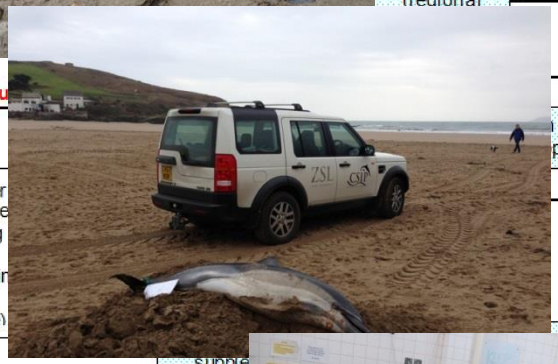
The killer whale apocalypse

Dr. Paul D. Jepson

BVMS PhD DipECZM (Wildlife Population Health) MRCVS

European Veterinary Specialist (Wildlife Population Health)

UK stranding network



defra
Department for Environment Food and Rural Affairs

Ariennir gan Lywodraeth Cynulliad Cymru
Funded by Welsh Assembly Government

The Scottish Government

JNCC
Joint Nature Conservation Committee

marinescotland

mca

AHVLA
Animal Health and Veterinary Laboratories Agency

British Divers Marine Life Rescue

SMRU

Cefas

Moredun

University of Aberdeen

National Museums Scotland

University of Exeter

RSPCA

Natural England

Scottish Natural Heritage
All of nature for all of Scotland

ZSL
Living Conservation

SRUC

Natural History Museum

Marine Environmental Monitoring

WDCS
Whale and Dolphin Conservation Society

Cetacean Research & Rescue Unit

sea watch FOUNDATION

Chemical pollutants: Organochlorines

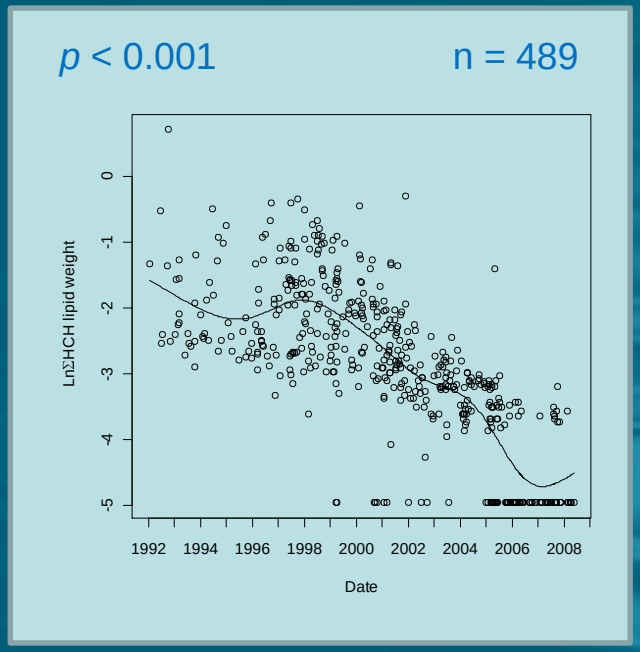
- **PCBs, DDTs, dieldrin, dioxins, etc.**
- synthesized from mid-1940s for industrial and agricultural uses
- highly lipophilic
- environmentally persistent
- bioaccumulate in food chain
- banned in developed countries
- highest global exposure occurs in marine mammals
- range of toxicities in experimental animals
  - **immunosuppression (**e.g. increased infectious disease susceptibility)
  - **reproductive impairment** (e.g. reduced female fecundity)

Other marine pollutants

- **Heavy metals** (Hg, Cd, Pb, As)
  - high exposure in top predators (bioaccumulation)
  - little evidence toxicity in marine mammals/detoxification mechanisms
- **Hydrocarbons** esp. polycyclic aromatic hydrocarbons (PAHs)
  - some PAHs carcinogenic (e.g. benzo[a]pyrene)
- **Polybrominated compounds** (e.g. flame retardants)
- **Alternative flame retardants** (e.g. PFOS/PFAS)
- **Butyltins** (e.g. TBT in anti-fouling paints)
- **Plastics**

Hexachlorocyclohexanes

- use of lindane in agriculture banned in 2009 under the Stockholm Convention
- pharmaceutical use continued until 2014

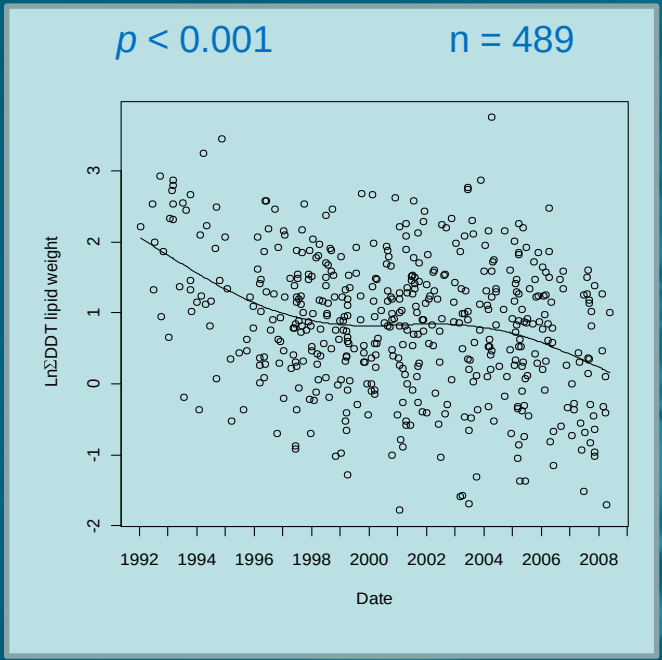


Law *et al*. Marine Pollution Bulletin 2012; 64: 1485-1494

Cefas

Sum DDT

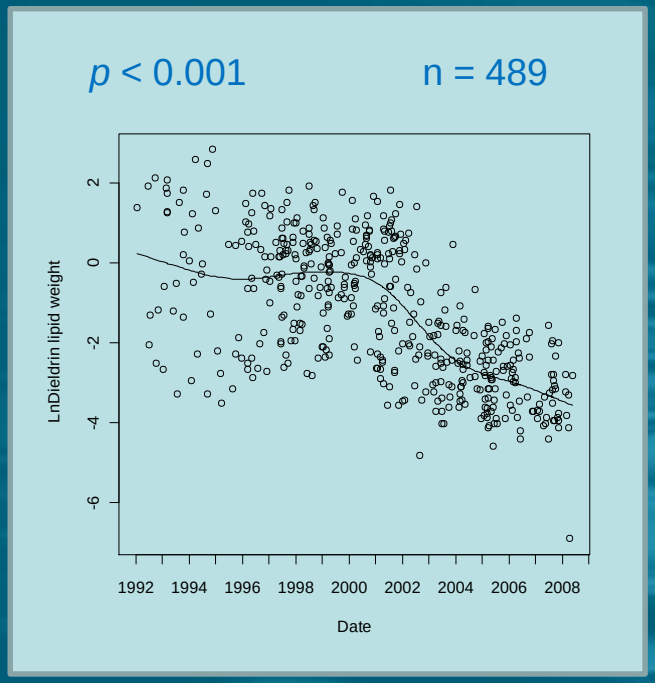
- use in agriculture banned in UK in 2009 under the Stockholm Convention
- in porpoises, *p,p'*-DDE predominates



