Acute, chronic and multigenerational effects of pesticides in marine organisms

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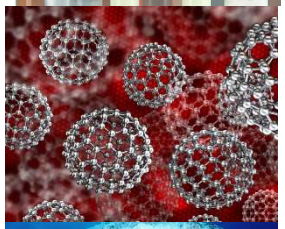
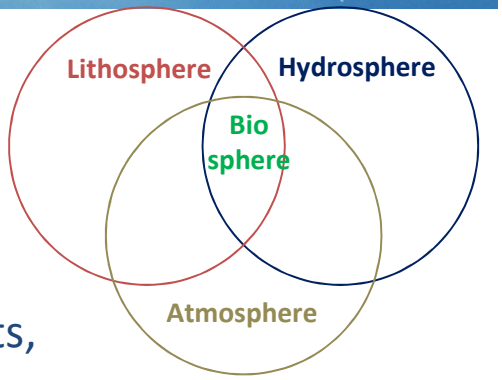
ESTIVAL ROCCH, Centre Ifremer Atlantique, Nantes, 18 octobre 2019



Scientific context: Global chemical pollution



- **High diversity of chemical substances**
  - historic pollutants (HAP, PCB, metallic trace elements, pesticides)
  - pollutants of emerging concern (PBDE, phtalates, synthetic hormones, steroids, medicines, personal care products, nanomaterials, microplastics…)

- **Multiplicity and diversity of sources (diffuse, punctual, accidental inputs):**
  - atmospheric input
  - urban, industrial and agricultural effluents
  - river input
  - surface runoff
  - pollutant spills

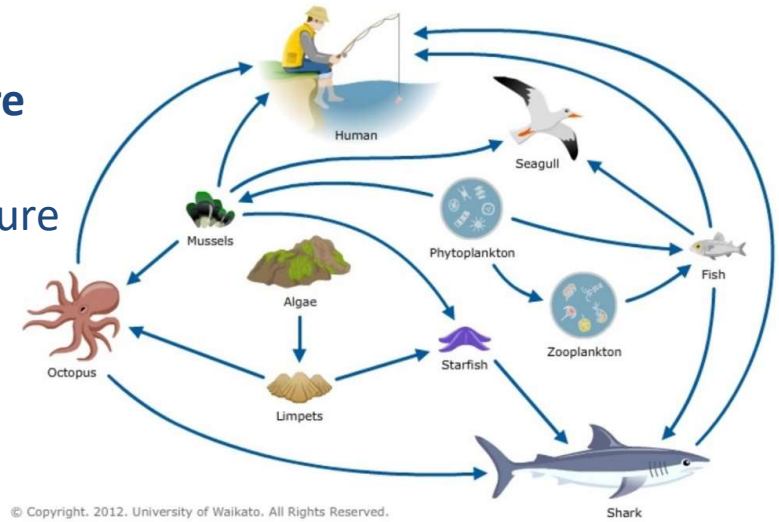
- **Qualitative and quantitative variations in both space and time**

- **Multiplicity and diversity of toxic effects**
  genotoxic, carcinogenic, neurotoxic, embryotoxic, immunotoxic, reprotoxic (EDCs), …

Global chemical pollution:
Issues in ecotoxicology and chemical risk assessment

- **Better characterization of chemical pollution exposure**

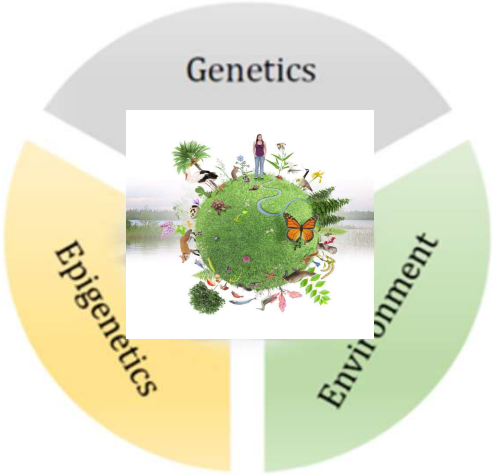
  Different exposure pathways, including indirect exposure pathways (parental exposure, secondary poisoning by trophic transfer)

