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# Metals, organic chemicals, microplastics – how sensitive is zooplankton to pollution?

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Session 2, Interactions between zooplankton and pollution, 15 March 2024





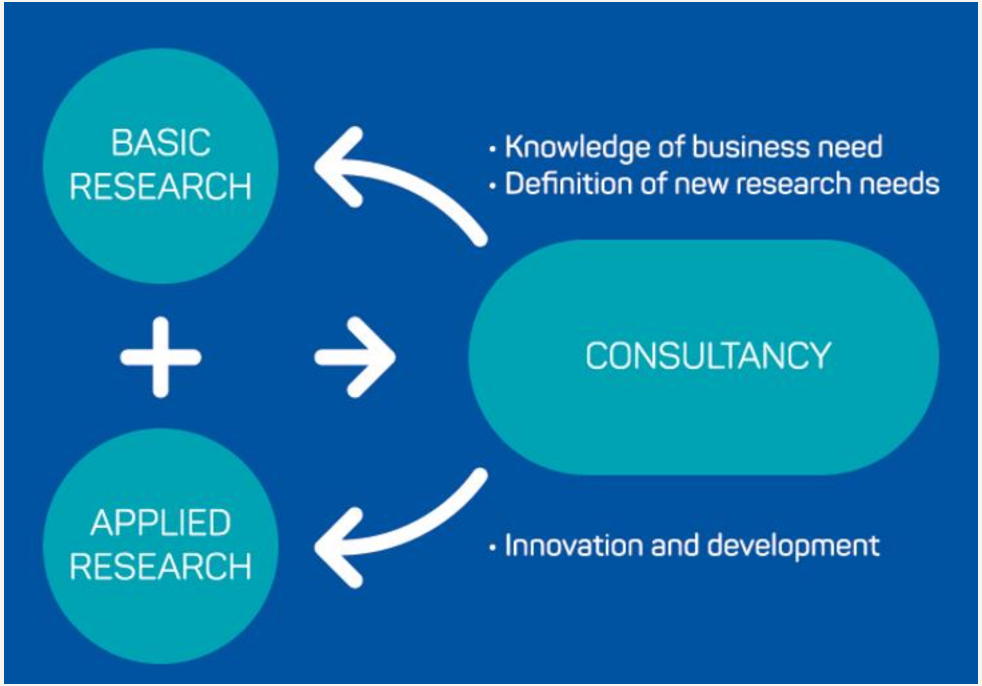
# About me and APN

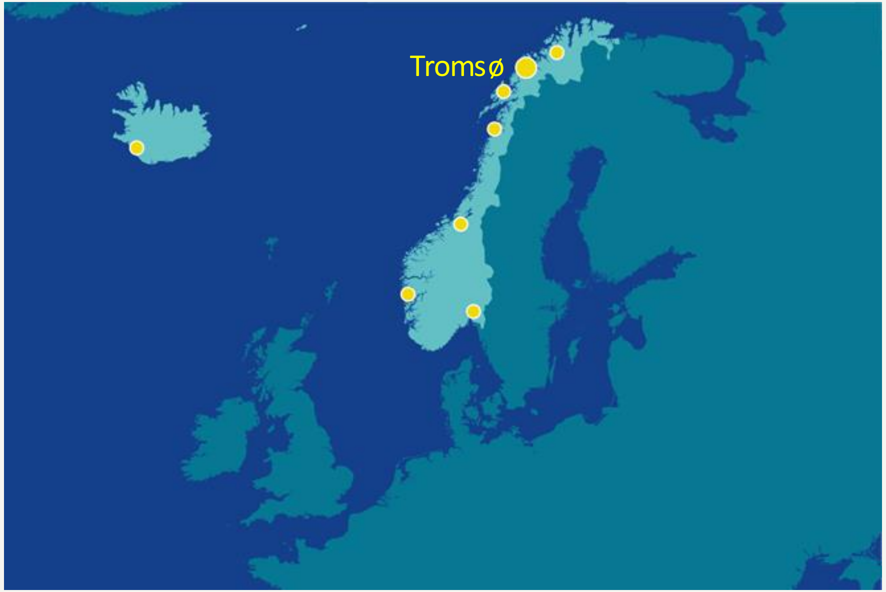



**Research interests:**

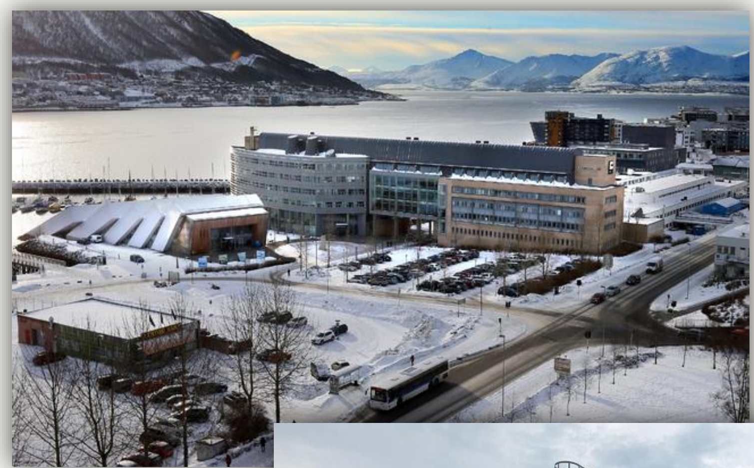
- Temperature effects on copepod life cycle traits
- Impacts of OA on copepod physiology/fitness
- Interactions between zooplankton and microplastic (MP)
- Uptake and toxicity of MP chemicals in biota
- Impacts of temp, OA, metals on copepod DNA integrity

# About me and APN



# About me and APN




# Zooplankton and pollution

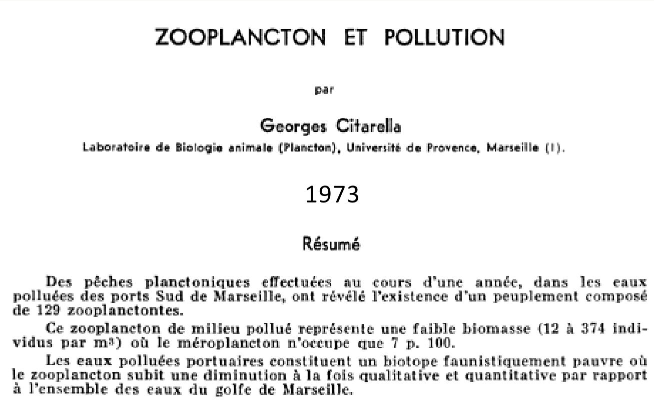
- Pollution: making an environment unsuitable or unsafe for use by introducing man-made waste (Merriam-Webster.com Dictionary)
- Pollution: introduction of contaminants into the natural environment that cause adverse change (Wikipedia)
  - any substance (solid, liquid, gas) or energy (radioactivity, heat, sound, light)
  - foreign (man-made) or naturally occurring contaminants





# Zooplankton and pollution

- Pollution reaches marine zooplankton habitats



ZOOPLANCTON ET POLLUTION

par


Georges Citarella

Laboratoire de Biologie animale (Plancton), Université de Provence, Marseille (1).

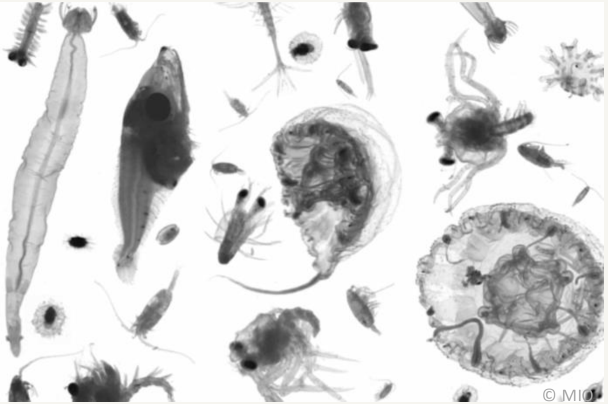

1973


Résumé

Des pêches planctoniques effectuées au cours d'une année, dans les eaux polluées des ports Sud de Marseille, ont révélé l'existence d'un peuplement composé de 129 zooplanctontes.

Ce zooplancton de milieu pollué représente une faible biomasse (12 à 374 individus par $m^3$) où le méroplancton n'occupe que 7 p. 100.

Les eaux polluées portuaires constituent un biotope faunistiquement pauvre où le zooplancton subit une diminution à la fois qualitative et quantitative par rapport à l'ensemble des eaux du golfe de Marseille.