Cefas

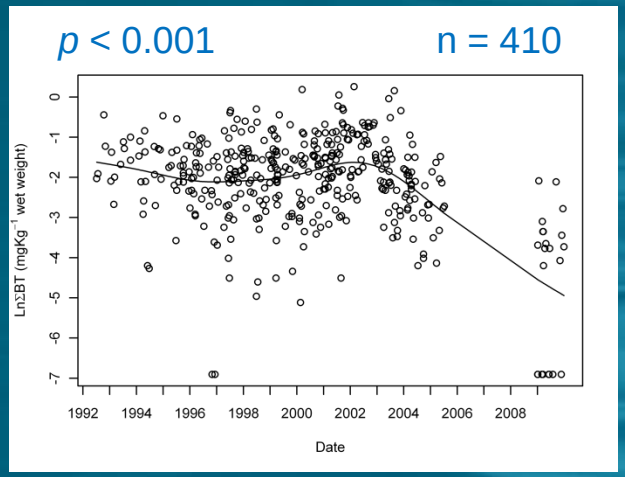
Dieldrin

- Use of dieldrin (and aldrin) banned in most countries ca. 1970s-1980s – also in the initial group of Stockholm Convention POPs



Butyltins

- IMO ban on use of TBT paints 2003-2008
- porpoise livers analysed 1992-2005 & 2009
- 1995 – TBT detected in 100% of samples
- 2009 – only found in 4.3% of samples

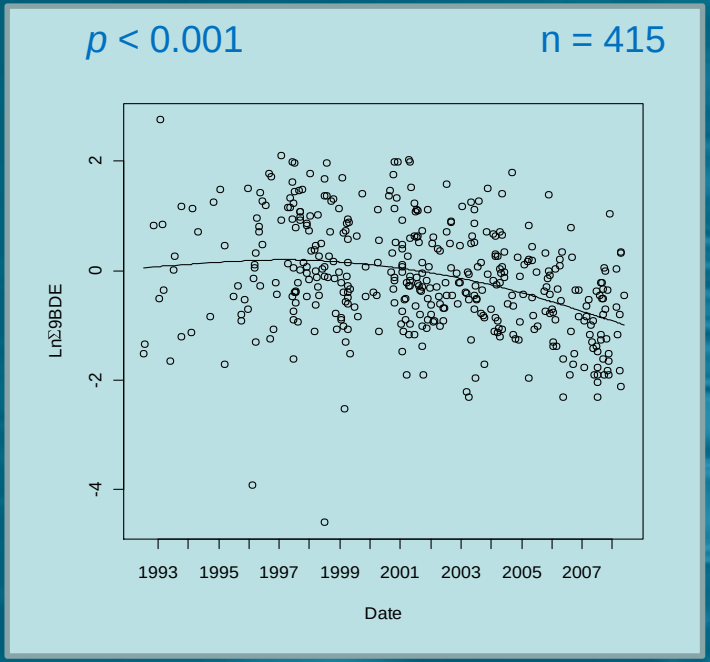


Law *et al*. Marine Pollution Bulletin 2012; 64: 2576-2580

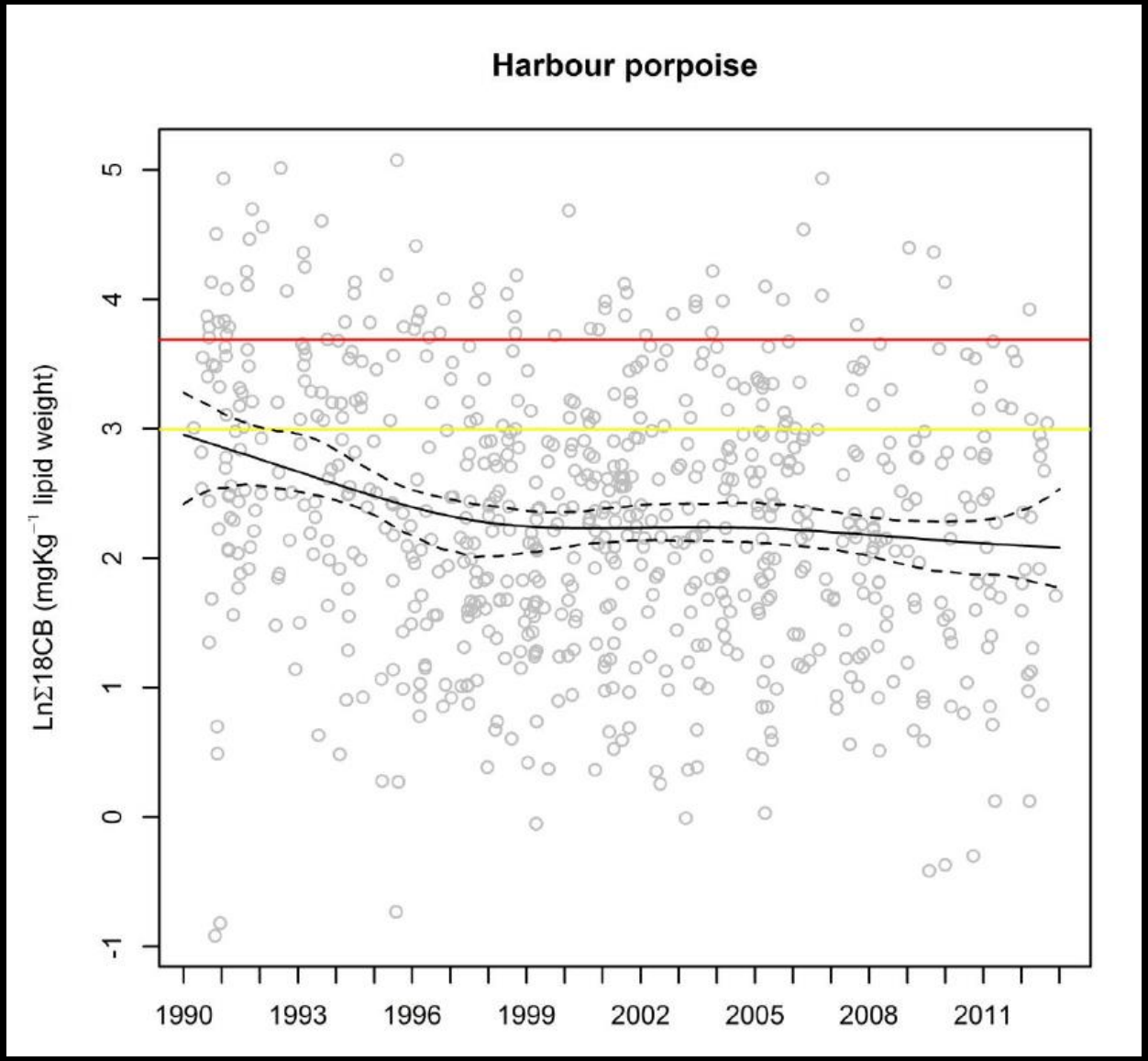
Cefas

Brominated diphenyl ethers

- penta- and octa-mix products removed from EU market, probably before 2004
- congeners in porpoises reflect penta-PBDE



