usage or terrain cover. Land categories are not shown by their distribution around the world but are representative of the total area that they cover.
Land uses as a percentage of global land area area are shown in square brackets.
– Cropland is shown as land area used for crop production minus area used for production of animal feed.
– Livestock area is inclusive of both grazing land and cropland for animal feed. 'Barren land' refers to land cover in which less than one-third of the area has vegetation or other cover.

Based on data by the UN Food and Agricultural Organization (FAO) and World Bank Statistics. This map is based on the equal-area Eckert IV map projection.
The data visualization is available at OurWorldinData.org. There you find research and more visualizations on this topic. Licensed under CC-BY-SA by the authors Hannah Ritchie and Max Roser.

(https://ourworldindata.org)

Share of land used for agriculture



Share of land area used for agriculture, 2014

The share of land area used for agriculture, measured as a percentage of total land area. Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures.

Source: World Bank – WDI OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA

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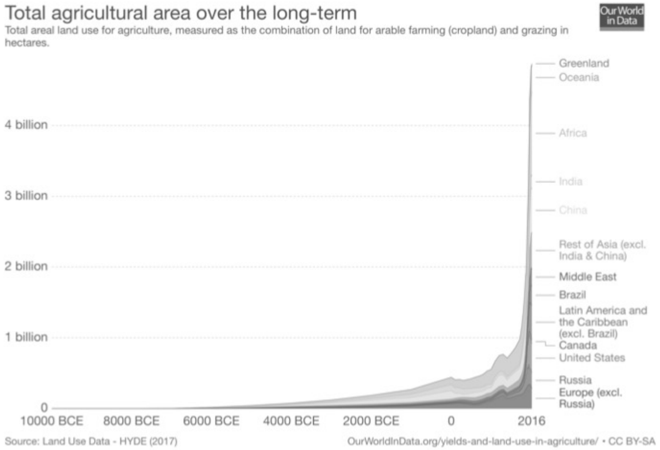
Increase in agricultural areas



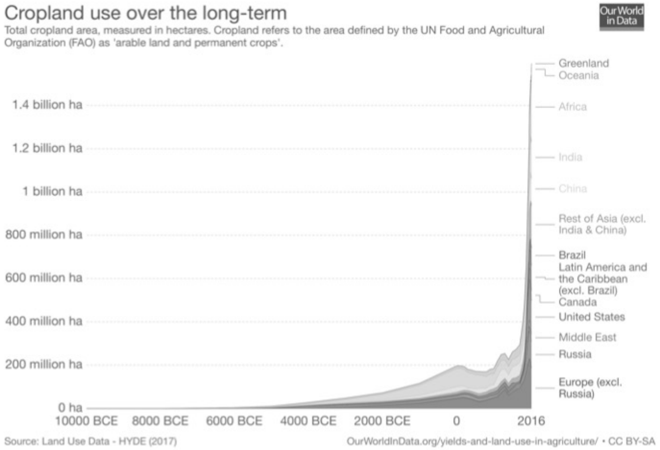
Total agricultural area over the long-term

Total areal land use for agriculture, measured as the combination of land for arable farming (cropland) and grazing in hectares.

Source: Land Use Data - HYDE (2017) OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA

(https://ourworldindata.org)

Increase in cropland areas



Cropland use over the long-term

Total cropland area, measured in hectares. Cropland refers to the area defined by the UN Food and Agricultural Organization (FAO) as 'arable land and permanent crops'.

Source: Land Use Data - HYDE (2017) OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA

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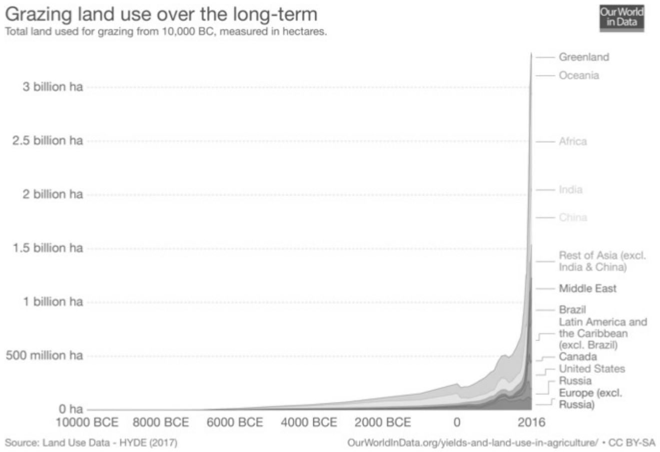
Increase in grazing areas

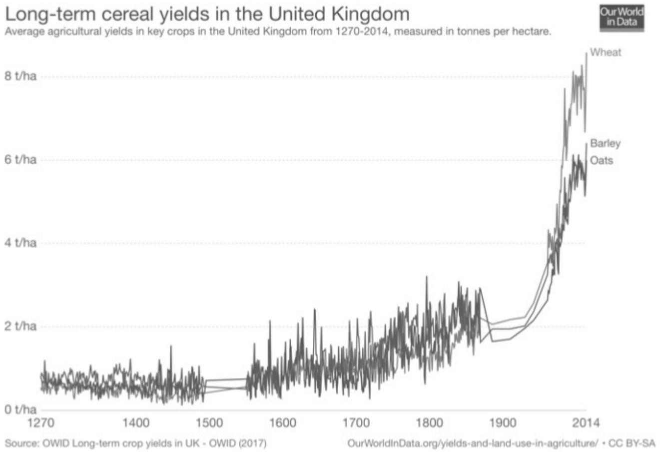

Grazing land use over the long-term
Total land used for grazing from 10,000 BC, measured in hectares.

Source: Land Use Data - HYDE (2017)
OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA

(https://ourworldindata.org)

Criticism 4: Neglects role of technology

Exponential increase in yields


Long-term cereal yields in the United Kingdom
Average agricultural yields in key crops in the United Kingdom from 1270-2014, measured in tonnes per hectare.

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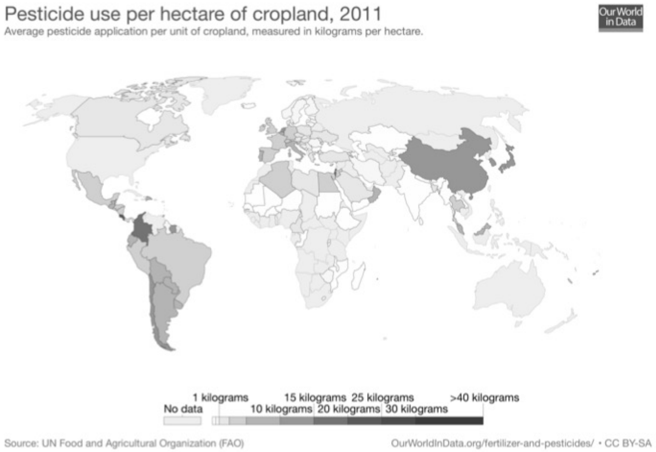
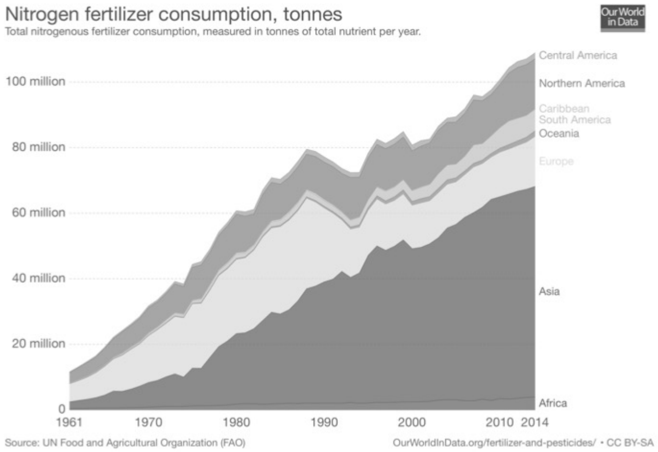
Technology to the rescue


Pesticide use per hectare of cropland, 2011
Average pesticide application per unit of cropland, measured in kilograms per hectare.

Source: UN Food and Agricultural Organization (FAO)
OurWorldInData.org/fertilizer-and-pesticides/ • CC BY-SA

(https://ourworldindata.org)

Technology to the rescue



Nitrogen fertilizer consumption, tonnes

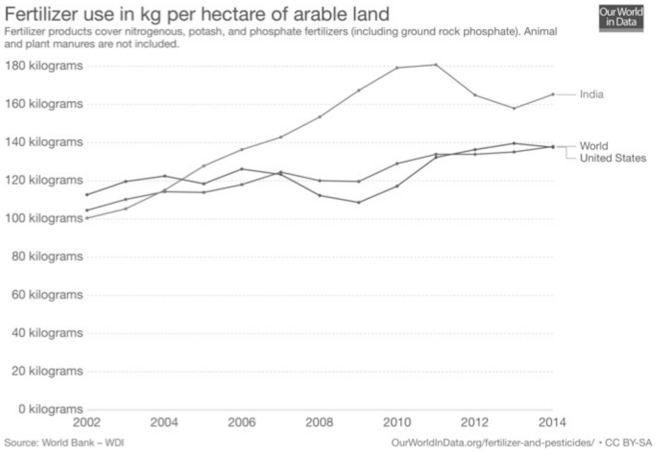
Total nitrogenous fertilizer consumption, measured in tonnes of total nutrient per year.

Source: UN Food and Agricultural Organization (FAO)

OurWorldInData.org/fertilizer-and-pesticides/ • CC BY-SA

(https://ourworldindata.org)

Technology to the rescue



Fertilizer use in kg per hectare of arable land

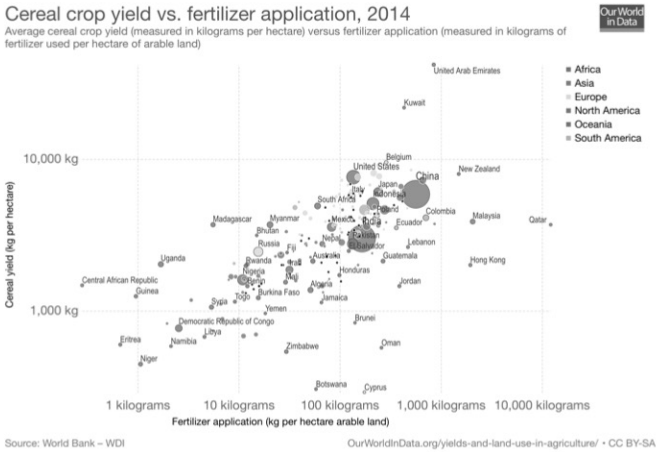
Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Animal and plant manures are not included.