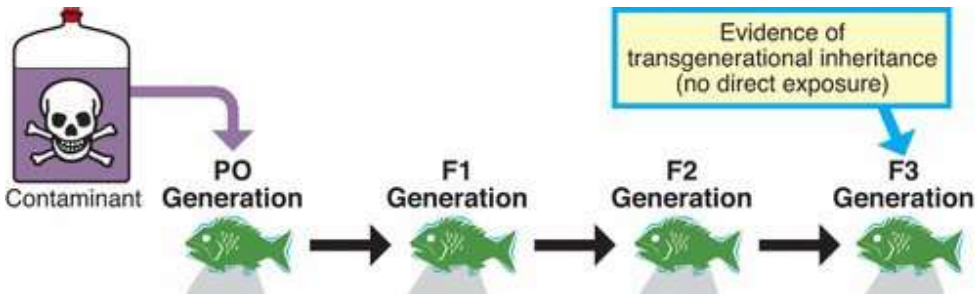


- **Better characterization of the biological effects of chemical pollution:**
  - cocktail effects of chemical substances
  - combined effects of pollution exposure with variations of environmental factors impacted by global change (T°C, pH,..)

Global chemical pollution:
Issues on ecotoxicology and chemical risk assessment

- **Investigation of long term effects of chemical substances:**
  - multi- and transgenerational effects
  - capacity to adapt to chemical stress (e.g mutations, epigenetic changes)





- **Mathematical and statistical predictive modelling of pollutant effects**

Necessity to make choices

- Diversity of chemical substances

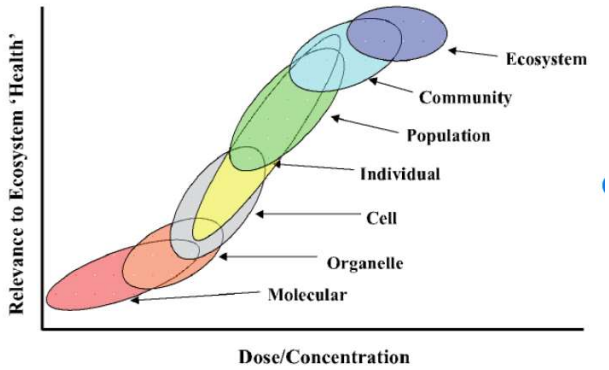
  ECHA (European Chemical Agency) > 20000

- Diversity of sources and cocktails

- Multiple exposure routes

- Diversity of target and non target organisms (plant, animal, uni and pluricellular, invertebrates and vertebrates)

- Diversity of toxic effects at different biological and time scales:
  - from DNA to ecosystem level
  - Short to long term



Schematic diagram of the hierarchical relationship between ecotoxicological responses measured at different levels of biological organization (after Spurgeon et al., 2005).

A particular interest in pesticides

- Pesticides gathered Phytosanitary Products «Substances used in agriculture to protect crops from pests" and Biocides « Substances used for other purposes to destroy, repel or render harmless harmful organisms"

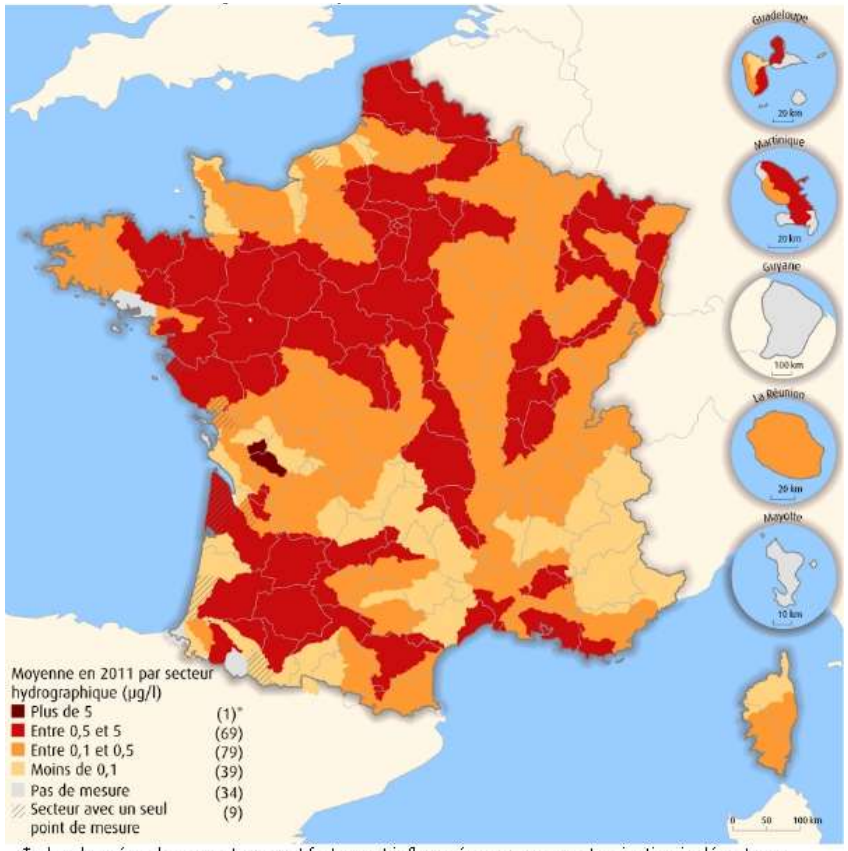
- 1233 active substances registered (ECHA, 2018)
  - 492 phytosanitary products
  - 741 biocides