PCB time series data (GAM) (1990-2012): UK harbour porpoises (Jepson et al 2016)



Methods (Jepson P.D. *et al*. 2016)

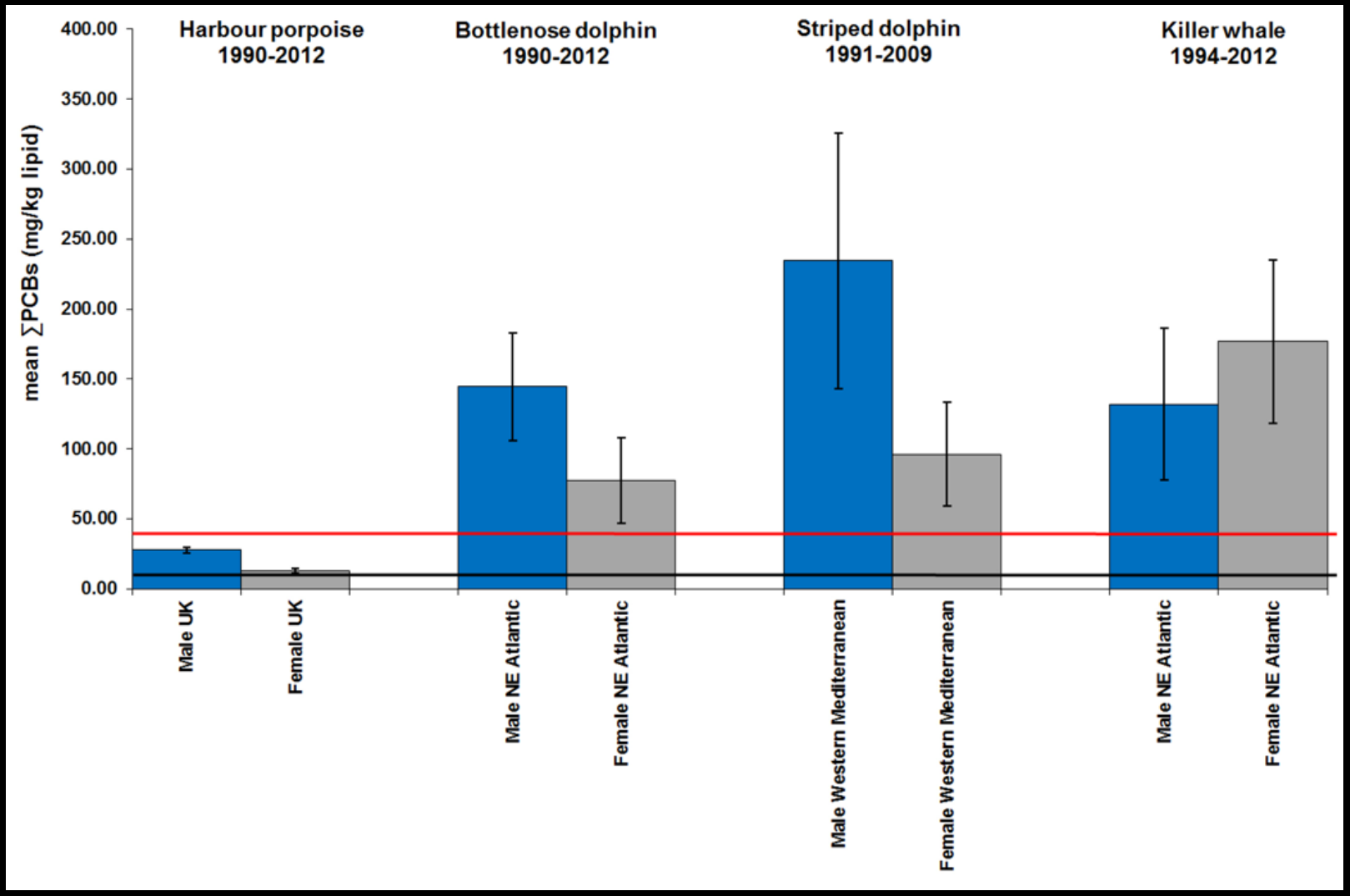
- **Time series (1990-2012) (n=1,081)**
- **Species (n=4) – mix of necropsy and live biopsy blubber samples**
  - **Harbour porpoises** (UK) (n=706)
  - **Bottlenose dolphins** (Europe) (n=131)
    - Spain (NE Atlantic/Med)(n=61): UK (n=38); Ireland (n=7); Slovenia (n=6); Portugal (n=5)
  - **Striped dolphins** (W. Mediterranean) (n=220)
  - **Killer whales** (Europe)(n=24)
    - Strait of Gibraltar (n=8); Canary Islands (n=8); UK (n=7); Ireland (n=1)
    - **mainly adults** (mostly female)
- **Toxicology** (blubber)
  - PCBs (sum 18-25 CBs lipid wt) (n = 1,081)
  - immunosuppression/reproductive impairment (adult females/calves)

Marine Mammal PCB toxicity thresholds used (Jepson et al 2016)

- **Low PCB threshold** (Kannan et al 2000)
  - 9 mg/kg lipid (sum 25 CBs) (marine mammals)