Source: World Bank – WDI

OurWorldInData.org/fertilizer-and-pesticides/ • CC BY-SA

(https://ourworldindata.org)

Increased yields due to fertilisers



Cereal crop yield vs. fertilizer application, 2014

Average cereal crop yield (measured in kilograms per hectare) versus fertilizer application (measured in kilograms of fertilizer used per hectare of arable land)

Source: World Bank – WDI

OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA

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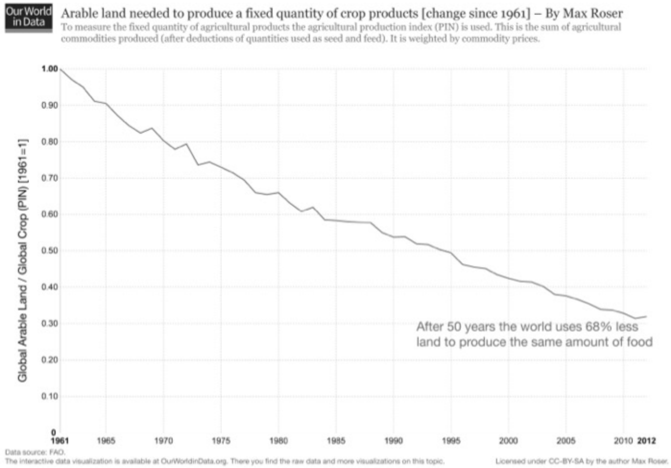
Productivity reduces land requirement



Arable land needed to produce a fixed quantity of crop products [change since 1961] – By Max Roser

To measure the fixed quantity of agricultural products the agricultural production index (PIN) is used. This is the sum of agricultural commodities produced (after deductions of quantities used as seed and feed). It is weighted by commodity prices.

After 50 years the world uses 68% less land to produce the same amount of food

Data source: FAO.

The interactive data visualization is available at OurWorldInData.org. There you find the raw data and more visualizations on this topic.

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(https://ourworldindata.org)

Other criticisms

5. Population not related to food supply but to total wealth
6. Does not consider population increase due to lowering of death rates
7. Preventive checks do not pertain only to moral restraint, e.g. contraceptives
8. Positive checks may occur even in low-populated countries, e.g. Japan

Glimpses from Wildlife Population Ecology

Rate of population growth

$$N_{t+1} = R_0 \times N_t$$

where

N_t = Population size at generation t

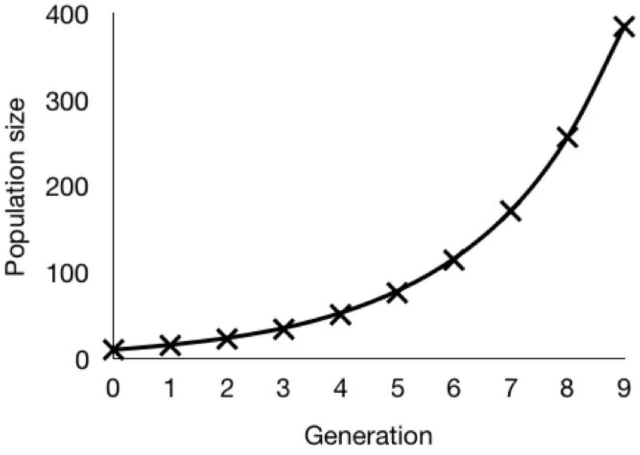
N_{t+1} = Population size at generation t + 1

R_0 = Net reproductive rate = Number of female offsprings produced per female per generation

Condition of constant $R_0 = 1.5$

GENERATION	POPULATION SIZE
0	10
1	15
2	22.5
3	33.75
4	50.625
5	75.9375
6	113.90625
7	170.859375
8	256.2890625
9	384.43359375

Condition of constant $R_0 = 1.5$



But R_0 is not constant. It varies with population size.

The logistic growth equation

$$\frac{dN}{dt} = rN \times (\frac{K - N}{K})$$

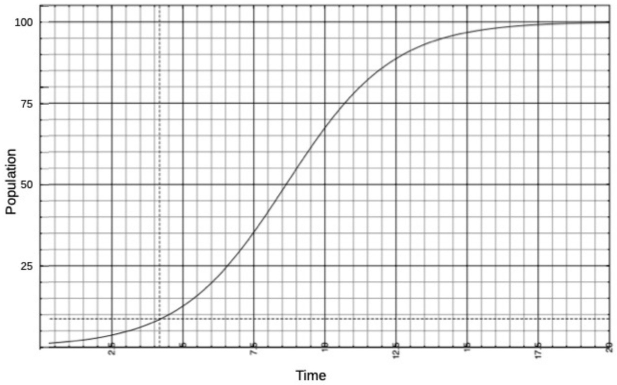
where

$N =$ Population size at time t

$K =$ Carrying capacity of the environment

$r =$ intrinsic growth rate

The logistic growth equation



Some common agents regulating population

1. Extrinsic agents
   a. weather
   b. predators
   c. parasites
   d. diseases
   e. quantity and quality of food available
   f. shelter
2. Intrinsic agents
   a. physiological
   b. behavioural

Thank you

14. Threats to biodiversity and ecology

Threat factors discerned from Ecology

The opposite question to: Why things are found where they are found?

Push factors everywhere, pull factors nowhere.

Threat factors discerned from Ecology: Push factors

1. No suitable habitat
    a. too hot, too cold
    b. no trees, no food, no nutrients
    c. completely burnt out
    d. rich in noxious factors: too polluted
    e. not suited behaviourally: Habitat selection at play
2. Competed out
    a. invasive species
    b. too many predators or diseases
3. Killed out
    a. heavy poaching
    b. too many predators or diseases
4. Small-population dynamics
    a. Allee effect
    b. stochastic deaths

Threat factors discerned from Ecology: Push factors

These can be divided into

1. factors pushing a population towards smaller numbers through population dynamics: Called the **Declining population paradigm**.
2. factors pushing a small population towards extinction: Called the **Small population paradigm**.

Declining population paradigm: Cause of smallness[1]

1. **No suitable habitat**
    1.1 too hot, too cold
    1.2 no trees, no food, no nutrients
    1.3 completely burnt out
    1.4 rich in noxious factors: too polluted
    1.5 not suited behaviourally: Habitat selection at play
2. **Competed out**
    2.1 invasive species
    2.2 too many predators or diseases
3. **Killed out**
    3.1 heavy poaching
4. Small-population dynamics
    4.1 Allee effect
    4.2 stochastic deaths

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[1] Caughley, G., 1994. Directions in conservation biology. Journal of animal ecology, pp.215-244.

Small factor paradigm: Impact of smallness[2]

1. No suitable habitat
    1.1 too hot, too cold
    1.2 no trees, no food, no nutrients
    1.3 completely burnt out
    1.4 rich in noxious factors: too polluted
    1.5 not suited behaviourally: Habitat selection at play
2. Competed out
    2.1 invasive species
    2.2 too many predators or diseases
3. Killed out
    3.1 heavy poaching
4. **Small-population dynamics**
    4.1 Allee effect
    4.2 stochastic deaths

---

[2] Caughley, G., 1994. Directions in conservation biology. Journal of animal ecology, pp.215-244.

Population dynamics and extinction

2 kinds of factors operate at all times:

1. deterministic factors (acting at large population sizes)
2. stochastic factors (more important when the population sizes are smaller)

Extinction factors at large sizes

Deterministic factors (acting at large population sizes):

1. birth rate
2. death rate
3. population structure

Extinction factors at small sizes

Stochastic factors (more important when the population sizes are smaller):

1. demographic stochasticity including occurrence of probabilistic events such as reproduction, litter size, sex determination, and death
2. environmental variation and fluctuations
3. catastrophes such as forest fires and diseases
4. genetic processes including loss of heterogeneity and inbreeding depression
5. deterministic processes such as density dependent mortality on exceeding the carrying capacity of the habitat
6. migration among populations

The factors driving a species towards extinction

can be remembered using the acronym HIPPO:

1. Habitat loss
2. Invasive species
3. Pollution
4. human over-Population
5. Over-harvesting

Impact of humans

Sensitivity of the species to human impacts is dependent upon

1. adaptability and resilience of the species
2. human attention: charismatic species like tigers are more sensitive because humans have high demand for their skin, bones and other parts
3. ecological overlap between humans and the species: the greater the overlap, the greater the impact
4. home range requirements of the species: species requiring larger home ranges are more sensitive to human impacts

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How real is the threat? Glimpses from Biogeography

According to the island biogeography model[3], species richness, S of an island is given by

$$S = C \times A^z$$

where

A is the size of the island

C, z are constants depending on the set of species and the island

---

[3] MacArthur and Wilson 1967

Estimating the rate of species loss using Biogeography

z varies between 0.15 and 0.35.

Taking z = 0.30, for an area A_1

$$S_1 = C \times A_1^{0.30}$$

Let the area decrease by 90%:

$A_2 = 0.1 \times A_1$

Then,

$$S_2 = C \times (0.1 \times A_1)^{0.30}$$

Estimating the rate of species loss using Biogeography

This gives

$$\frac{S_2}{S_1} = \frac{C \times (0.1 \times A_1)^{0.30}}{C \times A_1^{0.30}}$$

$$\implies \frac{S_2}{S_1} = 0.1^{0.3}$$

$$\implies \frac{S_2}{S_1} = 0.5012 \approx 50\%$$

Thus, $S_2 = \frac{1}{2} \times S_1$

So, by reducing area by 90%, the species richness becomes halved.