  - conclusion: reduced biomass & diversity, especially meroplankton

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# Zooplankton and pollution

- Pollution reaches marine zooplankton habitats
  - green house gas emissions → climate change
  - chemicals → metals, fertilizers, (organic) chemicals
  - particles → combustion ash (black carbon), microplastics

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# Zooplankton and pollution

- indirect impacts (climate change from $CO_2$ emissions):
  - temperature rise
  - ocean acidification (OA)
  - → Arctic/polar: release of natural contaminants (e.g. metals)

- direct (local) impacts from human activities
  - Microplastics
  - Organic chemicals
  - Metals

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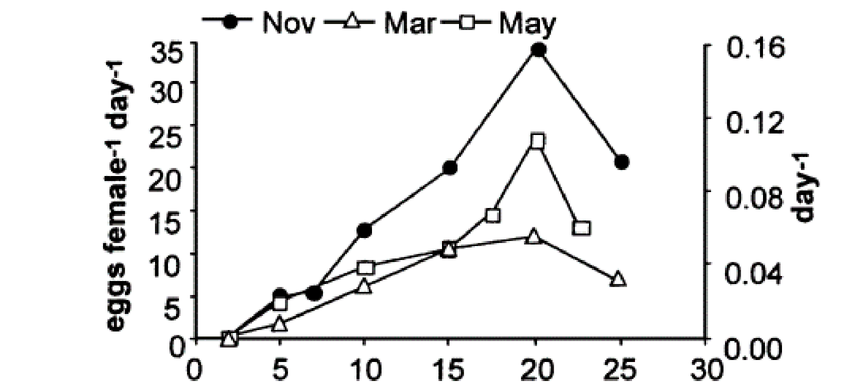
# Zooplankton and climate change

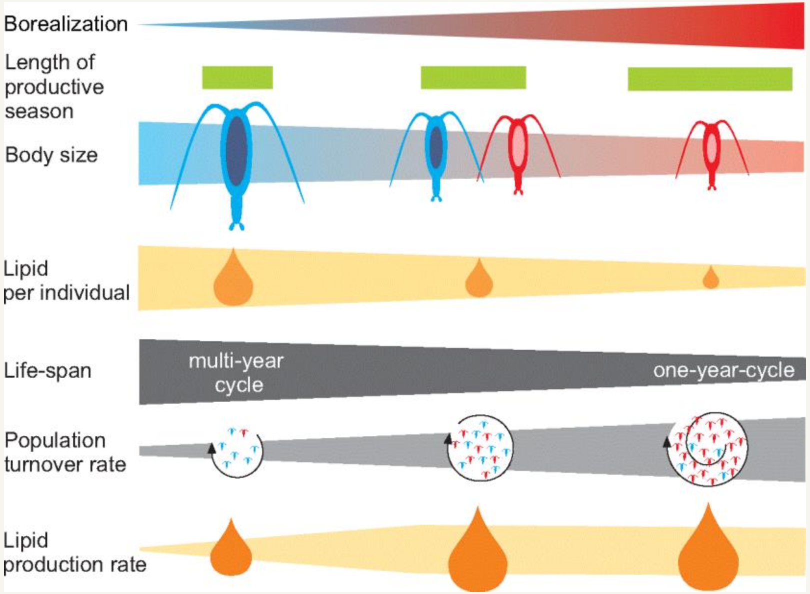
- increasing temperature
  - shorter development time → smaller body size
  - range expansions/contractions
  - altered phenologies




Seasonal variation of egg production of *C. typicus* (Mediterranean Sea), Halsband et al. 2004

# Zooplankton and climate change

- increasing temperature
  - shorter development time → smaller body size
  - range expansions/contractions
  - altered phenologies
  - resilience?




Hypothesized borealisation of the *Calanus* complex, Renaud et al. 2018

# Zooplankton and climate change

- more $CO_2$ = OA
  - zooplankton largely unaffected

Journal of Experimental Marine Biology and Ecology
ELSEVIER
Volume 428, 1 October 2012, Pages 39-42

**Influence of $CO_2$-induced acidification on the reproduction of a key Arctic copepod *Calanus glacialis***

Agata Weydmann [a], Janne E. Søreide [b], Slawomir Kwasniewski [a], Stephen Widdicombe [c]

Marine Pollution Bulletin
ELSEVIER
Volume 73, Issue 2, 30 August 2013, Pages 428-434

**Effects of elevated $CO_2$ on the reproduction of two calanoid copepods**

Kristian McConville [a c], Claudia Halsband [a b], Elaine S. Fileman [a], Paul J. Somerfield [a], Helen S. Findlay [a], John I. Spicer [c]



https://doi.org/10.1016/j.marpolbul.2013.02.010 Get rights and content

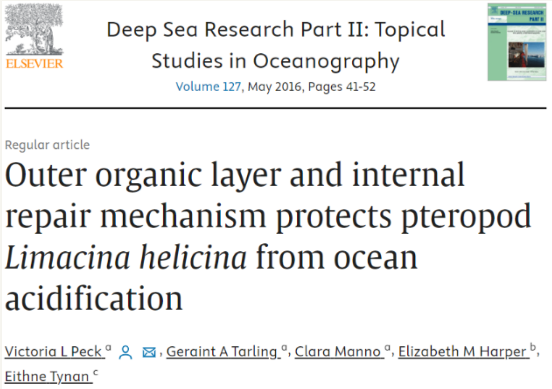
**High tolerance of microzooplankton to ocean acidification in an Arctic coastal plankton community**

N. Aberle[1], K. G. Schulz[2], A. Stuhr[2], A. M. Malzahn[1,3], A. Ludwig[2], and U. Riebesell[2]

[1]Biologische Anstalt Helgoland, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Kurpromenade, 27498 Helgoland, Germany
[2]GEOMAR – Helmholtz Centre for Ocean Research, Düsternbrooker Weg 20, 24105 Kiel, Germany
[3]Sultan Qaboos University, College of Agricultural and Marine Sciences, Dept. of Marine Sciences and Fisheries, P.O. Box 34, 123 Al-Khoud, Sultanate of Oman

# Zooplankton and climate change

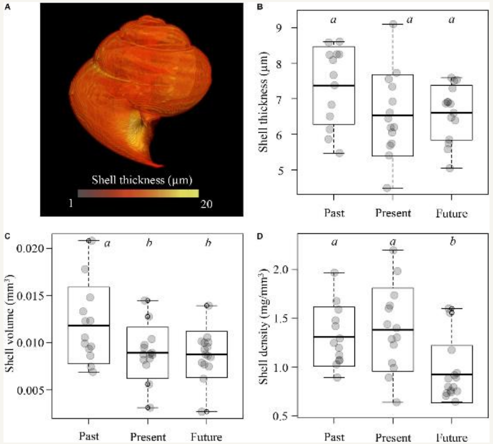
- more $CO_2$ = OA
  - zooplankton largely unaffected
  - but: vulnerable calcifiers (e.g. pteropods)


ELSEVIER
Deep Sea Research Part II: Topical Studies in Oceanography
Volume 127, May 2016, Pages 41-52

Regular article

Outer organic layer and internal repair mechanism protects pteropod *Limacina helicina* from ocean acidification

Victoria L Peck[a], Geraint A Tarling[a], Clara Manno[a], Elizabeth M Harper[b], Eithne Tynan[c]




Shell properties of *Limacina retroversa* in response to OA (Mekke et al. 2021)

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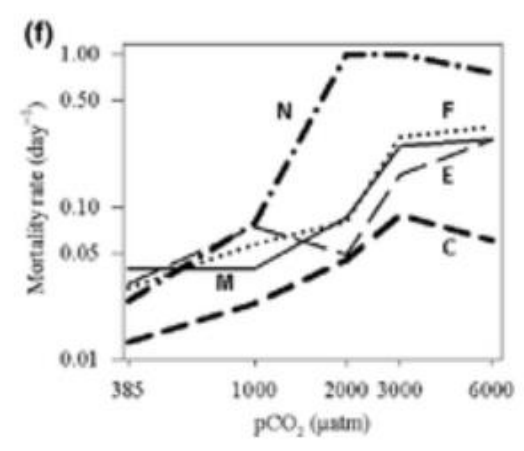
# Zooplankton and climate change

- more $CO_2$ = OA
  - zooplankton largely unaffected
  - but: effects on young stages





Global Change Biology

Global Change Biology (2015) 20, 3377–3385, doi: 10.1111/gcb.12582


## Have we been underestimating the effects of ocean acidification in zooplankton?


GEMMA CRIPPS[1,2], PENELOPE LINDEQUE[2] and KEVIN J. FLYNN[1]