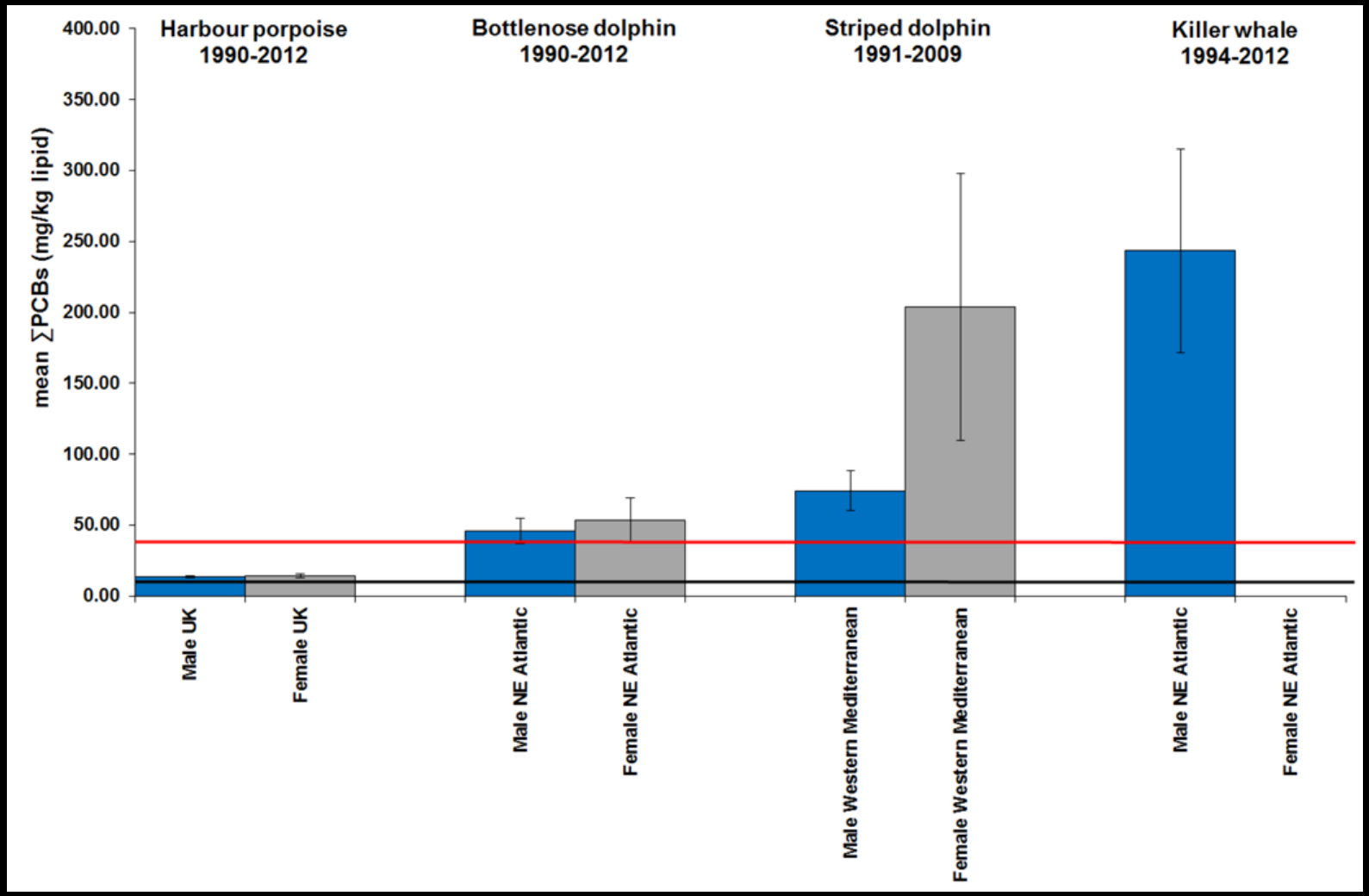
- **High PCB threshold** (Helle, Olsson and Jensen 1976)
  - 41 mg/kg lipid (sum 25 CBs) (ringed seals)

Mean PCB exposure: ADULTS only
by sex and PCB toxicity thresholds (marine mammals)



Jepson P.D. et al. (2016) *Scientific Reports*

Mean PCB exposure: IMMATURES only
by sex and PCB toxicity thresholds (marine mammals)



Jepson P.D. et al. (2016) *Scientific Reports*

Mean PCB exposure: kernal smoothing PCB distribution maps (1996-2012) – HP/BND/SD/KW

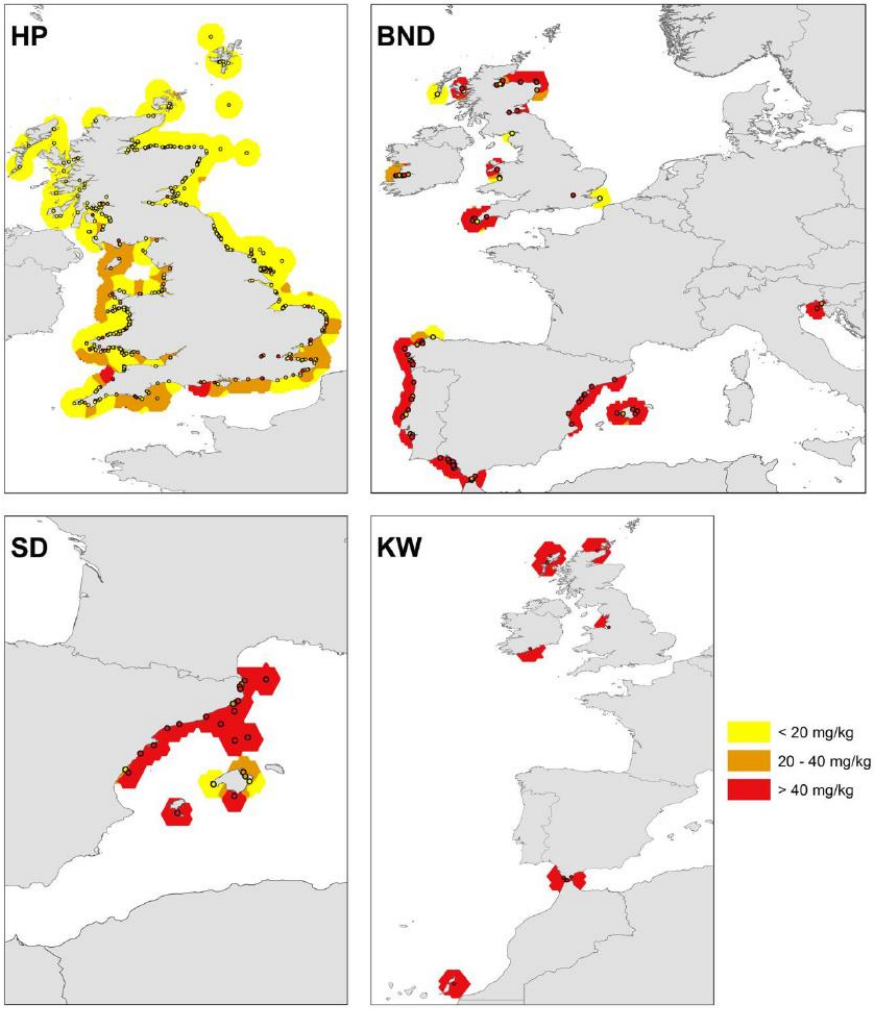


Figure 3A-D: Kernel smoothed estimates of mean PCB levels for all four species (A) - HPs; (B) - BNDs; (C) - SDs; (D) - KWs sampled between 1996 and 2013.