Estimating the rate of species loss using Biogeography

The rate at which tropical forests are actually decreasing is $\approx 1.8\%$ per annum. With the lowest value of z (0.15), this would translate to an annual loss of 0.27%

The estimated number of species in tropical forests is 10 million.

Thus, annual loss of species from tropical forests is given by

$10{,}000{,}000 \times 0.27 / 100$

$=$ 27,000 species per year

And this is the most conservative estimate!

Similarly, we may estimate the loss from other ecosystems.

Are all species equally susceptible to extinction?

No.

The susceptibility depends on the rarity of the species, the rarer the species, the more its chances of getting extinct.

And rarity is a function of the ecology and evolutionary characteristics of the species.

Why are some species rarer?

Three reasons:

1. habitat selection and evolutionary characteristics: restriction to an uncommon habitat, e.g. species found in desert springs
2. limited geographical range, e.g. those species found in a single lake
3. low population densities, e.g. because larger animals require more space

Four impacts on the habitat

1. Habitat degradation
2. Habitat fragmentation
3. Habitat displacement
4. Habitat loss

Habitat degradation

Habitat degradation is the process by which habitat quality for a given species is diminished.

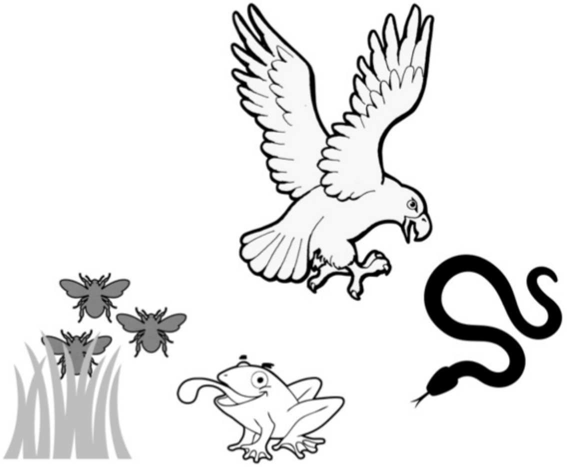
Some causal agents for habitat degradation

1. Contamination
    a. air pollution
    b. water pollution
    c. eutrophication
    d. pesticides and accumulative toxins

Potomac river: Eutrophic state

(By Alexandr Trubetskoy Wikimedia curid=19117918)

Bioaccumulation



Biomagnification

Concentration of DDD in Clear Lake ecosystem[4]

Water 0.01 ppm → Planktons 5 ppm → Fish 40 - 300 ppm → Piscivorous birds 1600 - 2500 ppm

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[4] Carson, R., 2002. Silent spring. Houghton Mifflin Harcourt.

Some causal agents for habitat degradation

1. Contamination
2. Trash
    a. ghost nets
    b. plastics

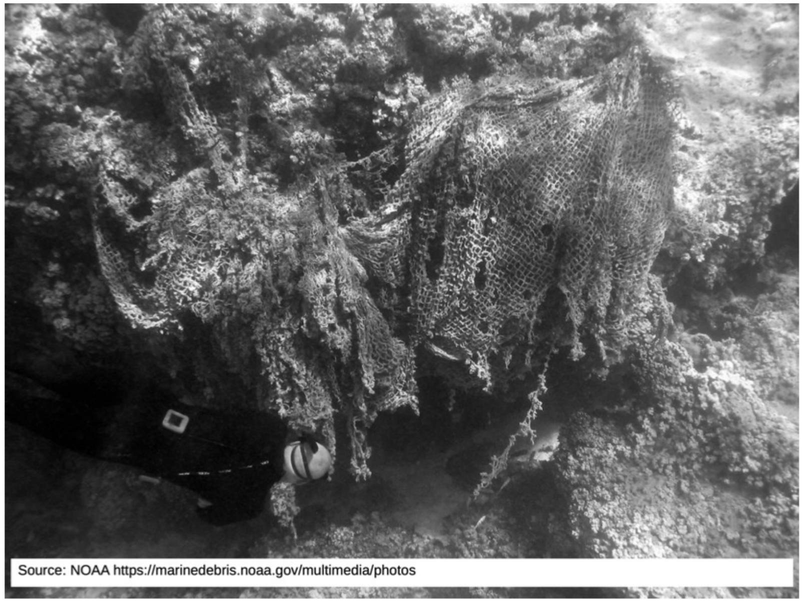
Entanglement

Source: NOAA https://marinedebris.noaa.gov/multimedia/photos

Ghost nets

Source: NOAA https://marinedebris.noaa.gov/multimedia/photos

Smothering of sea bed life



Source: NOAA https://marinedebris.noaa.gov/multimedia/photos

Destruction of habitat: Penguins

(Ankur Awadhiya 2018 'Boulders' Table Mountain National Park)

Trash with Tahr

(Ankur Awadhiya 2018 Mukurthi National Park)

Plastics in rhino dung

(Ankur Awadhiya 2018 Manas Tiger Reserve)

Plastics and animal behaviour

(Ankur Awadhiya 2018 Mahabaleshwar)

Some causal agents for habitat degradation

1. Contamination
2. Trash
3. Soil erosion
4. Fire regimes

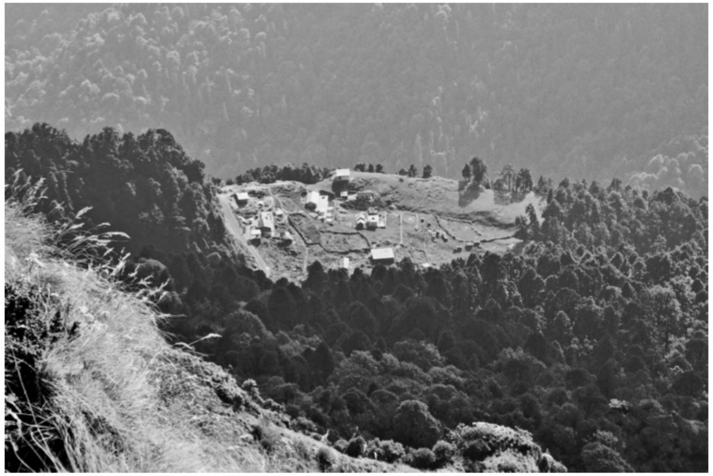
Forest fire

(Ankur Awadhiya 2017 Kanha Tiger Reserve)

Some causal agents for habitat degradation

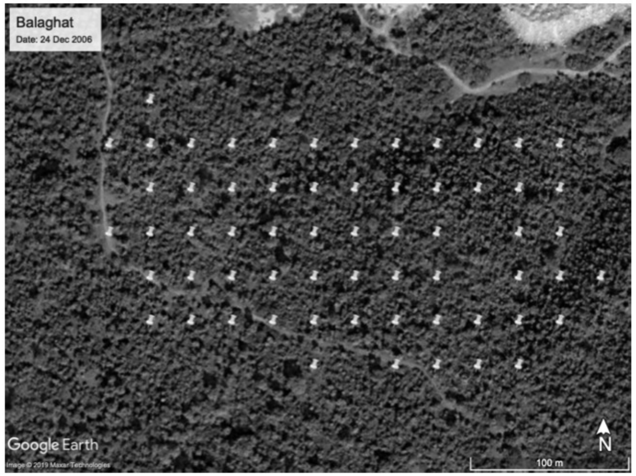
1. Contamination
2. Trash
3. Soil erosion
4. Fire regimes
5. Water over-exploitation
6. Deforestation

Clearing of forest



(Ankur Awadhiya 2017 Shivalik Range, Uttarakhand)

Balaghat 2006

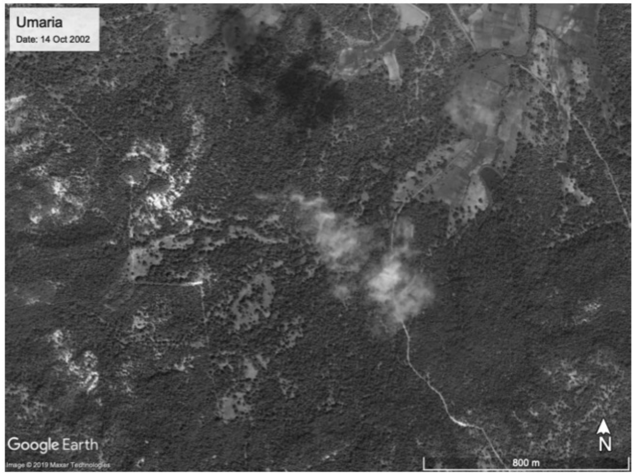


(Ankur and Abhijit Awadhiya, Deforestation in Madhya Pradesh 2000-2018)

Balaghat 2018

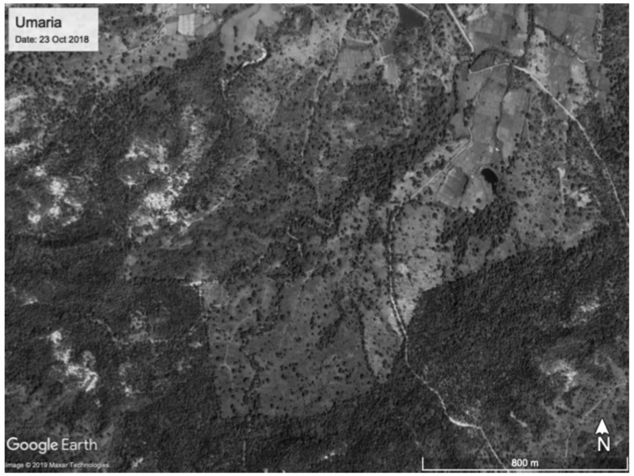
(Ankur and Abhijit Awadhiya, Deforestation in Madhya Pradesh 2000-2018)

Umaria 2002



(Ankur and Abhijit Awadhiya, Deforestation in Madhya Pradesh 2000-2018)