[1]*Centre of Sustainable Aquatic Research (CSAR), Swansea University, Swansea SA2 8PP, UK,* [2]*Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK*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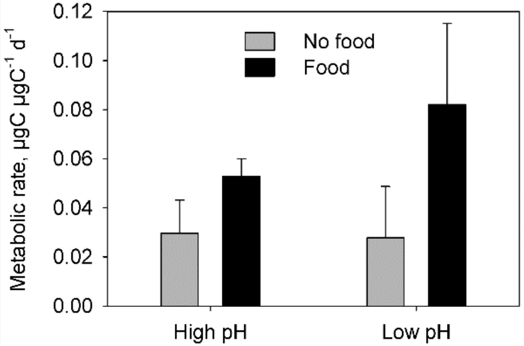
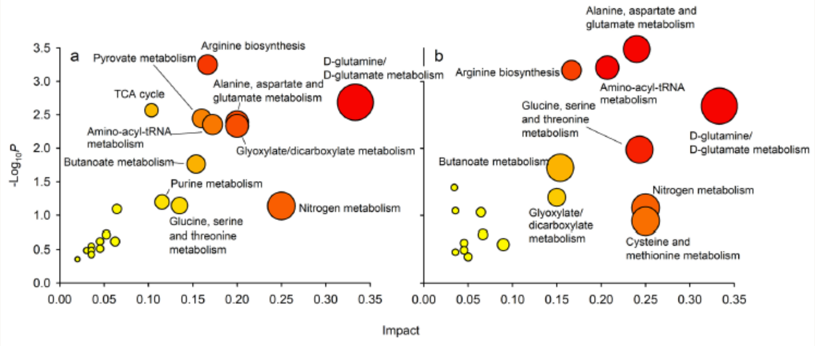
# Zooplankton and climate change

- more $CO_2$ = OA
  - zooplankton largely unaffected
  - but: effects on young stages, cellular processes → mitigation?



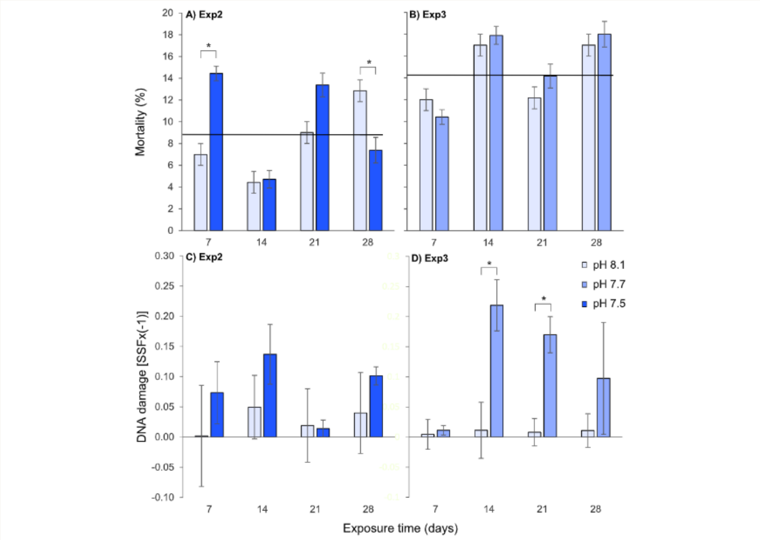

*Calanus* C2-3 have high metabolic costs under OA+low food conditions, Thor et al. 2017




*Calanus* metabolic pathways altered by OA
Thor et al. 2022

# Zooplankton and climate change

- more $CO_2$ = OA
  - zooplankton largely unaffected
  - but: effects at molecular level → DNA damage




Mortality and DNA damage in *Acartia longiremis* following 28-day exposure to control and low pH treatments, Halsband et al. 2021

see S2 Thur, 11:15, Helena Reinardy ☺

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# Zooplankton and climate change

- more $CO_2$ = OA
  - zooplankton largely unaffected
  - but: indirect community effects

Global Change Biology

PRIMARY RESEARCH ARTICLE

**Ocean acidification alters zooplankton communities and increases top-down pressure of a cubozoan predator**

Edd Hammill, Ellery Johnson, Trisha B. Atwood, Januar Harianto, Charles Hinchliffe, Piero Calosi, Maria Byrne

First published: 29 August 2017 | https://doi.org/10.1111/gcb.13849 | 

# Zooplankton and climate change

- more $CO_2$ = OA
  - zooplankton largely unaffected
  - back to square1?

PERSPECTIVE article

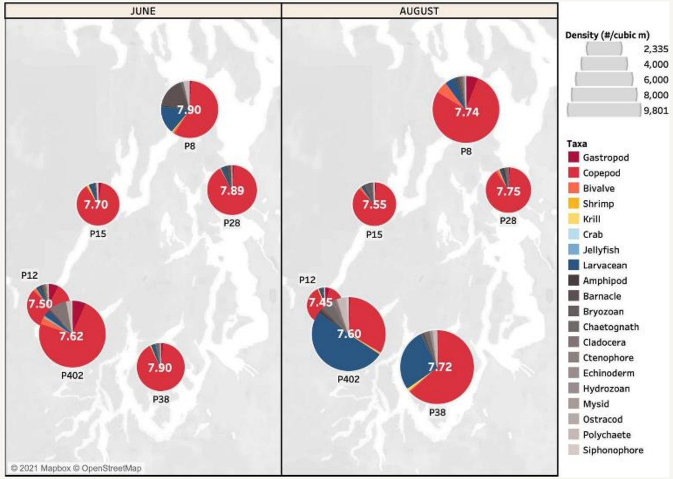
Front. Mar. Sci., 13 May 2021
Sec. Coastal Ocean Processes
Volume 8 - 2021 | https://doi.org/10.3389/fmars.2021.613778

This article is part of the Research Topic
Acidification and Hypoxia in Marginal Seas
View all 36 Articles >

## Comparative Sensitivities of Zooplankton to Ocean Acidification Conditions in Experimental and Natural Settings

Katherine E. Keil[1] Terrie Klinger[1*] Julie E. Keister[2] Anna K. McLaskey[2,3,4]

[1] School of Marine and Environmental Affairs, University of Washington, Seattle, WA, United States
[2] School of Oceanography, University of Washington, Seattle, WA, United States
[3] Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, BC, Canada
[4] Hakai Institute, Campbell River, BC, Canada



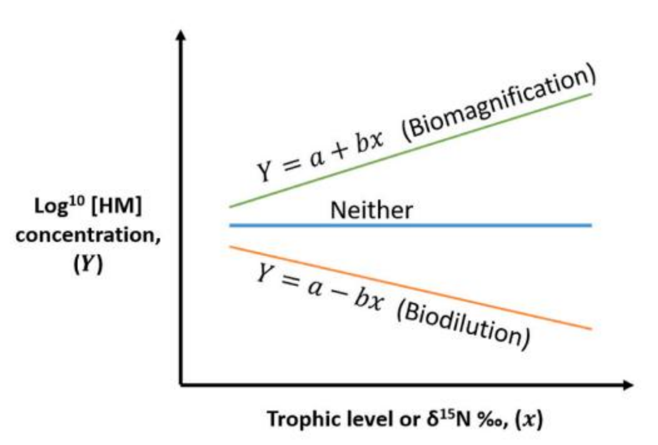
# Zooplankton and metals

- Climate change → elevated temperature → release of metals from permafrost and glaciers (incl. Cu)
- Human activities → shipping, mining, sewage, anti-fouling coatings → metal contamination
- Long-range transport
  - atmospheric
  - oceanic
- Lack of pelagic data

# Zooplankton and metals

- Pelagic metal concentrations in Svalbard

| Region | Cd | Cr | Cu | Pb | Zn | References |
|---|---|---|---|---|---|---|
| | | | [µg/L] | | | |
| Adventfjorden | 0.01-0.04 | 0.1-0.4 | 0.15-1.58 | 0.09-0.13 | 0.56-3.35 | Kalinowska et al., 2020 |
| Hornsund | 0.001-4.99 | | 0.08-6.28 | 0.003-2.69 | 0.12-17.77 | Zaborska et al., 2020 |