Jepson P.D. et al 2016 *Scientific Reports*

Population Dynamics

- **few remaining coastal killer whale populations are:- close to extinction in industrialised regions of Europe**
- **marked/historic contraction of range (KWs and BNDs)**
  - stranding records (UK; North Sea; France; Iberia)
- **remaining resident populations of BNDs and KWs in the NE Atlantic**
  - associated with low/zero calf recruitment
  - consistent with PCB-induced reproductive toxicity
- **HIGH PCBs** in **adult Fs (esp. KWs) – consistent with reproductive FAILURE**
- **all dolphin populations suffering long-term declines** (Mediterranean and Black Seas)

Jepson P.D. et al. (2016) *Scientific Reports*

Killer whale distribution map (*O. orca*) (IUCN)

Mammalia > Cetartiodactyla > Delphinidae

Orcinus orca

Killer Whale

Download Spatial data

(Linnaeus, 1758)

>Back to Red List Page

NE | DD DATA DEFICIENT | LC | NT | VU | EN | CR | EW | EX

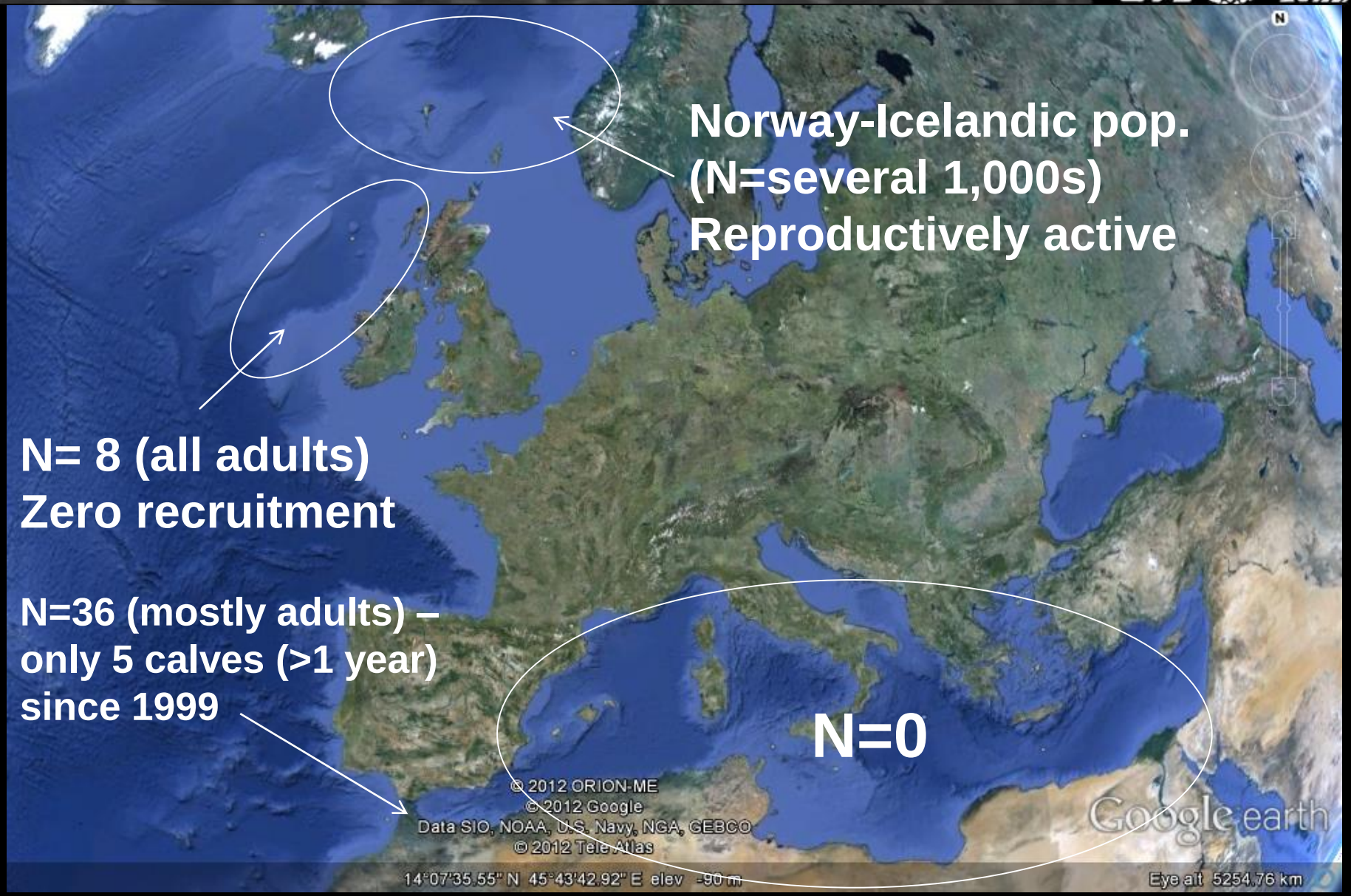
Extant (resident)

BROWSE IMAGES

ARKive *(30 found)*

IUCN (International Union for Conservation of Nature) 2008. Orcinus orca. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2012.1

Killer whale groups (coastal)
NE Atlantic/Mediterranean Sea



Global review PCB risk in marine apex predators (incl. seabirds)

INSIGHTS

PERSPECTIVES

MARINE ENVIRONMENT

Persistent pollutants, persistent threats

Polychlorinated biphenyls remain a major threat to marine apex predators such as orcas

By **Paul D. Jepson[1] *and* Robin J. Law[1,2]**

Persistent organic pollutants (POPs) are chemical substances that persist in the environment, accumulate in the food web, and pose a risk of adverse effects in humans and wildlife (*1*). Rachel Carson first identified the potentially devastating effect of POPs on wildlife in the early 1960s (*2*). In the late 1960s, polychlorinated biphenyls (PCBs) were detected in high concentrations in wildlife in Sweden (*3*). After PCB use and manufacture were banned in 1979 (US), 1981 (UK), and 1987 (EU), levels started to decline slowly in all biota around the world (*4*–*6*). In 2004, the Stockholm Convention committed more than 90 signatory countries to phasing out or eliminating large stocks or other sources of POPs, including PCBs (*1*). Yet, PCBs continue to threaten the survival of marine predators. Concerted efforts are thus still needed to mitigate PCB pollution.

Since legislative restrictions on different POPs have been introduced, tissue concentrations of POPs, including PCBs and DDT-related compounds (DDTs), have declined, and many wildlife populations have recovered. For example, populations and reproductive indices of grey seal, otter, and white-tailed sea eagle recovered in Sweden during the 1980s as tissue PCB and DDT concentrations fell substantially from the 1960s and 1970s to 2010 (*5*, *7*). Most avian marine apex predators, including herons, gulls, ospreys, petrels, and skuas, are no longer listed as threatened on the International Union for Conservation of Nature (IUCN) Red List, although half of the remaining sea eagle species are still threatened with extinction due to a range of threats, potentially including PCBs (*8*). Among pinnipeds, only the Hawaiian and Mediterranean monk seals and several spe-

[1]Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK. [2]Centre for Environment, Fisheries and Aquaculture Science (Lowestoft Laboratory), Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK. Email: paul.jepson@ioz.ac.uk

PHOTO: PAUL NICKLEN/NATIONAL GEOGRAPHIC CREATIVE

Published by AAAS

- PCBs remain a major global threat to marine apex predators
- killer whales (orcas) = most PCB-polluted species globally
- other species probably still impacted by PCBs (based on *IUCN Red Lists*):-
  - false killer whales; bottlenose dolphins (resident/coastal)
  - river dolphins/porpoises (S.E. Asia)
  - polar bears (Arctic)
  - great white/tiger/bull/short-fin mako/hammerhead sharks

Jepson P.D. and Law R.J. (2016) *Science* **352**: 1388-1389.