Umaria 2018

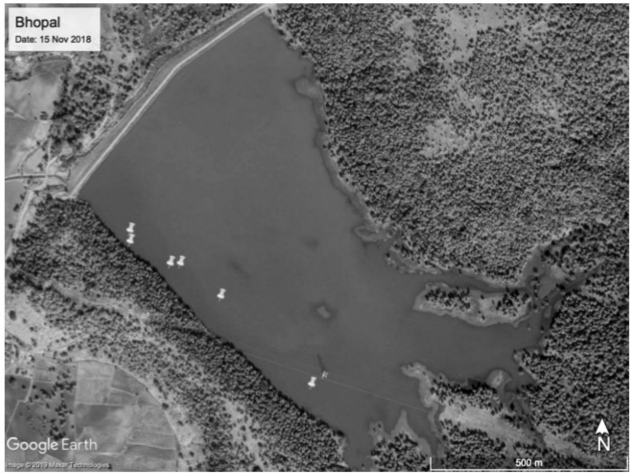


(Ankur and Abhijit Awadhiya, Deforestation in Madhya Pradesh 2000-2018)

Bhopal 2003

(Ankur and Abhijit Awadhiya, Deforestation in Madhya Pradesh 2000-2018)

Bhopal 2018

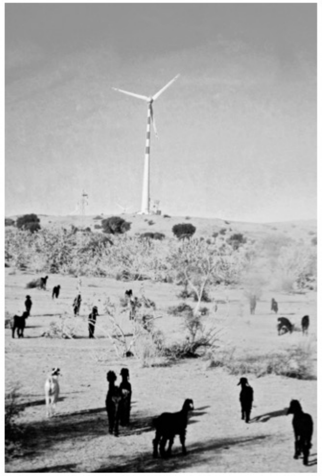


(Ankur and Abhijit Awadhiya, Deforestation in Madhya Pradesh 2000-2018)

Some causal agents for habitat degradation

1. Contamination
2. Trash
3. Soil erosion
4. Fire regimes
5. Water over-exploitation
6. Deforestation
7. Desertification
    a. over-grazing
    b. cultivation practices

Desertification and over-grazing



(Ankur Awadhiya 2015 Gujarat)

Some causal agents for habitat degradation

1. Contamination
2. Trash
3. Soil erosion
4. Fire regimes
5. Water over-exploitation
6. Deforestation
7. Desertification
8. Draining, dredging, damming, etc.
9. Over-exploitation of biota
10. Introduction of exotic species

Habitat loss

Habitat loss occurs when the quality of the habitat is so low that the habitat is no longer usable by a given species.

Habitat fragmentation

Fragmentation occurs when a natural landscape is broken up into small parcels of natural ecosystems, isolated from one another in a matrix of lands dominated by human activities.

It involves both loss and isolation of ecosystems.

Why do larger fragments support more species?

1. Larger fragments have more diverse environments, so more habitats.
2. Larger fragments are more likely to have both common and uncommon species; smaller fragments are more likely to have only common species.
3. Smaller fragments have smaller populations, so the chances of getting extinct are greater.

Some causal agents for habitat fragmentation

1. Roads, railways, dams and other structures
   a. mortality
   b. physical barrier
   c. psychological barrier
   d. access to anthropogenic influence
   e. access to invasives and exotics
2. Diversion of land for agriculture

Linear infrastructure

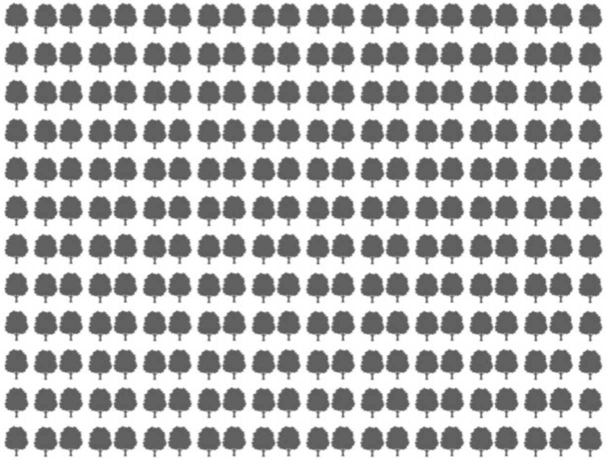
(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

Dam

(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

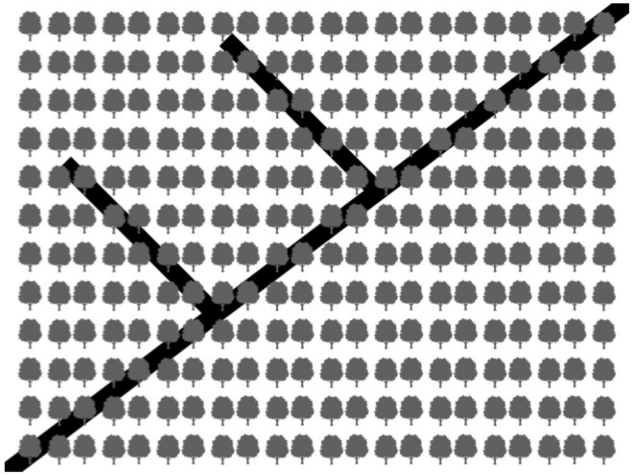
The process of habitat fragmentation and loss

Original forest



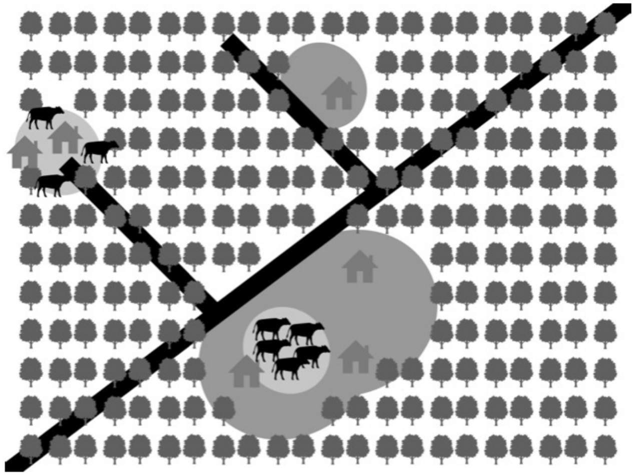
(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

Dissection



(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

Perforation

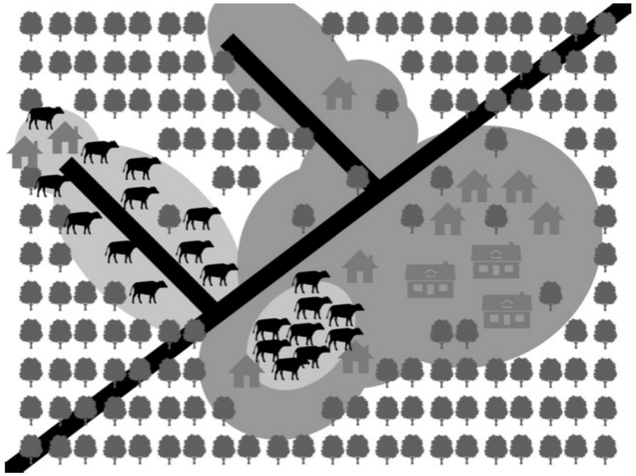


(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

Livestock in the forest

(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

Fragmentation

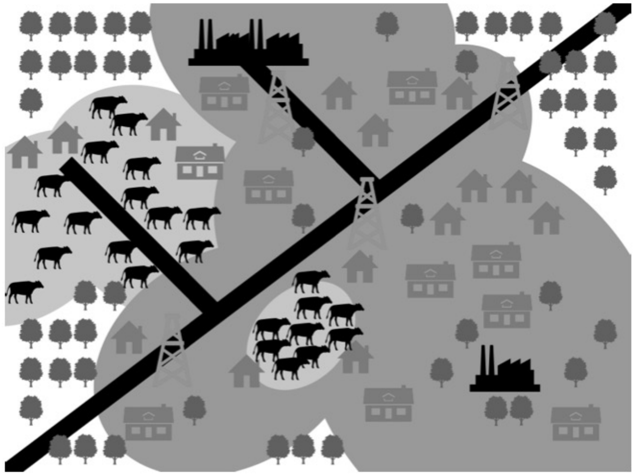


(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

Fragmentation

(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

Attrition



(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

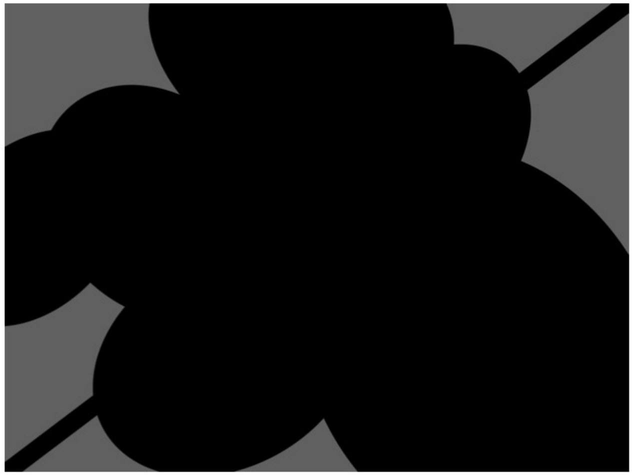
Attrition

(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

Before

(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

After



(Ankur Awadhiya 2021 Principles of Wildlife Conservation. Florida and Oxfordshire: CRC Press / Taylor & Francis)

Extremely fragmented habitat

(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

Habitat displacement

Shifting of wildlife to non-prime / sub-prime habitats e.g. hills or rocky patches.

Extremely fragmented habitat

(Ankur Awadhiya 2018 Mudumalai Tiger Reserve)

Population viability analysis

Population viability is the ability of a population to persist, or to avoid extinction. Thus, population viability analysis is an analysis of the viability of a population.

Population viability analysis

PVA is a process by which the extinction probability of a single species population is assessed[5] by integrating data on the life history, demography and genetics of the species with information on the variability of the environment, diseases, stochasticity, etc., by utilising mathematical models and computer simulations in order to predict whether the population will remain viable or go extinct in a decided time frame under various management options[6].