- France :
  - 2nd consumer in Europe (72 000 t in 2016, Eurostats)
  - 9th considering the quantity used per kg per ha : 2.5 kg ha^{-1} (Eurostats)

→ water pollution

90% of freshwater bodies contaminated by pesticides

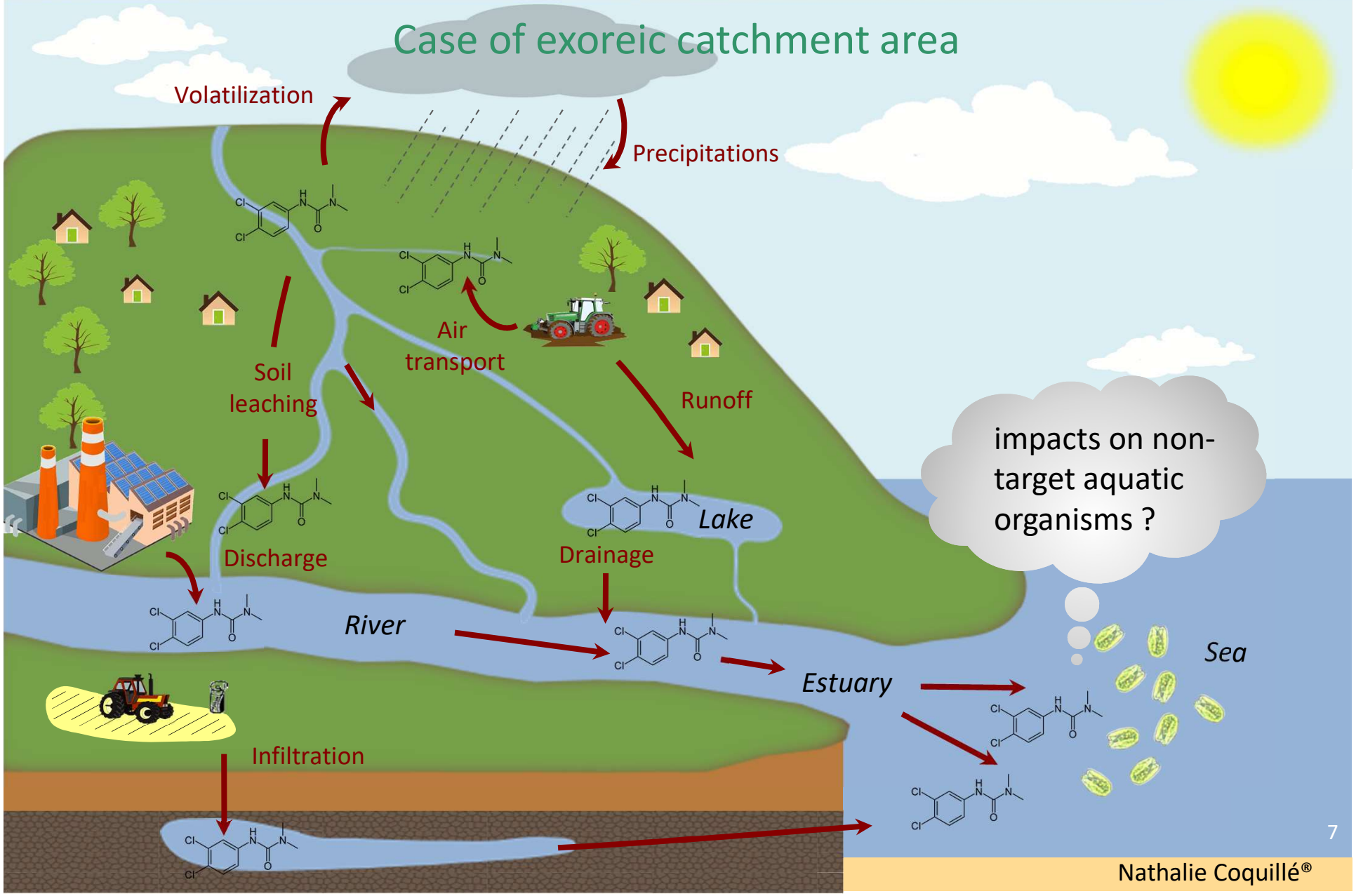
Mean pesticide concentration in freshwater system in 2011