Global PCB manufacture and environmental mitigation (UNEP 2015)

- **United States (US)** made **476,000-648,000** tonnes (total)
  - US banned PCBs in 1979
  - conducts very active PCB mitigation (e.g. "**Superfund**" sites)
  - PCB levels declining slowly (decades)
- **Europe 299,000-585,000** tonnes (total)
  - EU banned PCBs in 1987
  - EU member states should have destroyed large stocks PCBs by 2010 (not happened – **UNEP 2015**)
  - EU PCB levels stable & highest on earth (Jepson et al 2016)
- **Rest of the world** approx. **100,000-300,000** tonnes (total)
  - mostly **China/Russia**
  - lower PCB levels (but still a risk to **killer whales**)

Is Europe doing enough to mitigate PCBs?

Conservancy, West End Brisbane, QLD 4101, Australia. *Corresponding author. Email: m.martinezharms@uq.edu.au

REFERENCES

1. Corporación Nacional Forestal (CONAF), Situación Diaria de Incendios Forestales (www.conaf.cl/situacion-nacional-de-incendios-forestales/).
2. N. Myers *et al.*, *Nature* **403**, 853 (2000).
3. A. Alaniz, M. Gallegullos, J. F. Perez-Quezada, *Biol. Conserv.* **204**, 378 (2016).
4. J. P. Boisier, R. Rondanelli, R. D. Garreaud, F. Muñoz, *Geophys. Res. Lett.* **43**, 413 (2016).
5. I. Diaz-Hormazabal, M. E. Gonzalez, *BOSQUE* **37**, 147 (2016).
6. I. Ring, *Land Use Pol.* **25**, 485 (2008).
7. E. Di Minin *et al.*, *Biol. Conserv.* **206**, 56 (2017).

10.1126/science.aan0701

Europe's insufficient pollutant remediation

Of all the banned persistent organic pollutants listed under the Stockholm Convention (*1*), the polychlorinated biphenyls (PCBs) pose the greatest difficulty in remediation because of their relative abundance, toxicity, and environmental persistence, even relative to other organochlorines (*2*, *3*). Many contracting parties of the Stockholm Convention are not adequately reporting progress on PCB elimination (*3*). Currently, the various bans on PCB manufacture and use are insufficient, on their own, to fully protect human health or to conserve wildlife. As an initial step, countries need to make a greater effort to comply with the terms of the Stockholm Convention, particularly in Europe. Europe produced between 299,000 and 585,000 tons of PCBs, but many EU member states are not assessing or decontaminating PCB-contaminated materials, sites, or waste stockpiles sufficiently (*3*). Only Norway, Sweden, and Switzerland in Europe have established procedures for secure disposal or destruction of highly contaminated PCB in joint sealants (*3*).

The United States produced the most PCBs globally (between 476,000 and 648,000 tons in total) and has signed but not ratified the Stockholm Convention (*3*). Nonetheless, the United States has been relatively proactive in terms of PCB mitigation nationally and at state level, including numerous U.S. Environmental Protection Agency (EPA) Superfund sites—areas polluted with high levels of PCBs and other hazardous substances, which the EPA is actively working to decontaminate (*2*). Perhaps as a direct result, PCB levels in the United States have slowly declined in humans and other biota such as fish for many years now, and overall PCB mitigation is generally considered to be successful (*4*). Given that the aggressive PCB risk assessment and decontamination adopted in the United States has produced sustained and ongoing declines in PCBs in humans and wildlife over several decades (*4*), we should advocate a similar approach as a matter of urgency, particularly in Europe.

Robin J. Law[1,2] and Paul D. Jepson[2]

[1]Cefas (Lowestoft Laboratory), Lowestoft, Suffolk, NR33 0HT, UK. [2]Institute of Zoology, Zoological Society of London, Regent's Park, London, NW1 4RY, UK.

*Corresponding author. Email: robin.law@cefas.co.uk

REFERENCES

1. The Stockholm Convention, Listing of POPs in the Stockholm Convention (http://chm.pops.int/TheConvention/ThePOPs/ListingofPOPs/tabid/2509/Default.aspx).
2. U.S. EPA, Superfund Redevelopment Initiative (www.epa.gov/superfund).
3. United Nations Environment Programme, Division of Technology, Industry and Economics, Chemicals and Waste Branch, "Consolidated Assessment of Efforts Made Toward the Elimination of Polychlorinated Biphenyls" (2016); https://wedocs.unep.org/bitstream/handle/20.500.11822/13664/Consolidated%20PCB%20Assessment_2016.pdf.
4. J. Xue *et al.*, *J. Expo. Sci. Environ. Epidemiol.* **24**, 615 (2014).

10.1126/science.aam6274

The Gowanus Canal in New York City is one of the EPA's designated federal Superfund sites.

PHOTO: SPENCER PLATT/STAFF/GETTY IMAGES

Published by AAAS

- Europe produced between 299,000 and 585,000 tons of PCBs
- many EU member states are not assessing or decontaminating PCB-contaminated materials, sites, or waste stockpiles sufficiently
- Only Norway, Sweden, and Switzerland in Europe have established procedures for secure disposal or destruction of highly contaminated PCB in joint sealants

Law R.J. and Jepson P.D. (2017). *Science* **356**, 148.

Is the **world** doing enough to mitigate PCBs?

- There is a near global lack of compliance under the *Stockholm Convention* in relation to PCBs – the deadlines of 2025/2028 are **unlikely to be met** without a massive acceleration in PCB remediation/stock destruction
- Approx. **83%** of **global PCB stockpiles** are still pending destruction under the *Stockholm Convention* (2025 deadline to end PCB use/2028 deadline to destroy PCB stocks)
- There is **still NO compliance mechanism** agreed for implementation of PCBs under the *Stockholm Convention*.
- Many countries are probably under-reporting the PCB stocks they still have to dispose of under *Stockholm* (Japan used as a benchmark).
- **Morocco and Rwanda** are the only African countries to have destroyed their PCB stocks under the Convention

Stuart-Smith, S. and Jepson P.D. (2017). *Marine Policy* **84**: 69-75.