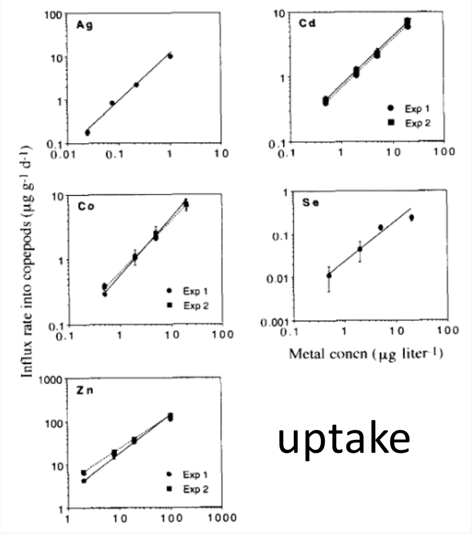



Saidon et al. 2024

- Different for different metals
- Different for different species/food chains

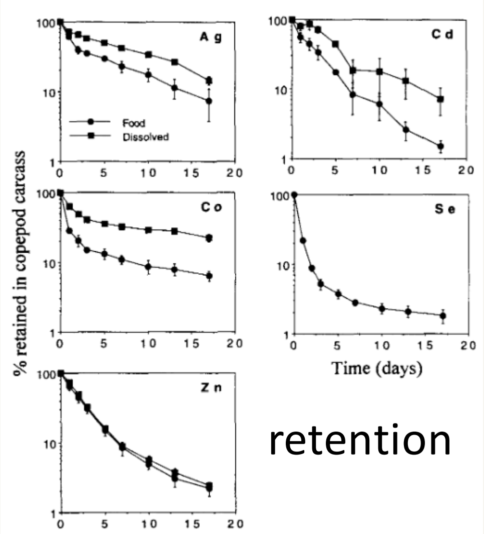
# Zooplankton and metals

- body burden/uptake
  - dissolved metal uptake: Ag > Zn > Cd > Co > Se
  - retention times




uptake

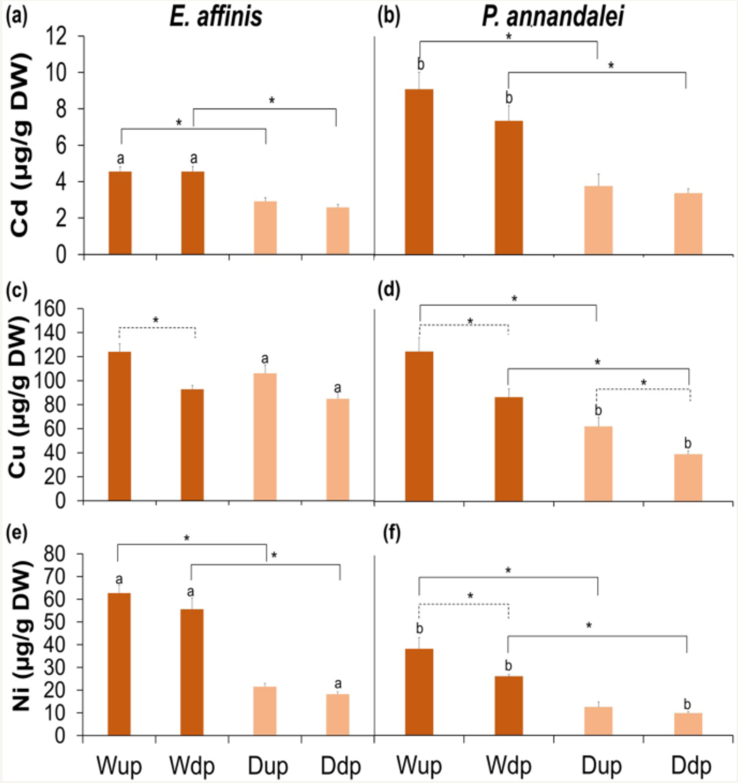
Wang & Fisher 1998




retention

# Zooplankton and metals

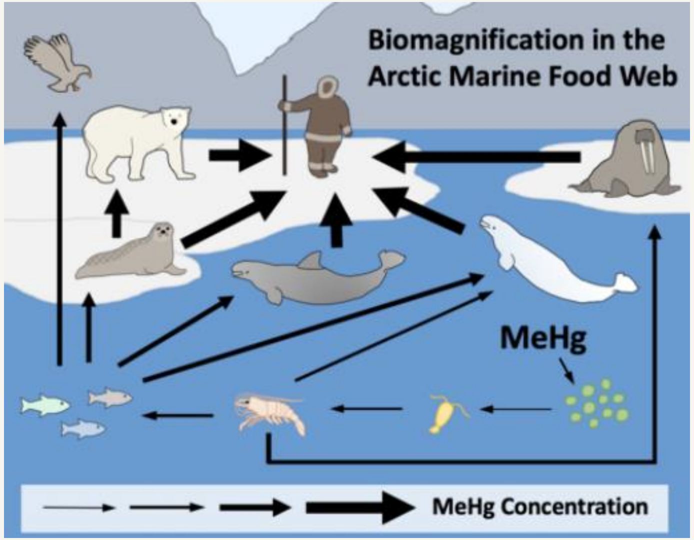
- body burden/uptake
  - dissolved versus dietary uptake
  - excretion rates




Metal uptake from water (W) and diet (D) after 4 h of exposure and excretion after 2 h depuration
Kadiene et al. 2019

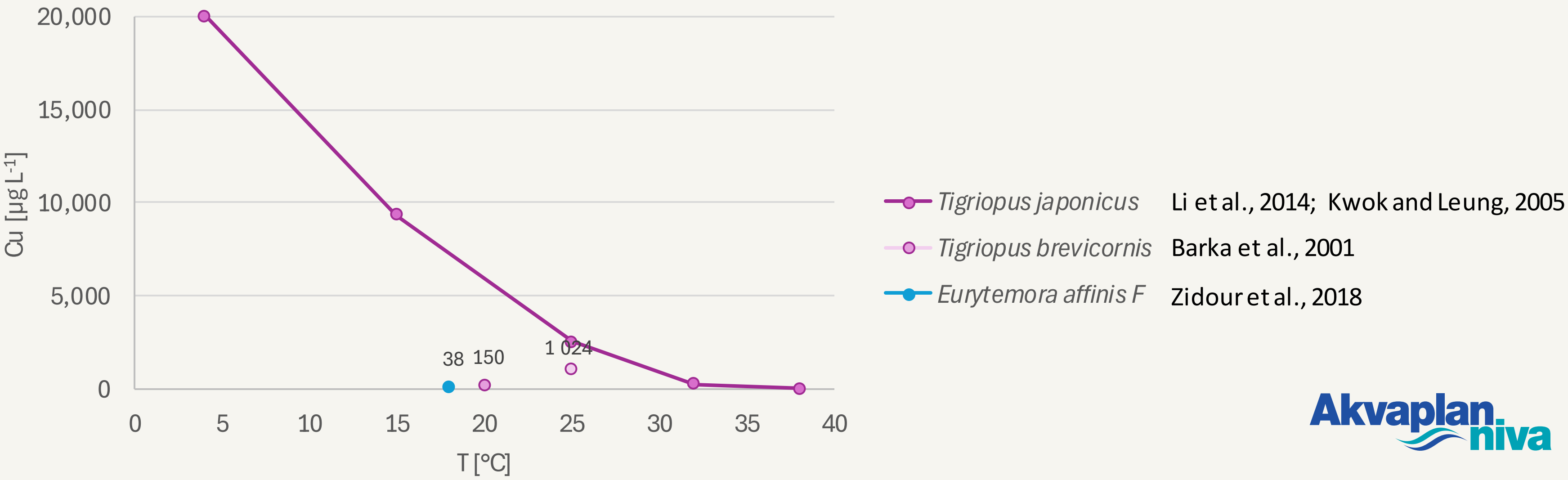
# Zooplankton and metals

- body burden/uptake
  - potential for trophic transfer and contamination of seafood
  - Hg, Cd, Cu, Ni, Zn have a significant relationship with trophic level (Madgett et al. 2021)



# Zooplankton and copper

- toxicity
  - species-specific $LC_{50}$ (96h)
  - temperature-dependent



# Zooplankton and copper

- *Calanus* spp. response to copper (and elevated temp)

see S2 Thur, 09:15,
Nele Thomsen ☺

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# Zooplankton and microplastics

- new research field; exponential increase in studies since 2013

ENVIRONMENTAL Science & Technology

Article

pubs.acs.org/est

## Microplastic Ingestion by Zooplankton

Matthew Cole,[†,‖,*] Pennie Lindeque,[†] Elaine Fileman,[†] Claudia Halsband,[‡] Rhys Goodhead,[§] Julian Moger,[§] and Tamara S. Galloway[‖]

[†]Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, United Kingdom

[‡]Akvaplan-niva AS, FRAM – High North Research Centre for Climate and the Environment, N-9296 Tromsø, Norway

[§]College of Engineering, Mathematics and Physical Sciences: Physics, Physics Building, University of Exeter, Stocker Road, Exeter EX4 4QL, United Kingdom

[‖]College of Life and Environmental Sciences: Biosciences, Geoffrey Pope Building, University of Exeter, Stocker Road, Exeter EX4 4QD, United Kingdom

ABSTRACT: Small plastic detritus, termed "microplastics", are a widespread and ubiquitous contaminant of marine ecosystems across the globe. Ingestion of microplastics by marine biota, including mussels, worms, fish, and seabirds, has been widely reported, but despite their vital ecological role in marine food-webs, the impact of microplastics on zooplankton remains under-researched. Here, we show that microplastics are ingested by, and may impact upon, zooplankton. We used bioimaging techniques to document ingestion, egestion, and adherence of microplastics in a range of zooplankton common to the northeast Atlantic, and employed feeding rate studies to determine the impact of plastic detritus on algal ingestion rates in copepods. Using fluorescence and coherent anti-Stokes Raman scattering (CARS) microscopy we identified that thirteen zooplankton taxa had the capacity to ingest 1.7–30.6 μm polystyrene beads, with uptake varying by taxa, life-stage and bead-size. Post-ingestion, copepods egested faecal pellets laden with microplastics. We further observed microplastics adhered to the external carapace and appendages of exposed zooplankton. Exposure of the copepod *Centropages typicus* to natural assemblages of algae with and without microplastics showed that 7.3 μm microplastics (>4000 mL$^{-1}$) significantly decreased algal feeding. Our findings imply that marine microplastic debris can negatively impact upon zooplankton function and health.