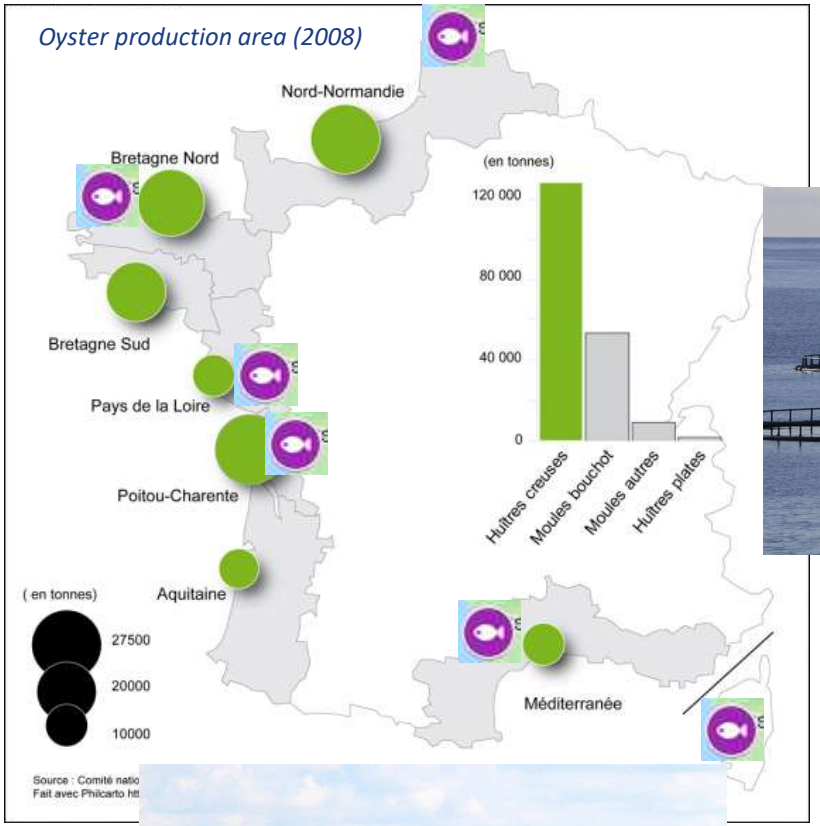
* : les données de ce secteur sont fortement influencées par une contamination isolée et non nécessairement représentative du secteur dans sa globalité

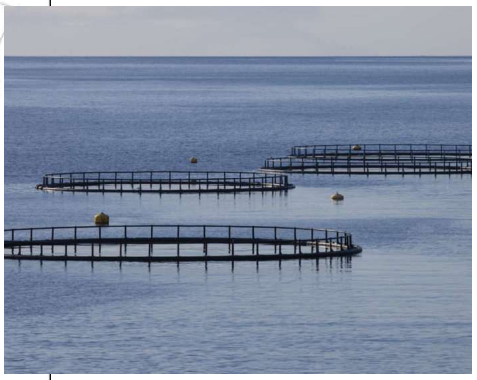
Source : : SOeS d'après agences de l'eau et offices de l'eau, 2013 – MEDDE, BD Carthage®, 2012