“Lulu” – PCBs conc. = **957**mg/kg lipid

Schematic diagram of individual based model (IBM) coupled to a Leslie matrix population model to predict impact of PCB exposure on cetacean population growth

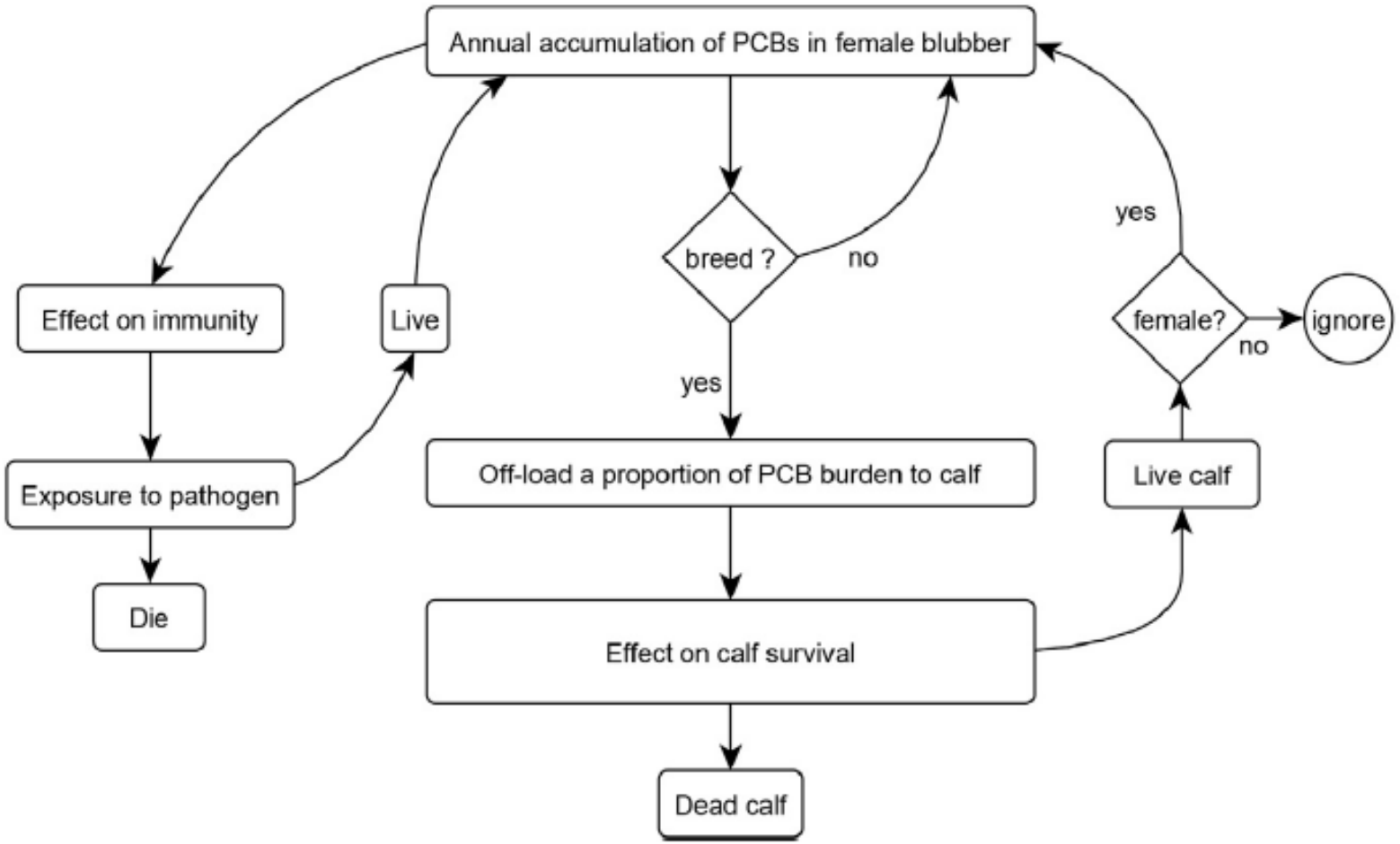
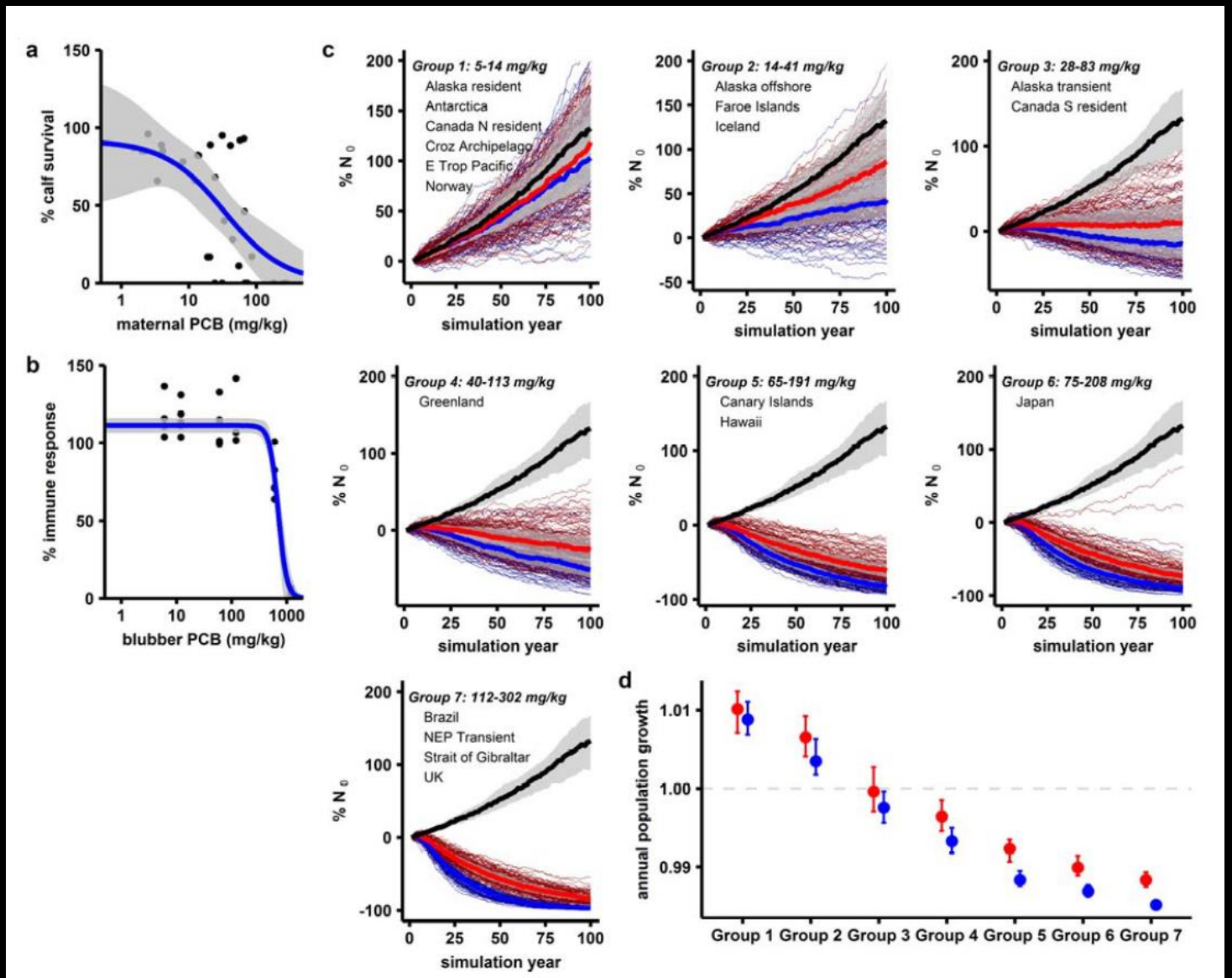


Fig. 1. Schematic diagram of individual based model to estimate impact of PCB exposure on cetacean population growth.