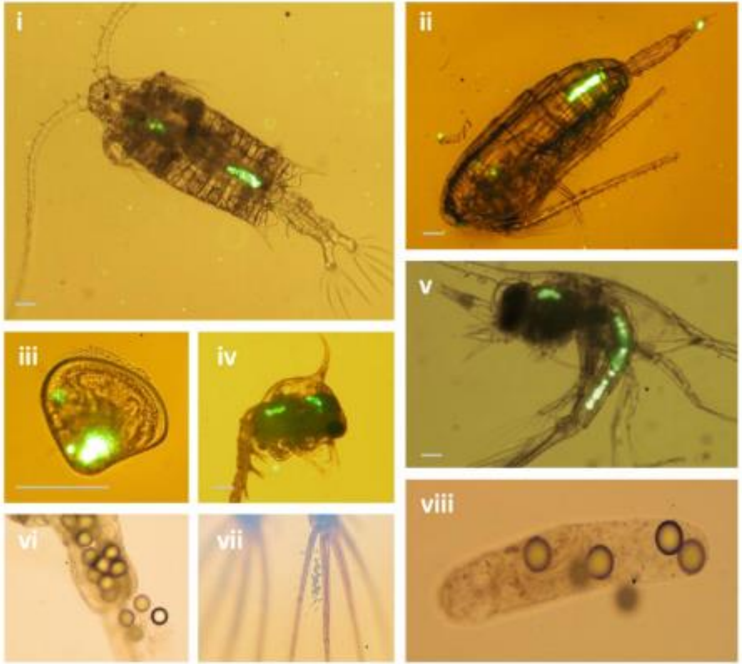



Table 1. Capacity for a Range of Zooplankton to Ingest Microplastics, Demonstrated Using Fluorescent Microscopy[a]

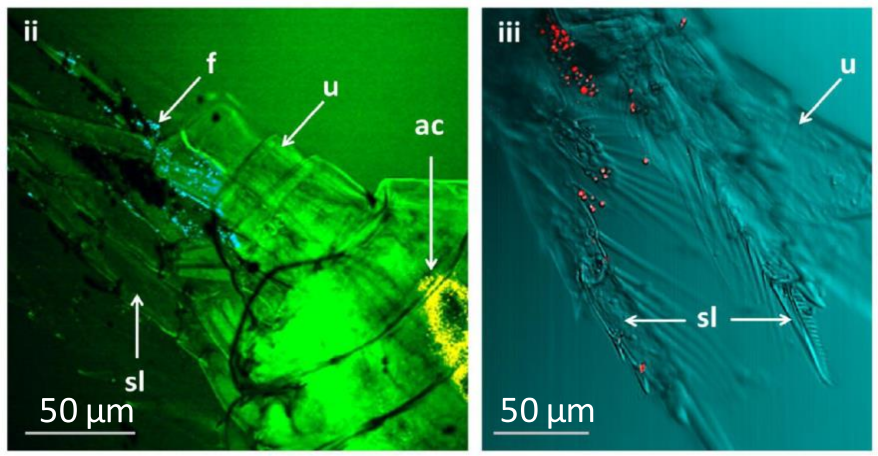
| organism | taxonomy | microplastic ESD (μm) | exposure duration (h) | ingestion (Y/P/N?) |
|---|---|---|---|---|
| Holoplankton (Copepods) | | | | |
| *Acartia clausi* | Copepoda (Calanoida) | 7.3 | 24 | yes |
| *Acartia clausi* | Copepoda (Calanoida) | 20.6 | 24 | no |
| *Acartia clausi* | Copepoda (Calanoida) | 30.6 | 24 | partial |
| *Calanus helgolandicus* | Copepoda (Calanoida) | 7.3 | 24 | yes |
| *Calanus helgolandicus* | Copepoda (Calanoida) | 20.6 | 24 | yes |
| *Calanus helgolandicus* (juv.) | Copepoda (Calanoida) | 20.6 | 24 | yes |
| *Calanus helgolandicus* | Copepoda (Calanoida) | 30.6 | 24 | partial |
| *Centropages typicus* | Copepoda (Calanoida) | 7.3 | 24 | yes |
| *Centropages typicus* | Copepoda (Calanoida) | 20.6 | 24 | yes |
| *Centropages typicus* | Copepoda (Calanoida) | 30.6 | 24 | yes |
| *Temora longicornis* | Copepoda (Calanoida) | 7.3 | 24 | yes |
| *Temora longicornis* | Copepoda (Calanoida) | 20.6 | 24 | yes |
| *Temora longicornis* | Copepoda (Calanoida) | 30.6 | 24 | yes |
| Holoplankton (Other) | | | | |
| Doliolidae | Tunicata | 7.3 | 1 | yes |
| Euphausiidae | Euphausiacea | 20.6 | 24 | yes |
| *Parasagitta* sp. | Chaetognatha | 20.6 | 1 | no |
| *Parasagitta* sp. | Chaetognatha | 30.6 | 24 | no |
| *Obelia* sp. | Cnidaria (Hydrozoa) | 20.6 | 1 | partial |
| Siphonophorae | Cnidaria (Hydrozoa) | 20.6 | 1 | no |
| Meroplankton | | | | |
| Bivalvia (larvae) | Mollusca | 7.3 | 24 | yes |
| Brachyura (megalopa) | Decapoda | 20.6 | 24 | yes |
| Brachyura (zoea) | Decapoda | 20.6 | 24 | no |
| Caridea (larvae) | Decapoda | 20.6 | 24 | yes |
| Paguridae (larvae) | Decapoda | 20.6 | 24 | partial |
| Porcellanidae (zoea) | Decapoda | 30.6 | 24 | partial |
| Microzooplankton | | | | |
| *Oxyrrhis marina* | Dinoflagellata | 7.3 | 1 | yes |

[a]Microplastic uptake is based upon the number of individuals in a treatment ($n = \geq 6$) that contained beads in their alimentary canals or body cavity following 1 or 24 h exposures to either 7.3, 20.6, or 30.6 μm fluorescent polystyrene beads. ESD = equivalent spherical diameter. Scoring system: yes (>50%); partial (<50%); no (0%).

# Zooplankton and microplastics

- entanglement, adherence


Kang et al. 2020




Cole et al. 2013

# Zooplankton and microplastics

- entanglement, adherence
  - unknown effects on behavior (swimming, escape, mating)
  - or predator responses

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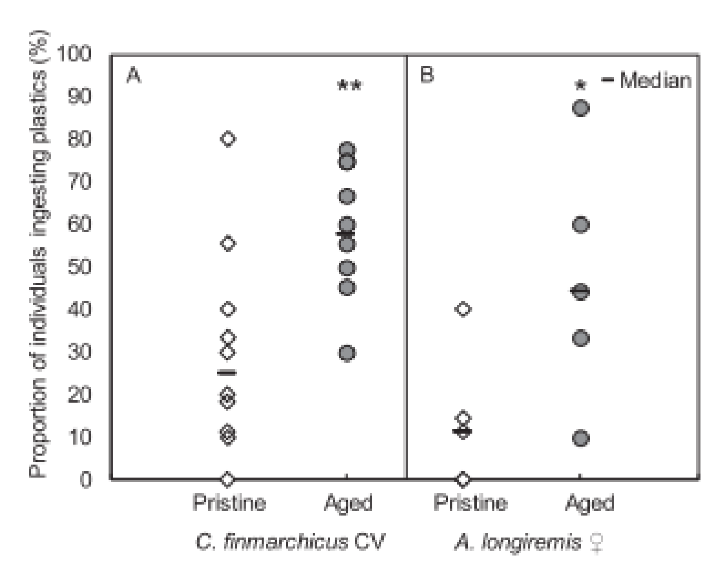
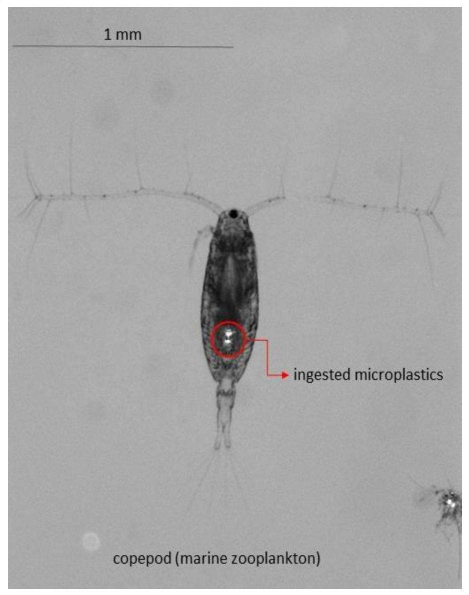
# Zooplankton and microplastics