Case of exoreic catchment area



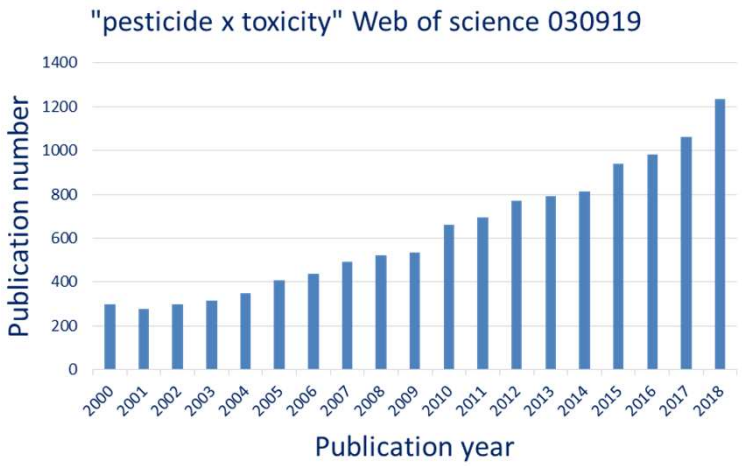
Environmental, sanitary and economical issues

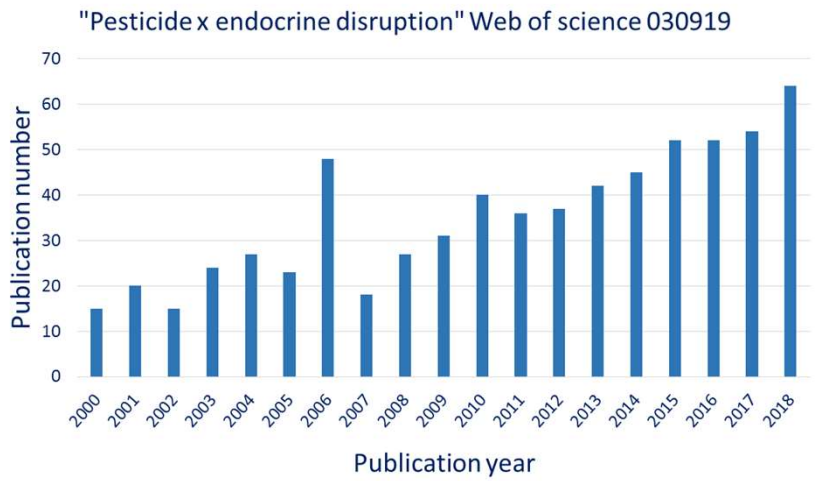


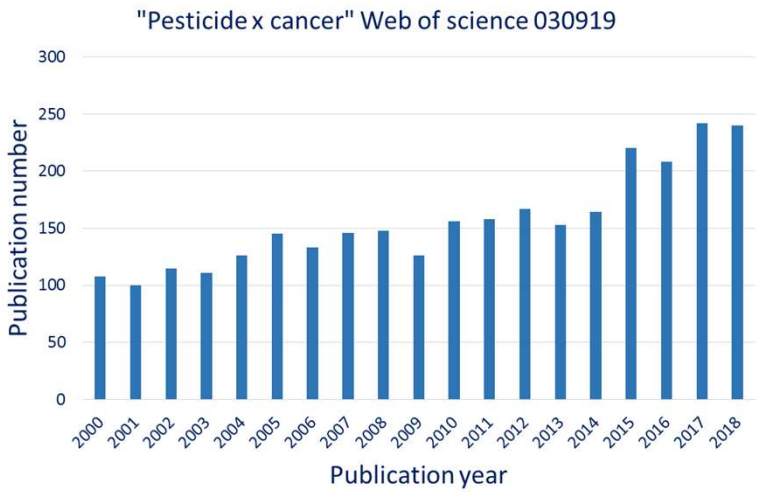


Pesticides pose a risk to human and environmental health

- Increased number of research dedicated to their toxicity study







High media coverage

Arising citizen awareness

Pesticides pose a risk to human and environmental health

- Policy decisions to protect human and its environment from chemical pollution
- EU Water Policies adopted 2 Directives:

  - the Water Framework Directive (WFD 2000/60/EC, → 1 nautical mile)

  - the Marine Strategy Framework Directive (MSFD 2008/56/CE, →200 nautical miles)

To manage, protect and improve the water environment: reaching Good Ecological Status (GES) for all water bodies

Among the 45 dangerous substances identified by the WFD 42% are pesticides

Occurrence of pesticides in coastal seawater

How to detect pesticide substances in water systems ?