---

[5] Hugh P. Possingham, Michael A. McCarthy and David B. Lindenmayer, Population Viability Analysis, In Encyclopedia of Biodiversity (Second Edition), edited by Simon A Levin,, Academic Press, Waltham, 2013, Pages 210-219, ISBN 9780123847201, https://doi.org/10.1016/B978-0-12-384719-5.00173-8.

[6] Beissinger, S.R. and McCullough, D.R., 2002. Population viability analysis. University of Chicago Press.

Thank you

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15. Case studies – Impacts of oil spills

Impact of disturbances

Normal community, single LID ⟹ Recovery

[7]

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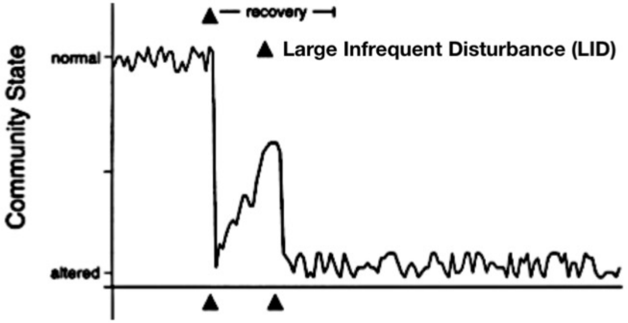
[7] Paine, R.T., Tegner, M.J. and Johnson, E.A., 1998. Compounded perturbations yield ecological surprises. Ecosystems, 1(6), pp.535-545.

Impact of disturbances

Normal community, multiple LID ⟹ Alterations



[8]

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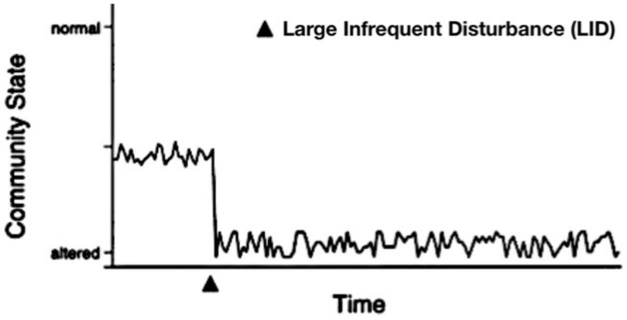
[8] Paine, R.T., Tegner, M.J. and Johnson, E.A., 1998. Compounded perturbations yield ecological surprises. Ecosystems, 1(6), pp.535-545.

Impact of disturbances

Disturbed community, single LID $\Longrightarrow$ Alterations



[9]

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[9] Paine, R.T., Tegner, M.J. and Johnson, E.A., 1998. Compounded perturbations yield ecological surprises. Ecosystems, 1(6), pp.535-545.

Large, Infrequent Disturbances

1. fire
2. storm
3. tsunami
4. oil spill
5. climatic extreme
6. heavy pollution, etc.

Disturbed community

1. diseased
2. weed infested
3. facing competition from livestock
4. pollutants-rich
5. facing climatic changes, etc.

Oil spill

"An oil spill is the release of a liquid petroleum hydrocarbon into the environment."

Location of oil spills

1. Terrestrial: e.g. Kuwaiti oil lakes formed during Iraq's invasion of Kuwait (1990 - 91).

Oil lake in Kuwait

(http://www.evidence.org.kw/photos.php?page=0117/_Oil-Well-Fires-and-Oil-Lake)

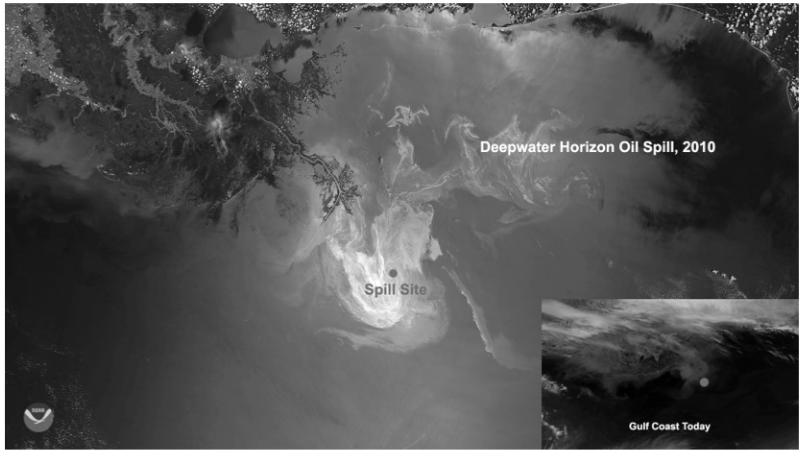
Oil fires in Kuwait

(Credit: NASA)

Location of oil spills

1. Terrestrial: e.g. Kuwaiti oil lakes formed during Iraq's invasion of Kuwait (1990 - 91).
2. Marine: e.g. Deepwater Horizon (2010).

Deepwater Horizon oil spill

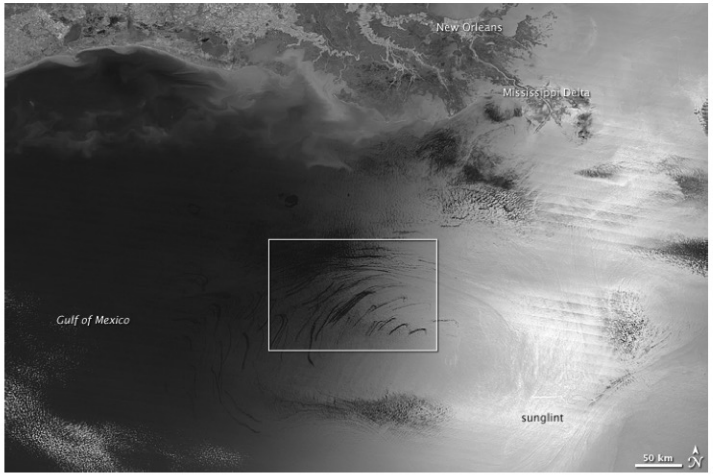


(Credit: NOAA)

Kinds of oil spills

1. Accidental: e.g. Deepwater Horizon incident
2. Intentional: e.g. Gulf war oil spill
3. Natural: e.g. Oil seeps in Gulf of Mexico

Gulf of Mexico oil seep



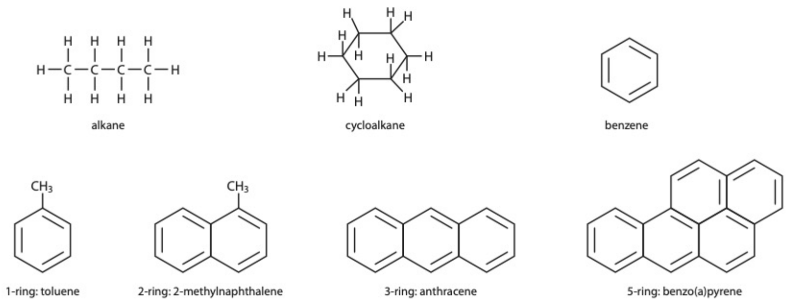
(Credit: NASA)

Hydrocarbon

"A hydrocarbon is an organic compound consisting entirely of hydrogen and carbon."

These form a major chunk of petroleum oil.

Some common hydrocarbons in oil



(Impacts of oil spills on marine ecology, IPIECA 2015)

Classification of hydrocarbons: Group 1 to 5 oils

Based on specific gravity

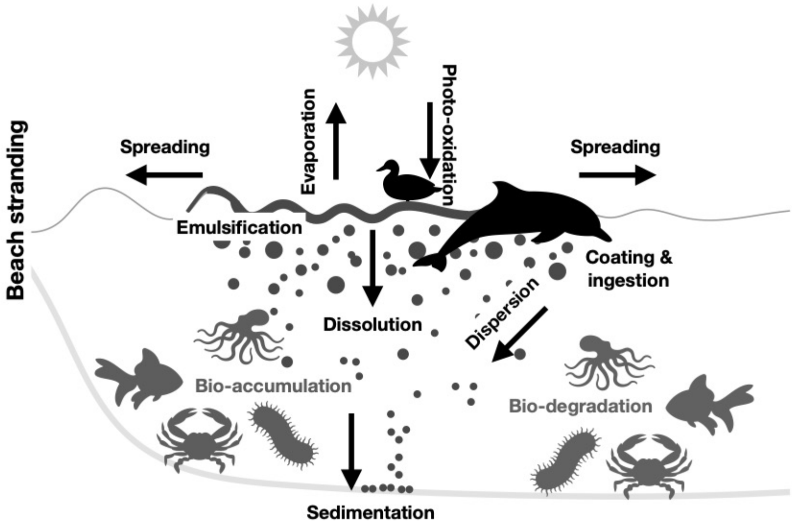
- Group 1: very low (< 0.8) specific gravity (e.g. kerosene)
- Group 5: very high (≥ 1.0) specific gravity (e.g. bitumen)

Useful when discussing the fate and persistence of oil spills.

Classification of hydrocarbons: Based on origin

1. Petrogenic hydrocarbons: Derived directly from mineral oils.
2. Pyrogenic hydrocarbons: Derived from incomplete burning of mineral oils.
3. Biogenic hydrocarbons: Derived from biological processes acting on mineral oils.

The fate of oil in marine ecosystem



Impact of oil spills on the ecosystem

1. Upon coating
   - Physical smothering: reduced ability to move, feed, etc., loss of thermoregulation
   - Inhalation of volatile hydrocarbons: toxicity
   - Absorption through skin and mucosa: toxicity
2. Dissolved products
   - Absorption through skin and food: toxicity

Factors influencing the impact on organisms

1. Seasonality: e.g. breeding season, presence of eggs or juveniles
2. Ecological functions of key species: e.g. impact on keystone species like mangroves
3. Lifestyle factors: e.g. animals with long lifespan and *k-selected* reproductive strategy are more impacted
4. Health and condition: e.g. stressed animals such as diseased or migrating animals are more impacted

Some terms associated with impacts I

1. Vulnerability: Vulnerability describes the likelihood that a resource will be exposed to oil.
2. Sensitivity: Sensitivity assumes that the resource is exposed to the oil, and describes the relative effect of that exposure. Thus, a deep water coral may be sensitive but not vulnerable to a surface oil spill, while a rocky shore seaweed may be vulnerable but not sensitive.
3. Toxicity: The potential or capacity of a material to have adverse effects on living organisms.
   a. Acute toxicity: Acute toxicity involves harmful effects in an organism through a single or short-term exposure.
   b. Chronic toxicity: Chronic toxicity is the ability of a substance or mixture of substances to have harmful effects over an extended period, usually upon repeated or continuous exposure, sometimes lasting for the entire life of the exposed organism.