- ingestion




Vroom et al. 2017

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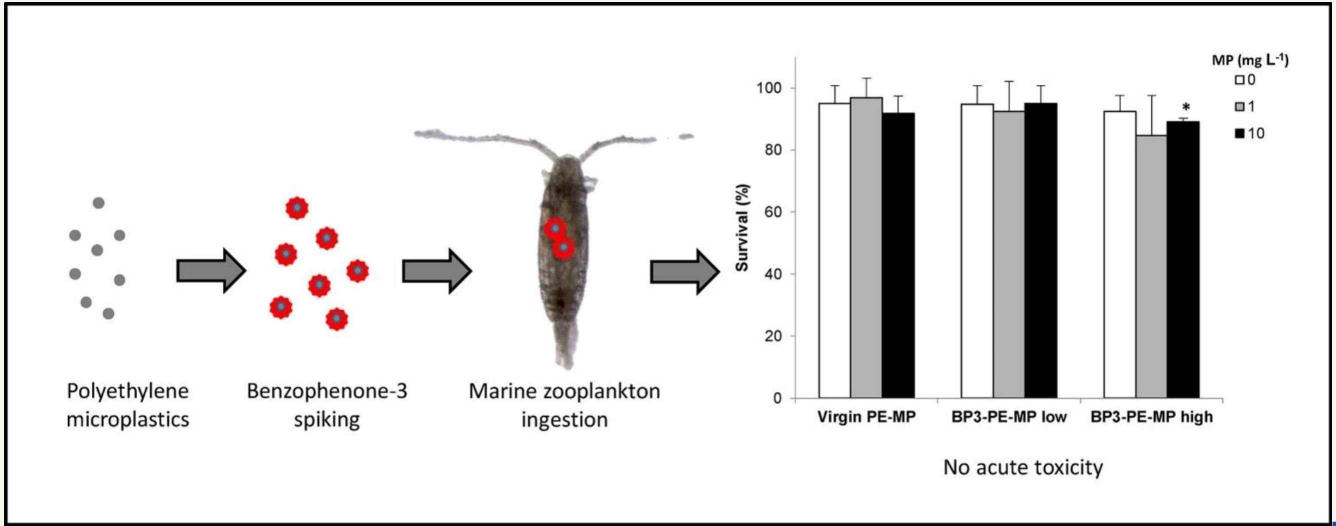
# Zooplankton and microplastics

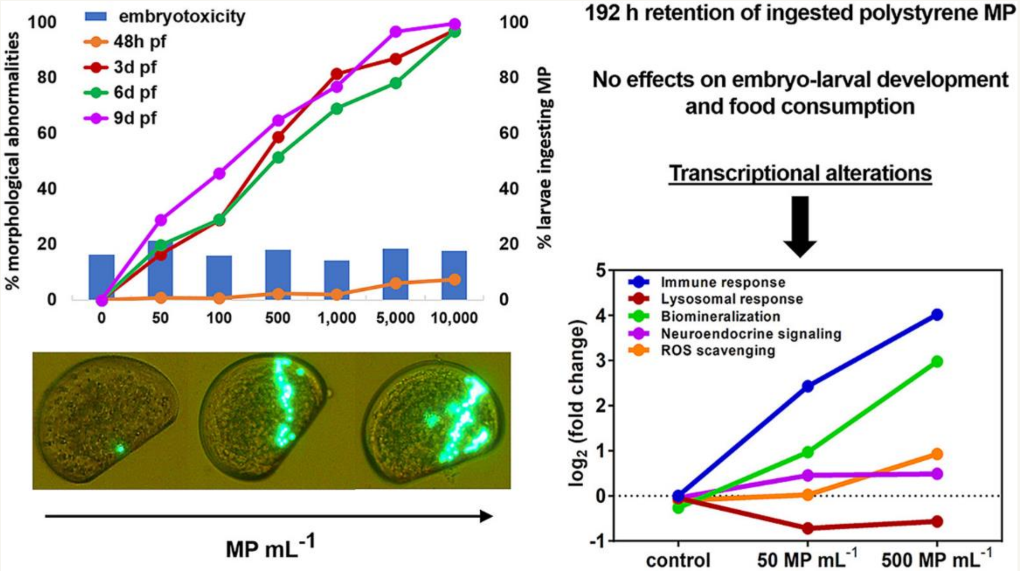
- Toxic or not toxic – that's the question
  - polyethylene (w or w/out BP-3) – not toxic




Beiras et al. 2018

# Zooplankton and microplastics

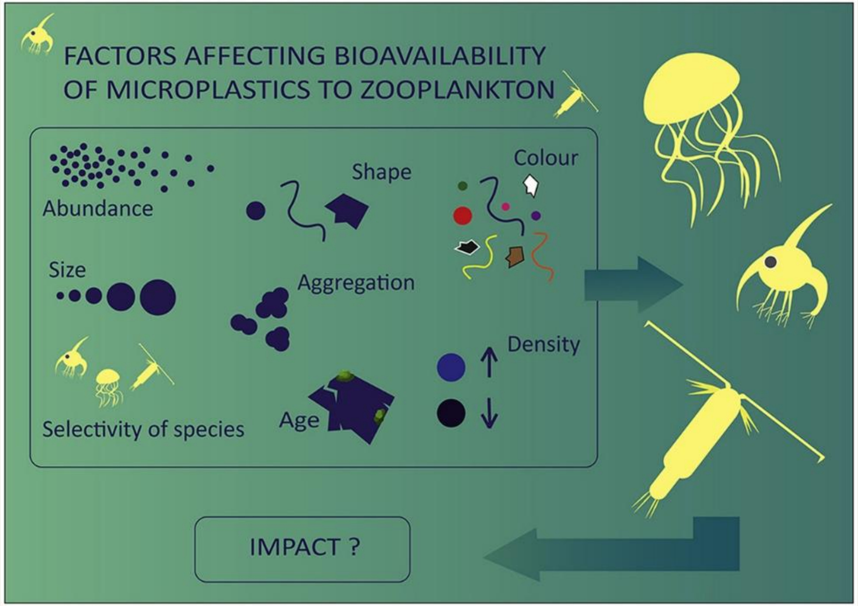
- Toxic or not toxic – that's the question
  - polystyrene – altered gene expression




Capolupo et al. 2018

# Zooplankton and microplastics

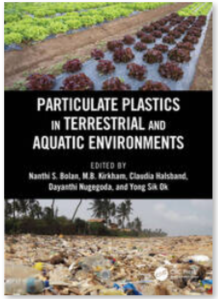
- Toxic or not toxic – that's the question
  - depends… on the MP properties




Botterell et al. 2018

# Zooplankton and microplastics

- Toxic or not toxic – that's the question
  - mainly competition with food (=reduced feeding), toxicity from additives




Chapter

## Ecological Impacts of Particulate Plastics in Marine Ecosystems

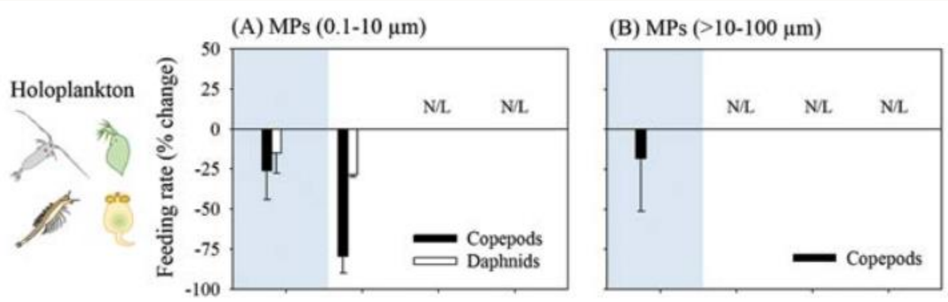
*By Claudia Halsband, Andy M. Booth*

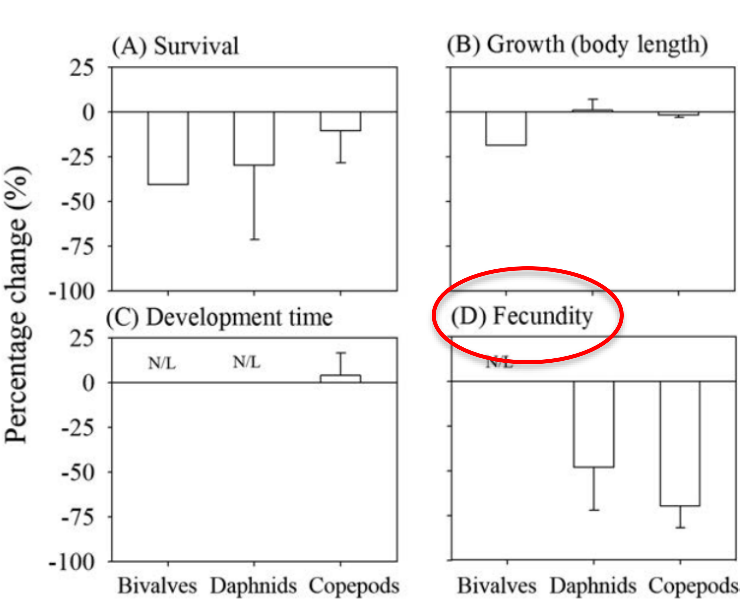
Book Particulate Plastics in Terrestrial and Aquatic Environments