- **Punctual sampling coupled to classical analytical chemistry techniques (GC-MS, LC- MS, LC-MS/MS):**
  - punctual sampling (discontinuity of pollutant inputs)
  - insufficient analytical detection limits (presence at trace levels)
- **Passive sampling using e.g Polar Organic Chemical Integrative Samplers (POCIS) coupled to classical analytical chemistry techniques (GC-MS, LC- MS, LC-MS/MS):**
  - fewer detection limit problems (concentration on membranes)
  - adapted to episodic pollution events
  - time-averaged exposure concentration (dissolved phase: bioavailable fraction)
  - possibility to use POCIS extracts for toxicity study

ELSEVIER

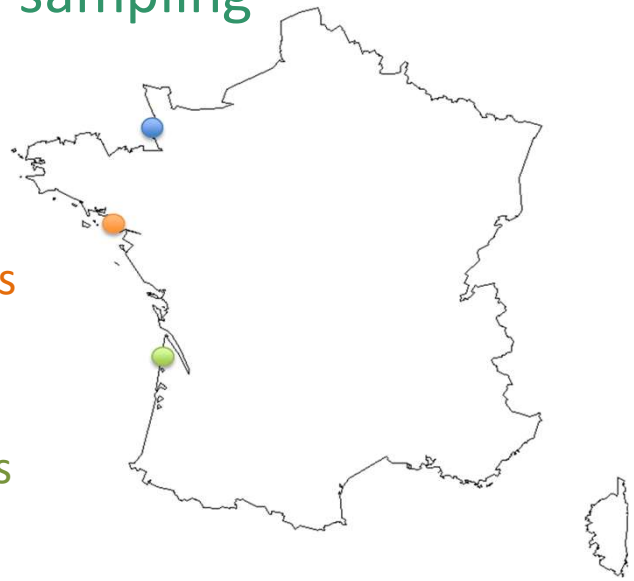
Environmental Pollution

Volume 159, Issue 3, March 2011, Pages 735–741

Combining polar organic chemical integrative samplers (POCIS) with toxicity testing to evaluate pesticide mixture effects on natural phototrophic biofilms

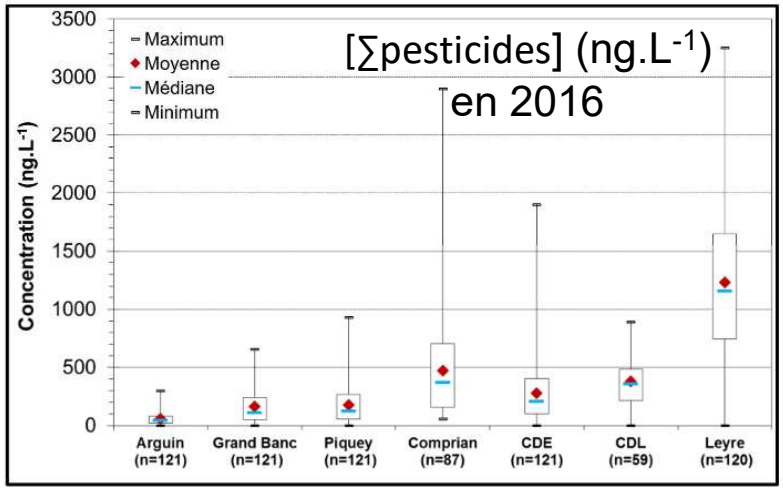
Stéphane Pesce[a], Soizic Morin[b], Sophie Lissalde[b], Bernard Montuelle[a, c], Nicolas Mazzella[b]