Some terms associated with impacts II

4. Exposure: The combination of duration of exposure to the chemical and concentration of the chemical.
5. Exposure route: The way the organism is exposed to the substance, including ingestion (directly or in food), absorption through the gills or contact with the skin.
6. Magnitude: The magnitude of a toxic effect depends on the sensitivity of an organism to the chemicals, but is also a function of both the concentration and duration of exposure to the chemical.
7. Lethal effect: A lethal effect results in the death of an organism.
8. Sub-lethal effect: A sublethal effect results in a reduction of biological function or health, e.g. its growth, ability to reproduce, or the condition of its skin.

Some terms associated with impacts III

9. Bioavailability: Bioavailability is the extent to which a chemical is available for uptake into an organism and, with respect to oil spills, is usually closely related to both the display of toxicity and the rate of biodegradation.
10. Bioaccumulation: Bioaccumulation occurs when an organism absorbs a toxic substance into its tissues at a rate greater than that at which the substance is lost.
11. Biomagnification: Biomagnification, also known as bioamplification or biological magnification, is the increasing concentration of a substance, such as a toxic chemical, in the tissues of tolerant organisms at successively higher levels in a food chain.

Biomagnification

Concentration of DDD in Clear Lake ecosystem[10]

Water 0.01 ppm → Planktons 5 ppm → Fish 40 - 300 ppm → Piscivorous birds 1600 - 2500 ppm

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[10] Carson, R., 2002. Silent spring. Houghton Mifflin Harcourt.

Impacts on different animals I

1. Planktons:
   - Sensitive to exposure.
   - Acute, chronic and sublethal effects.
   - Recover quickly due to short generation times.
2. Seabed life:
   - Ecologically-significant concentrations of dissolved or dispersed oil from surface slicks rarely reach below 10 metres.
   - Subsea blowouts may have higher potential for seabed impacts in deep water.
   - Sedimented hydrocarbons may pose risk to bottom dwellers.
3. Fish:
   - Acute, chronic and sublethal effects.
   - From fisheries perspective, tainting (hydrocarbons, even in very low concentrations, can be tasted or smelt in the meat) is a major concern.
4. Marine mammals:

Impacts on different animals II

   - Need to surface periodically for air $\implies$ exposure to high concentrations of oil.
   - Soiling of fur impairs insulation and water repellence.
   - Cleaning of fur may lead to ingestion.
   - Smothering of airways may also occur.
5. Marine reptiles:
   - Need to surface periodically for air $\implies$ exposure to high concentrations of oil.
   - Smothering of airways may also occur.
   - Seasonality of nesting and egg laying behaviours may increase magnitude of impact.
6. Birds:
   - Physical oiling of their feathers may cause hypothermia and reduced ability to move, feed etc.
   - Ingestion may occur through preening or consumption of contaminated food.
   - Transfer of oil to eggs or young may reduce survival.

Impacts on different animals III

7. Shoreline and coastal habitats:
    - Seaweeds are better protected from oil impacts due to their mucous coating that resists oil.
    - Mangroves can be killed by viscous oil that covers their pneumatophores.
    - Burrowing crabs may be killed when their burrows are penetrated.

Reducing the impacts on ecosystem[11]

1. Cleaning: Clean, in the context of an oil spill, may be defined as the return to a level of petroleum hydrocarbons that has no detectable impact on the function of an ecosystem.
2. Recovery: Recovery of an ecosystem is characterised by the re-establishment of a biological community in which the plants and animals characteristic of that community are present and functioning normally.

---

[11] Kingston, P.F., 2002. Long-term environmental impact of oil spills. Spill Science & Technology Bulletin, 7(1-2), pp.53-61.

Clean-up operations

1. Contain and scoop: Use booms to contain the spill, and skimmer to collect the oil from the surface.

Boom to protect salmon hatchery after Exxon Valdez spill

(Credit: NOAA)

Skimming oil after Deepwater Horizon spill

(Credit: NOAA)

Clean-up operations

1. Contain and scoop: Use booms to contain the spill, and skimmer to collect the oil from the surface.
2. Burn: Burn the released oil *in situ*.

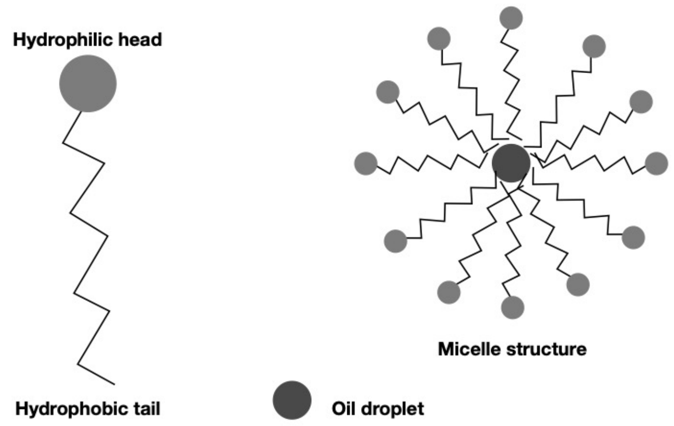
Burning oil after Deepwater Horizon spill

(Credit: NOAA)

Clean-up operations

1. Contain and scoop: Use booms to contain the spill, and skimmer to collect the oil from the surface.
2. Burn: Burn the released oil *in situ*.
3. Let nature act: When there is little possibility of the oil impacting the ecosystem, it can be left as such for nature to take care of it.
4. Use biological agents and fertilisers: The natural action can be speeded up by the addition of micro-organisms, or by the action of nitrogen and phosphorus that promote their growth.
5. Disperse: Use chemical dispersants to break oil into droplets, facilitating natural biodegradation.

Action of dispersants



Dispersing oil after Deepwater Horizon spill

(Credit: US Air Force Wikimedia curid=10277175)

Strategies to protect ecosystems

1. Avoid setting up oil rigs in especially vulnerable spots.
2. Prevent spills with better technologies.
3. Develop models to anticipate spread.
4. Maintain rapid response teams and technologies.
5. Utilise studies on long-term impacts and mitigation options.

Thank you

16. Case study – Impact of plastics on Ecology and Biodiversity

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Plastic

"a synthetic material made from a wide range of organic polymers such as polyethylene, PVC, nylon, etc., that can be moulded into shape while soft, and then set into a rigid or slightly elastic form[12]."

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[12] Oxford Dictionary of English

Some plastic items

(Wikimedia file: Plastic_household_items.jpg)

A short history of plastics[13]

1. 1600 B.C.: Mesoamericans process natural rubber into a plastic
2. 19th century: polystyrene and polyvinyl chloride invented
3. 1909: Bakelite used in commercial products
4. 1926: PVC commercialised
5. 1933: Saran invented
6. 1937: Polyurethane foam invented
7. 1938: Teflon invented
8. 1939: Nylon and neoprene invented
9. 1941: PET / polyester invented
10. World War 2: Metals become scarce, plastics widely manufactured to replace them
11. 1951: HDPE and polypropylene invented
12. 1954: Styrofoam invented
13. 1979: Plastic production in the US exceeds steel production

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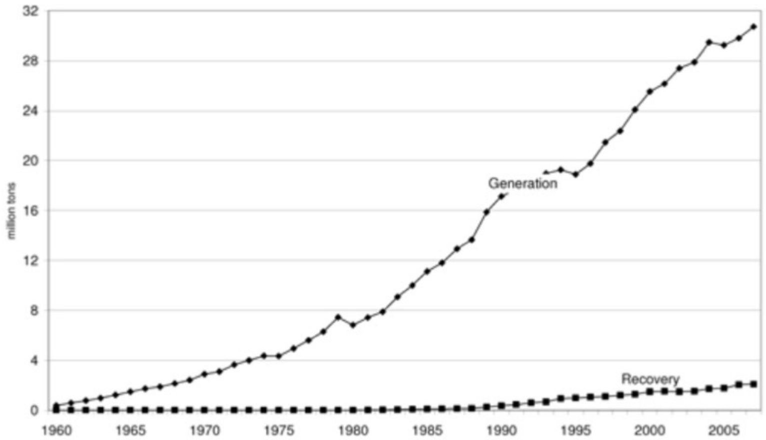
[13] Whitacre, D.M. ed., 2016. Reviews of environmental contamination and toxicology. Springer.

Plastic production is increasing @5% p.a.



(Source: UNEP and EPA)

Where does all this plastic go?

1. Reused and recycled: a small fraction
2. Burnt: releases dioxins and CO_2
3. Landfills: and we're running short of space!
4. Environment: both terrestrial and (ultimately) marine

Fate of marine plastics[14, 15]

1. 15% float on surface
2. 15% wash ashore
3. 70% sink to ocean bottom

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[14] Barnes KA, Galgani F, Thompson RC, Barlaz M (2009) Accumulation and fragmentation of plastic debris in global environments. Philos Trans Royal Soc Lond B: Biol Sci 364(1526): 1985 - 1998

[15] UNEP (2001) Marine litter - trash that kills, United Nations Environment Programme

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Floating debris

(Source: Randy Olson / National Geographic)

Washed ashore

(Source: Shawn Miller / National Geographic)

On seabed

(Source: David Jones / National Geographic)

Size classification of plastic debris

1. Macrodebris: $>$ 20 mm in size
   Ghost nets are the main concern.
2. Mesodebris: 5 - 20 mm in size
   Dominated by ‘nurdles’: resin granules that are intermediates in plastic production.
3. Microdebris: $<$ 5 mm in size
   Formed through fragmentation of macro- or meso- debris. Also consist of plastic scrubber particles as found in face wash and other cosmetic products.