| | |
|---|---|
| Edition | 1st Edition |
| First Published | 2020 |
| Imprint | CRC Press |
| Pages | 16 |
| eBook ISBN | 9781003053071 |

# Zooplankton and microplastics

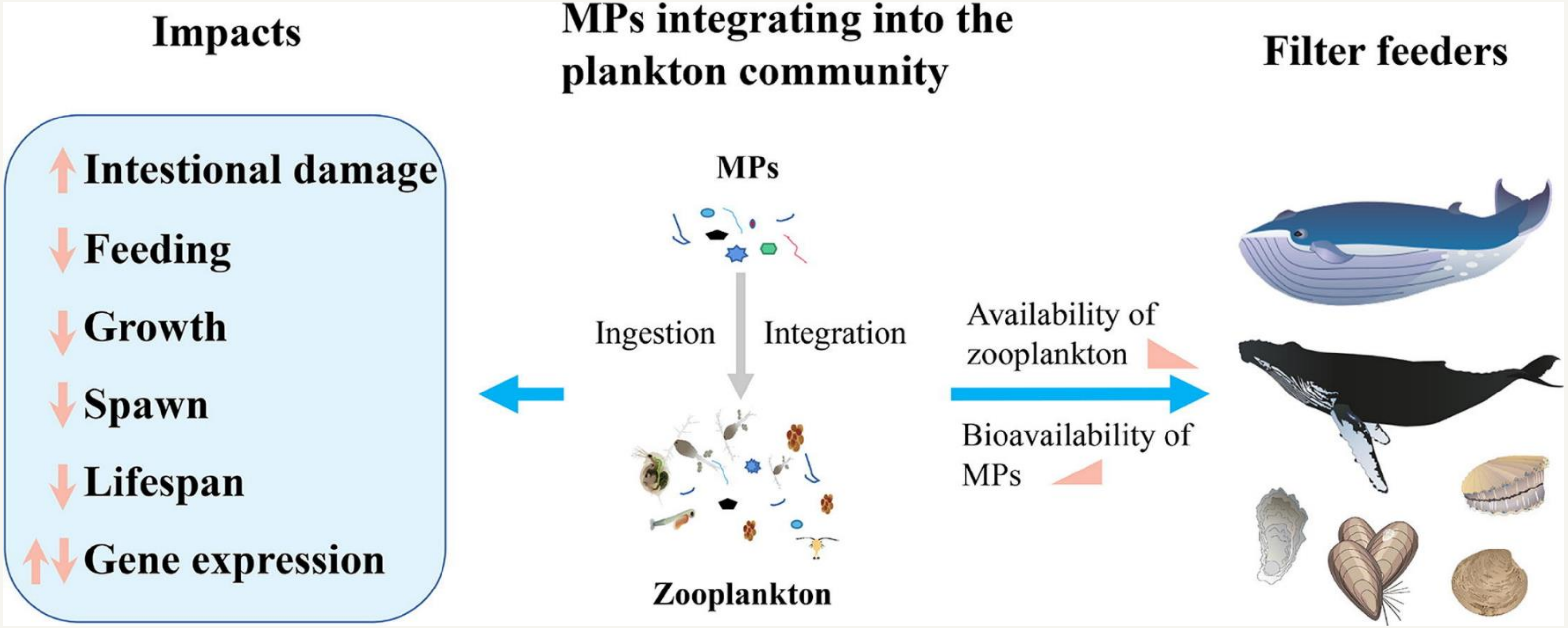
- Toxic or not toxic – that's the question
  - Yu et al. 2020: crustaceans (copepods, daphnids) >> meroplankton, euphausids



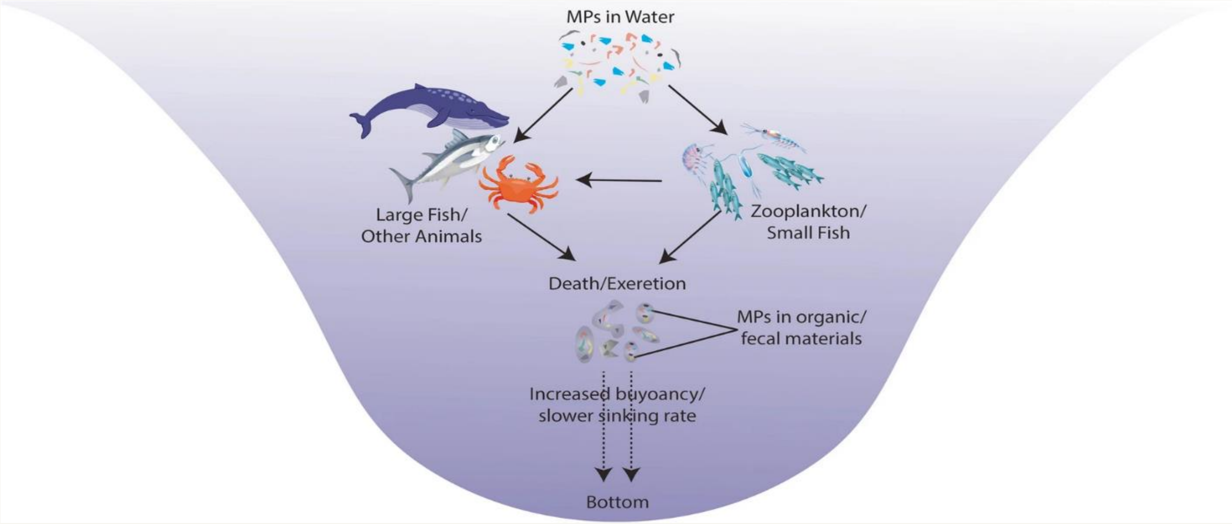
# Zooplankton and microplastics

- Toxic or not toxic – that's the question
  - He et al. 2022: yes, negative effects on…



# Zooplankton and microplastics

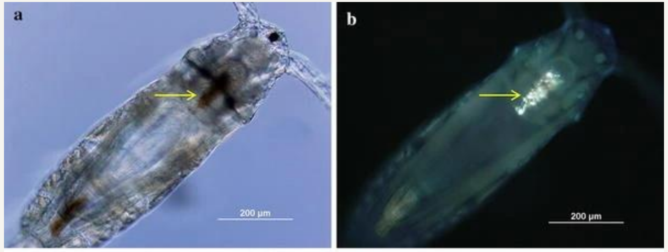
- Effects on the biological carbon pump?