Desforges J.-P. et al (2018) *Science*



Desforges J.-P. et al (2018) *Science*

Table 1. Global assessment of population-level risk from PCB exposure.

PCB risk	*Population*	*Location*	*Population size*	*Protection status*
Low	Alaska offshore	North Pacific	>200[†]	none[†]
(λ>1)	Alaska resident	North Pacific	2347[†]	none[†]
	Antarctica type C	Southern Ocean	unknown	unknown
	Canada North resident	North-East Pacific	290[‡]	threatened[‡]
	Crozet Archipelago	South Indian Ocean	37-98[§]	unknown
	Eastern Tropical Pacific	Tropical Pacific	8500[†]	unknown
	Faroe Islands	North-East Atlantic	unknown	unknown
	Iceland	North Atlantic	376[¶]	none[¶]
	Norway	North-East Atlantic	500-1100[£]	unknown
Moderate	Alaska transient	North Pacific	587[†]	none/depleted[†]
(λ=1)	Canada South resident	North-East Pacific	78[‡]	endangered[‡]
High	Brazil	South-West Atlantic	unknown	unknown
(λ<1)	Northeast Pacific transient	North-East Pacific	521[†]	none[†]/threatened[‡]
	Canary Islands	Atlantic Ocean	unknown	unknown
	Greenland	North Atlantic	unknown	none
	Hawaii	Tropical Pacific	101[†]	none[†]
	Japan	North-West Pacific	unknown	unknown
	Strait of Gibraltar	Mediterranean	36[¥]	vulnerable[¥]
	United Kingdom	North-East Atlantic	≤9[Ψ]	none

Risk categories were set based on predicted growth rates (λ) and significant difference using a one-sample t-test against a reference of no growth (λ=1): low risk (λ>1, little to no effect on population growth), moderate risk (λ=1, stagnant population growth), high risk (λ<1, population decline).

[†] National Oceanographic and Atmospheric Administration (NOAA) stock assessment reports (http://www.nmfs.noaa.gov/pr/sars/species.htm#smallwhales); AT1 transients in Alaska are a subgroup considered depleted under the US Marine Mammal Protection Act

Summary

- **The killer whale (KW)** is the **most PCB-contaminated mammalian species on earth** (Jepson et al 2016; Desforges et al 2018)
- **Many KW and other dolphin pops in Europe show evidence of population decline/collapse** (Jepson et al 2016)
- **KW ecotypes that eat large fish/other marine mammals face the greatest PCB risk** (Jepson et al 2016; Desforges et al 2018)
- **"Prey switching" in KWs from small fish** (e.g. herring) **to marine mammals (e.g. seals)** increases the PCB risk (e.g. NE Scotland KW pop.) (Desforges et al 2018)
- **PCB effects modelling study** (n=351) **predicts collapse of >50% of global KW populations** (Desforges et al. 2018)
- **Some KW pop.s appear to have collapsed already (**e.g. Europe; northern Gulf of Mexico, USA**)** (Jepson et al 2016; Desforges et al 2018)

Acknowledgments

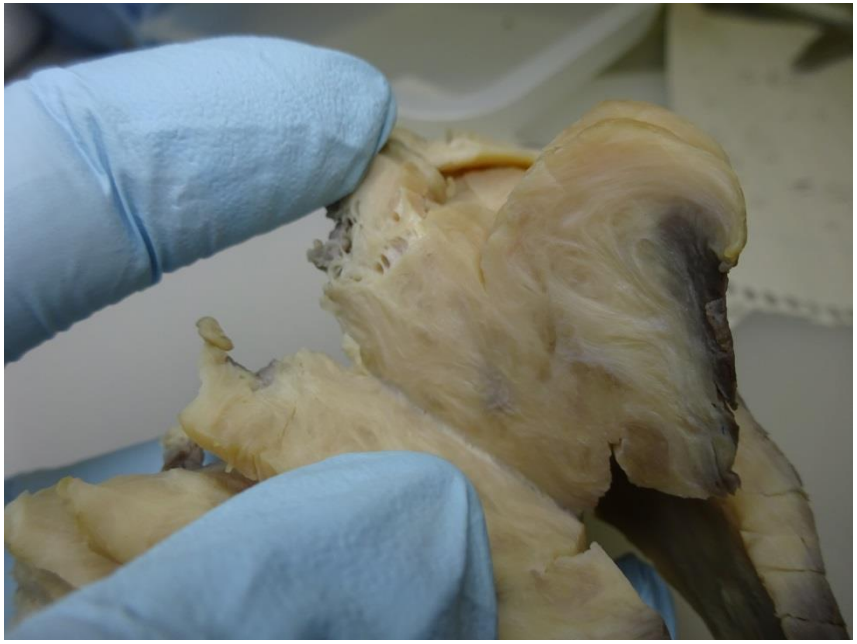
- **Funders-** Department for Environment, Food and Rural Affairs (Defra). Scottish Government (Marine Scotland). Welsh Government.
- **Contract manager-** Joint Nature Conservation Committee.
- **CSIP partner organisations-** Institute of Zoology, Scottish Agricultural College (Inverness), Natural History Museum, Marine Environmental Monitoring
- **Cornwall**- Cornwall Wildlife Trust Marine Strandings Network (and other wildlife trusts) and University of Exeter
- **Live strandings**- British Divers Marine Life Rescue (BDMLR)
- **Collaborators**- Sea Mammal Research Unit, CEFAS, Mordeun Institute, University of Aberdeen, National Museum of Scotland
- **Statutory Authorities-** Maritime and Coastguard Agency/Receiver of Wreck. Natural England, Scottish Natural Heritage and Natural Resources Wales
- **NGO's**- WDC, Seawatch Foundation, CRRU and HSI

Scottish Marine Animal Stranding Scheme

SRUC

Left ovary – 62.99 grams

Right ovary – 53.00 grams



No mature follicles or corpora visible internally, huge amount of connective tissue, very hard to cut, hence knife marks!

PART 1 (Murphy et al 2015): Comparisons with other areas

Country/ Region	Sampling period	Pregnancy rate	ASM Yrs	Reference
UK (All stranded and bycaught porpoises)	1990-2012	34% (n=76)	4.73 (n=250-	Current study
UK (Trauma sample)	1990-2012	50% (n=20)	4.92 (n=112)	Current study
Denmark	1985-1991	73% (n=33)		Sorensen & Kinze (1994)
Iceland	1991-1997	98% (n=74)	3.2 (n=269)	Olafsdottir et al., (2003)
Gulf of Maine, Bay of Fundy, North-west Atlantic	1989-1993	93% (n=14)	3.27 (n=11)	Read & Hohn (1995)