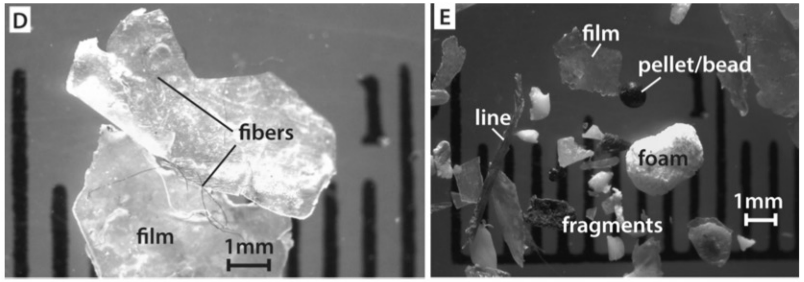
Production of smaller fragments

Synthetic polymers with stabilisers, fillers, extenders and other additives

$$\xrightarrow[\text{light absorption, photolytic reaction, formation of radicals, enzymatic degradation}]{h\nu,\ O_2,\ \text{microbes and worms}}$$

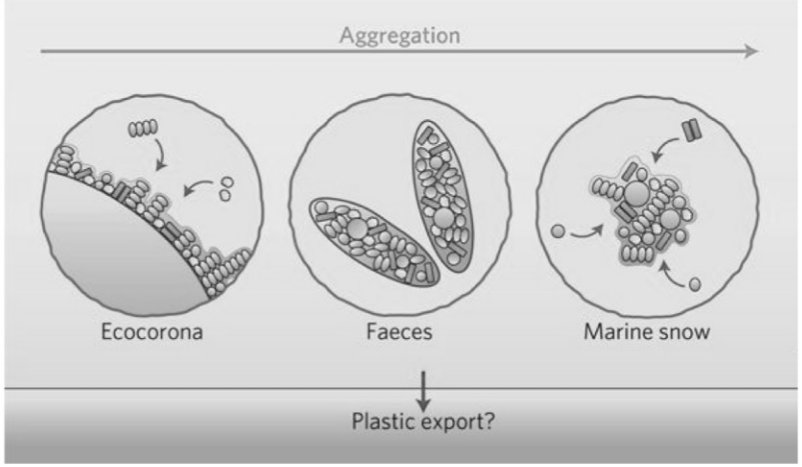
Oxidation and scission reactions causing discolouration, loss of mechanical integrity, strength and impact properties

Decomposing debris



(Baldwin, A.K., Corsi, S.R. and Mason, S.A., 2016. Plastic debris in 29 Great Lakes tributaries: relations to watershed attributes and hydrology. Environmental science & technology, 50(19), pp.10377-10385.)

Aggregation of smaller particles



(Galloway, T.S., Cole, M. and Lewis, C., 2017. Interactions of microplastic debris throughout the marine ecosystem. Nature ecology & evolution, 1(5), p.0116.)

How does this impact wildlife?[16]

1. Ingestion

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[16] Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

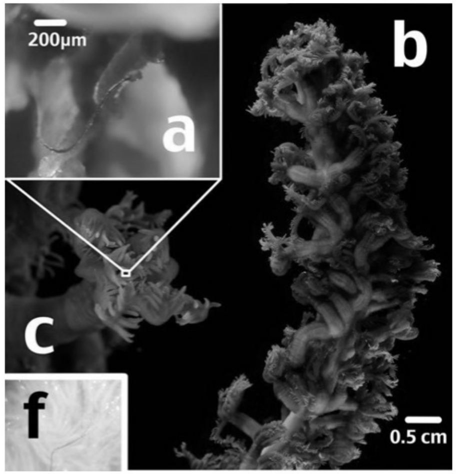
Ingestion

(Source: National Geographic)

Ingestion

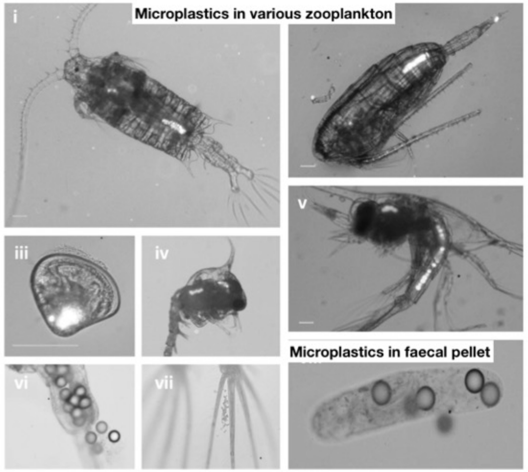
(Source: Smithsonian Ocean Portal)

Blue microfibre from the mouth area of a sea pen polyp



(Taylor, M.L., Gwinnett, C., Robinson, L.F. and Woodall, L.C., 2016. Plastic microfibre ingestion by deep-sea organisms. Scientific reports, 6, p.33997.)

Microplastics in zooplanktons and faecal pellets



(Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J. and Galloway, T.S., 2013. Microplastic ingestion by zooplankton. Environmental science & technology, 47(12),

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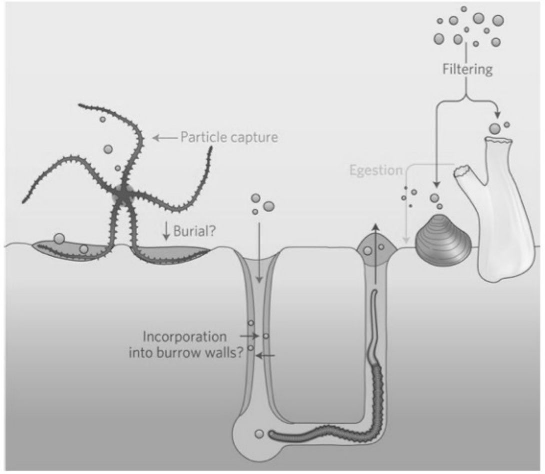
Influence on bottom dwellers and filter feeders



(Galloway, T.S., Cole, M. and Lewis, C., 2017. Interactions of microplastic debris throughout the marine ecosystem. Nature ecology & evolution, 1(5), p.0116.)

How does this impact wildlife?[17]

1. Ingestion
2. Entanglement, even smothering

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[17] Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

Entanglement

(Source: Jordi Chias / National Geographic)

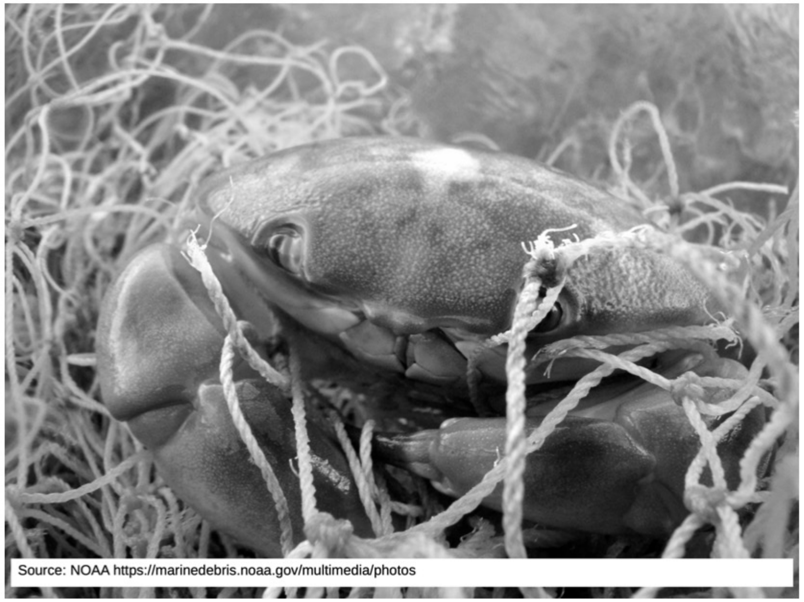
Entanglement

(Source: De Wolf S (2008) Zeehond Met Zwerfvuil. www.salkodewolf.nl)

Entanglement

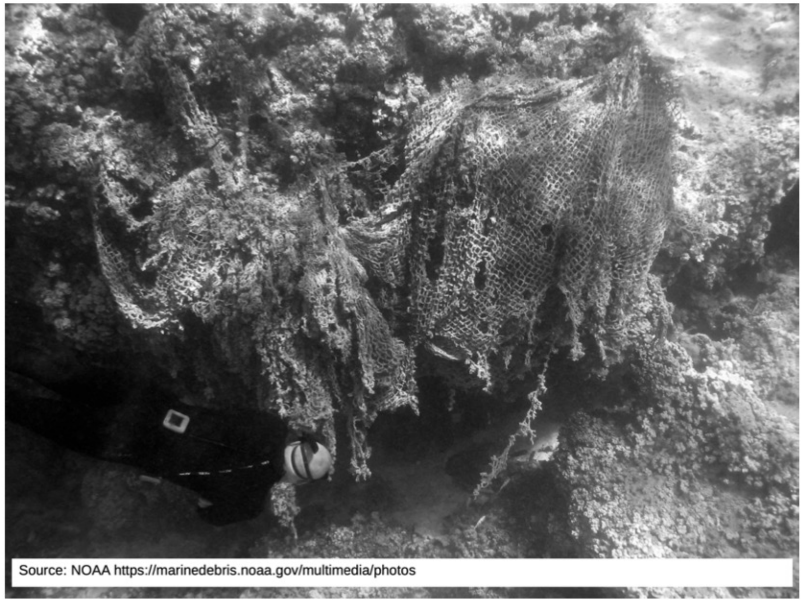
Source: NOAA https://marinedebris.noaa.gov/multimedia/photos

Ghost nets



Source: NOAA https://marinedebris.noaa.gov/multimedia/photos

Smothering of sea bed life



Source: NOAA https://marinedebris.noaa.gov/multimedia/photos

How does this impact wildlife?[18]