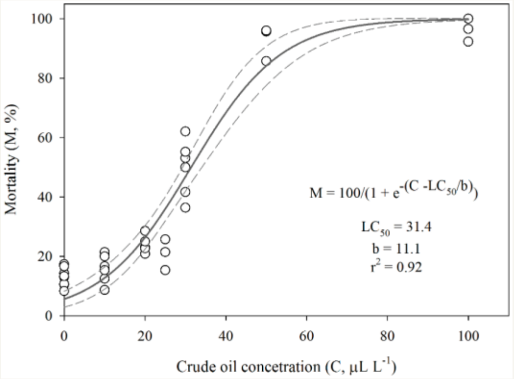


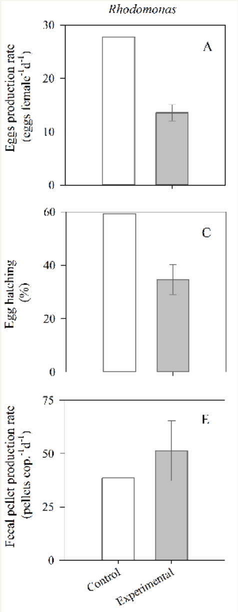

Parvez et al., 2024

# Zooplankton and organic chemicals

- oil pollution:
  - bioaccumulation and toxicity of PAHs (polycyclic aromatic hydrocarbons)



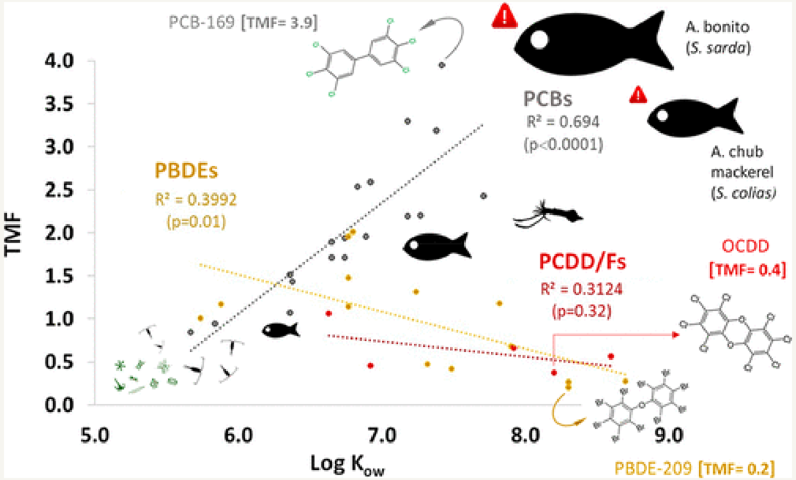




Almeda et al. 2013

# Zooplankton and organic chemicals

- POPs (persistent organic pollutants)
  - low trophic magnification = high retention

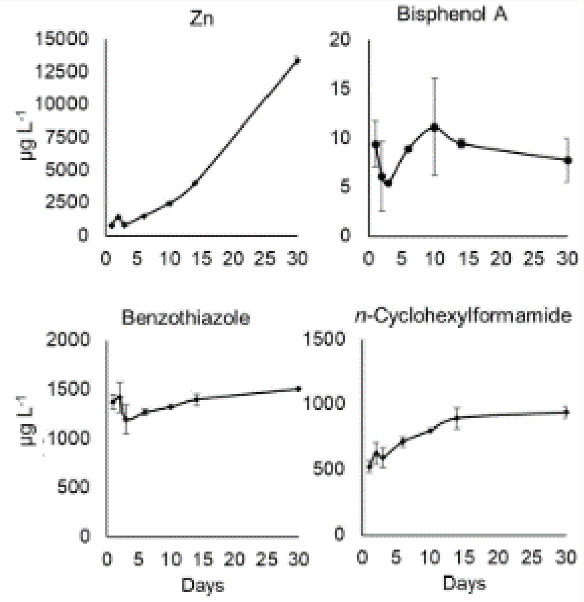


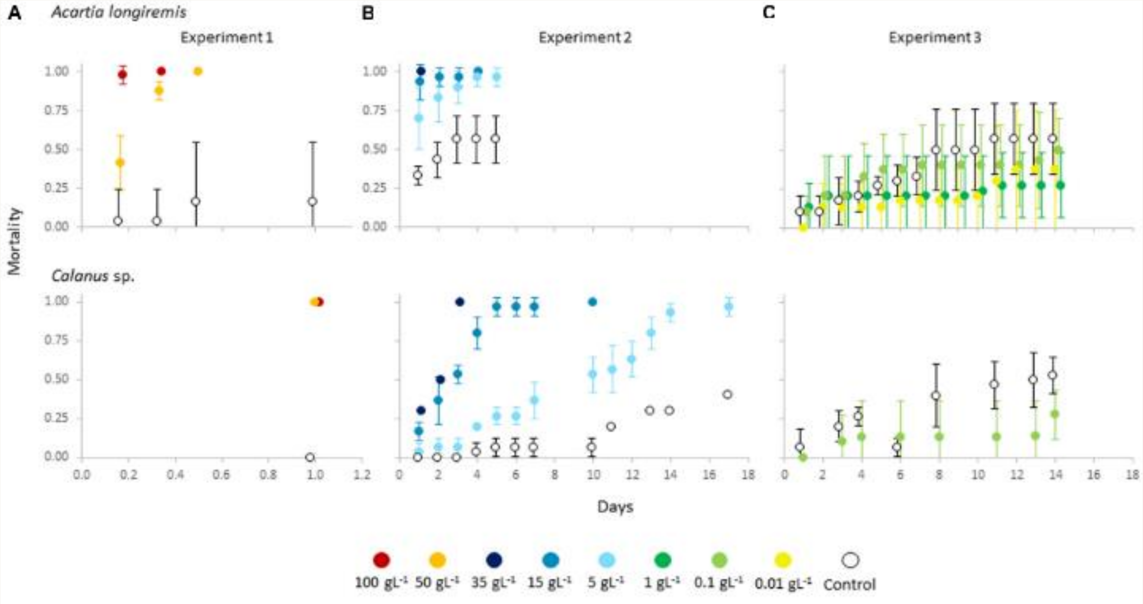

Plankton accumulate polybrominated diphenyl ethers (PBDEs) and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)

Castro-Jiménez et al. 2021

# Zooplankton and organic chemicals

- car tire rubber additives, toxic leachate cocktails




Halsband et al. 2020

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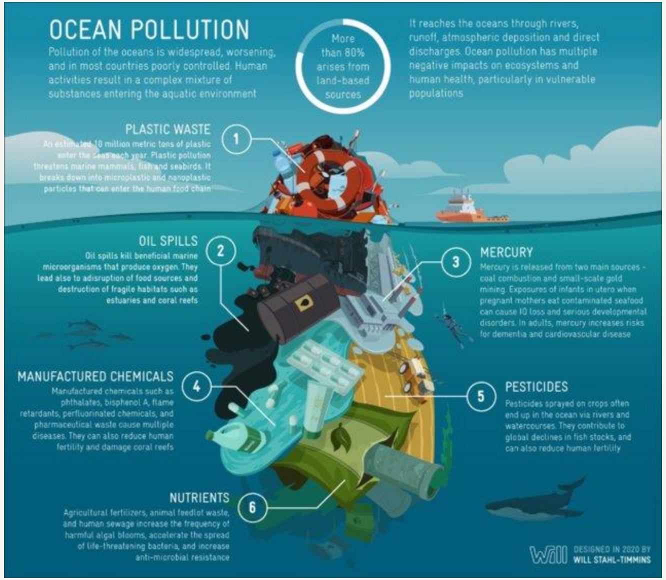
# Zooplankton and pollution

- Metals
- Microplastics
- Organic chemicals




Landrigan et al. 2020

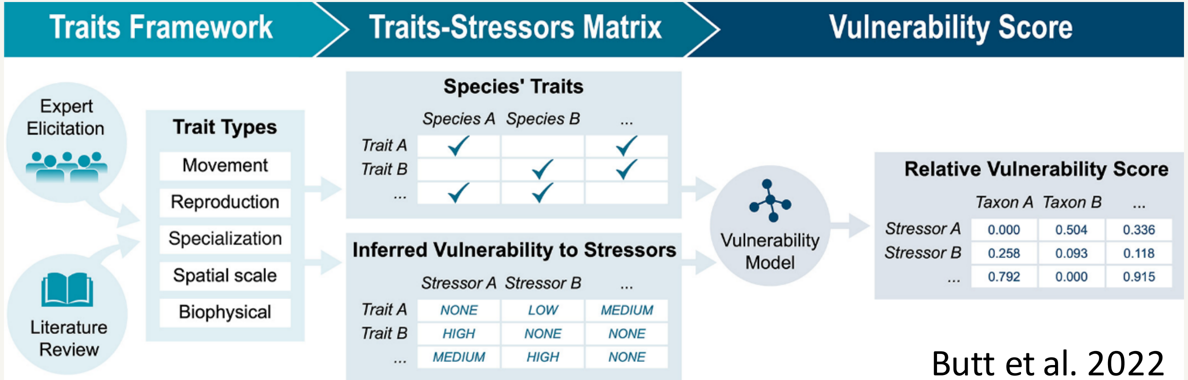
- backdrop of climate change et al.→ multistress!

# Zooplankton multistress in CLEAN

- CLEAN: cumulative impact and risk from multiple stressors in High North ecosystems
  - climate change
  - short and long-range transported pollutants
  - species invasions (e.g. king crab)
  - harvesting (fisheries)
  - aquaculture (salmon farming)
  - …

# Zooplankton multistress in CLEAN

- trait-based analysis of vulnerability
  - which traits are relevant to which stressor(s)?
  - integration with other trophic levels/functional groups
    - benthos, fish, mammals, seabirds




Butt et al. 2022

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# Conclusions

→ high individual and species-specific variability → resilience?

→ some inconclusive/contradictory results

→ cocktail effects understudied

→ multistressor conditions understudied

→ more trait-based approaches?

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