1. Ingestion
2. Entanglement, even smothering
3. Persistent, bio-accumulative, toxic substances

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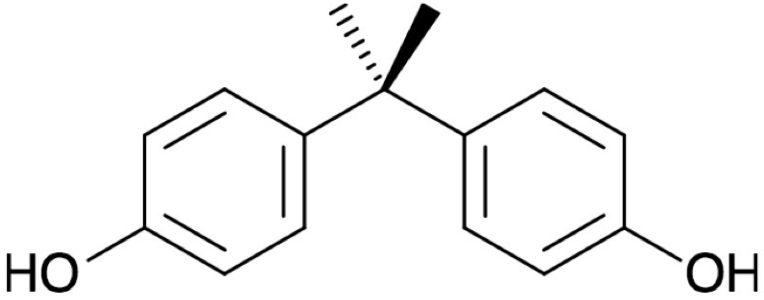
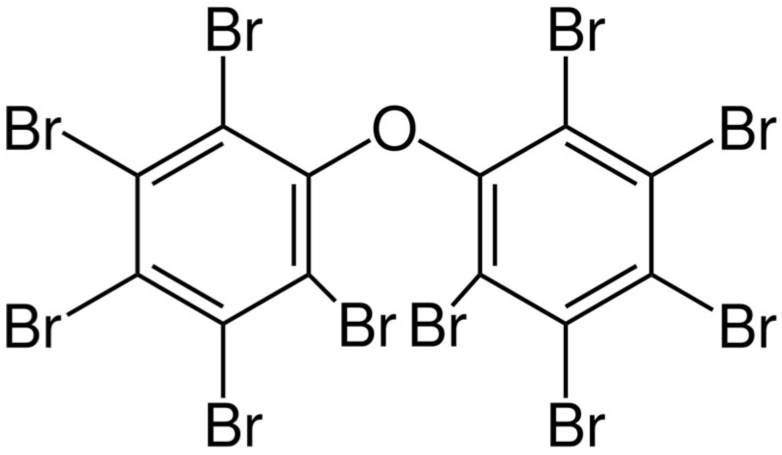
[18] Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

Bisphenol-A: Endocrine disruptor



Brominated flame retardants: Bio-accumulative toxins



(Whitacre, D.M. ed., 2016. Reviews of environmental contamination and toxicology. Springer.)

How does this impact wildlife?[19]

1. Ingestion
2. Entanglement, even smothering
3. Persistent, bio-accumulative, toxic substances
4. Accumulation and concentration of hydrophobic toxins

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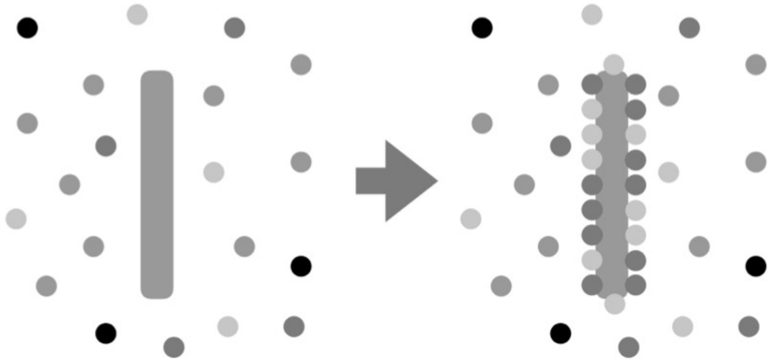
[19] Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

Accumulation and concentration of hydrophobic toxins



How does this impact wildlife?[20]

1. Ingestion
2. Entanglement, even smothering
3. Persistent, bio-accumulative, toxic substances
4. Accumulation and concentration of hydrophobic toxins
5. Potential to alter habitats and behaviours

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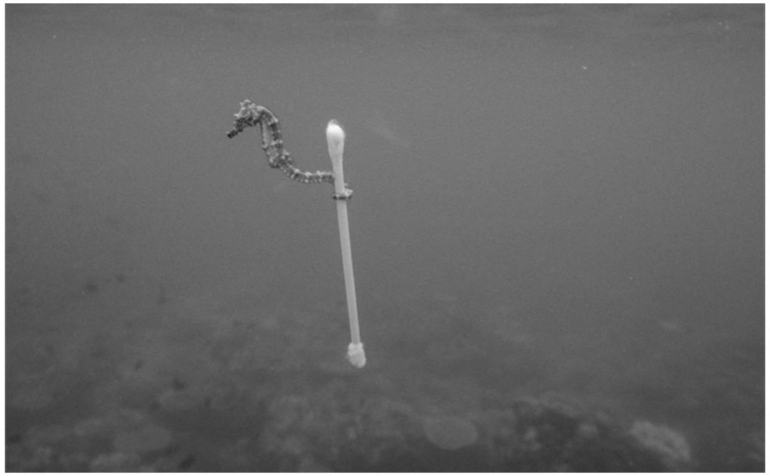
[20] Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

Hermit crab

(Source: Shawn Miller / National Geographic)

Sea horse



(Source: Justin Hofman / National Geographic)

Hyenas

(Source: Brian Lehmann / National Geographic)

Destruction of habitat: Penguins

(Ankur Awadhiya 2018 ‘Boulders’ Table Mountain National Park)

Trash with Tahr

(Ankur Awadhiya 2018 Mukurthi National Park)

Plastics in rhino dung

(Ankur Awadhiya 2018 Manas Tiger Reserve)

Plastics and animal behaviour

(Ankur Awadhiya 2018 Mahabaleshwar)

How does this impact wildlife?[21]

1. Ingestion
2. Entanglement, even smothering
3. Persistent, bio-accumulative, toxic substances
4. Accumulation and concentration of hydrophobic toxins
5. Potential to alter habitats and behaviours
6. Dispersal, including transport of invasive species

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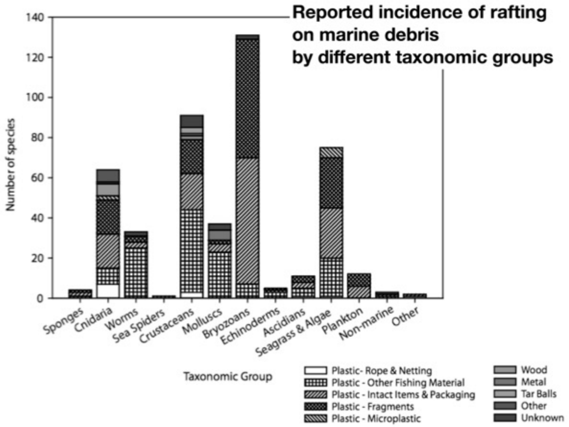
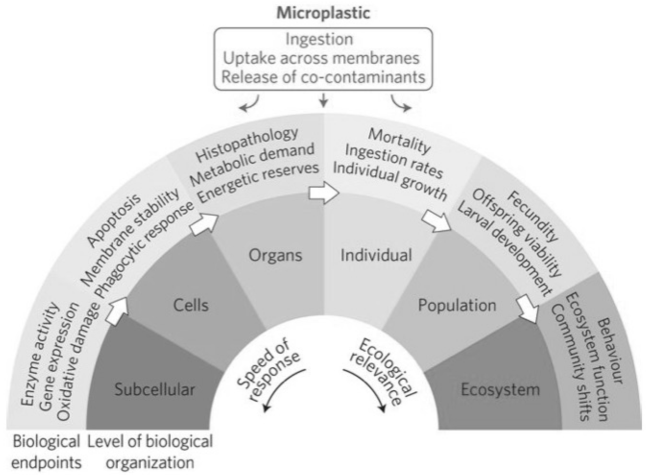
[21] Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

Rafting of animals on marine debris



(Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel - GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential

Even microplastics can influence the complete hierarchy



(Galloway, T.S., Cole, M. and Lewis, C., 2017. Interactions of microplastic debris throughout the marine ecosystem. Nature ecology & evolution, 1(5), p.0116.)

How can we help?

1. Reduce, reuse, recycle

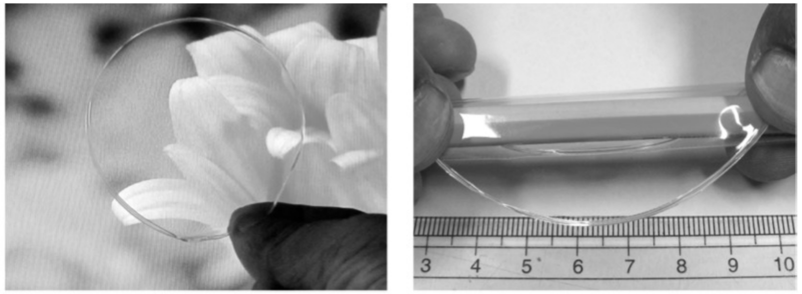
Plastic recycling

(Source: Randy Olson / National Geographic)

How can we help?

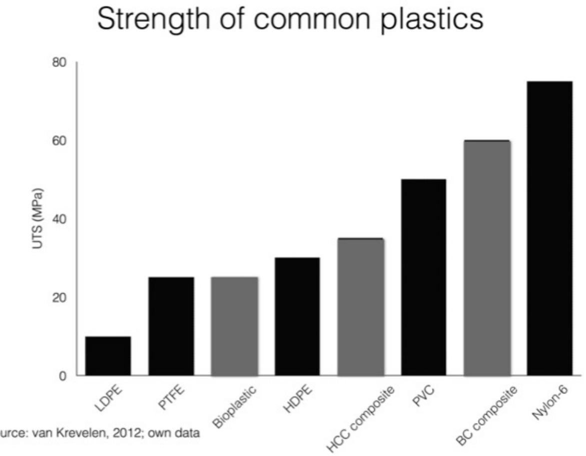
1. Reduce, reuse, recycle
2. Lifestyle changes: e.g. glasses in place of straws
3. Alternative materials: Bioplastics

Bioplastic material



(Ankur Awadhiya 2014 Studies in Agarose-based bioplastic material)

Bioplastic material strength



Source: van Krevelen, 2012; own data

(Ankur Awadhiya 2014 Studies in Agarose-based bioplastic material)

Thank you