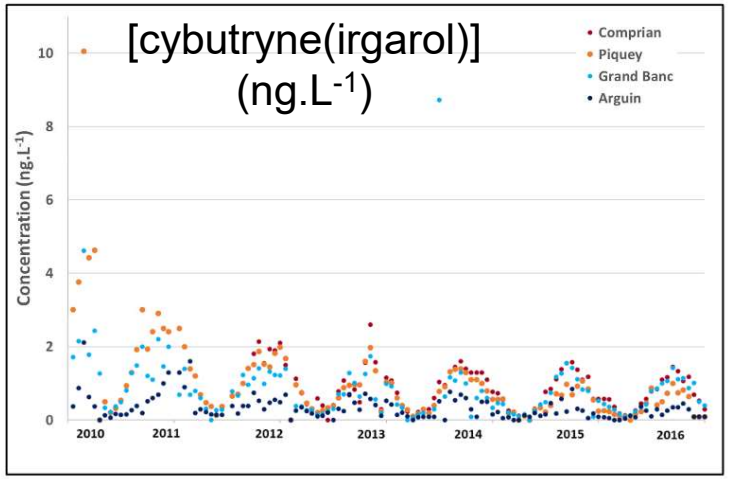
Contamination of coastal water in France: e.g Studies based on punctual sampling



- **Veys Bassin, Normandie**, (Buisson et al., 2008). 6 pesticides detected out of 15 investigated: atrazine, desethylatrazine, diuron, isoproturon, bentazone, alachlore
- **Vilaine Bassin, Bretagne**, (Caquet et al., 2013). 23 pesticides out of 30 investigated: atrazine, desethylatrazine, Irgarol, simazine, diuron and isoproturon
- **Arcachon Bassin, Aquitaine**, REPAR: since 2010, 55 pesticides detected out of 101 investigated

qualitative & quantitative variations with space and time (uses, weather conditions, hydrodynamics…)





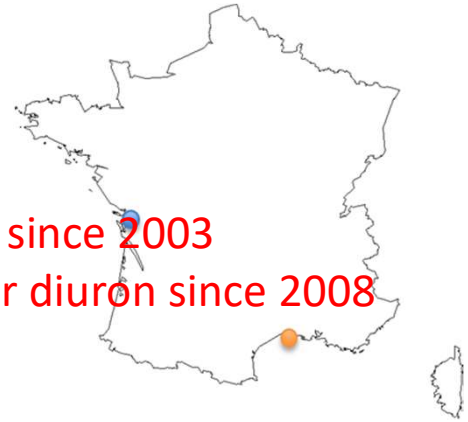
https://www.siba-bassin-arcachon.fr/sites/default/files/2018-04/REPAR_Rapport_DATA_2010-2016_2018-01-23_0.pdf

Contamination of coastal water in France: e.g Studies based on passive sampling

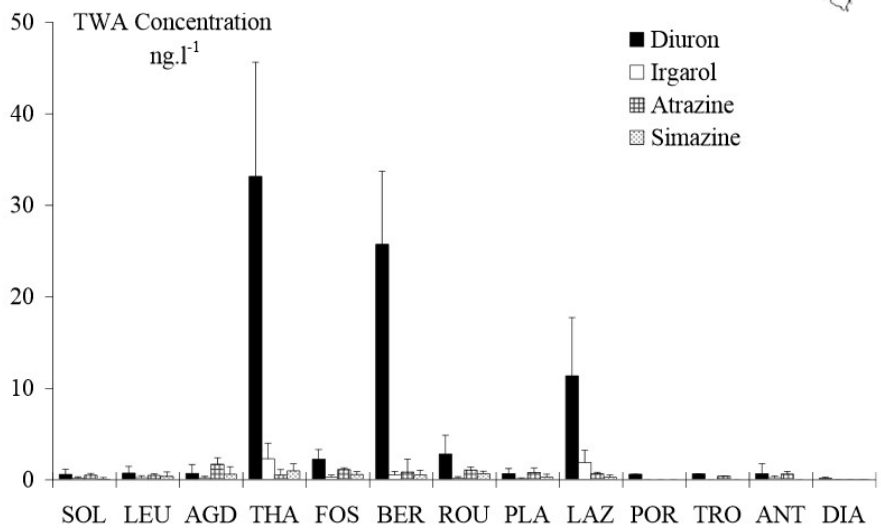
- **Port-des-Barques, Charentes Maritimes** (Akcha et al.):

  37 detected pesticides out of 57

Substances	[c] ngL^{-1}
Metolachlore ESA	65,8
Metolachlore OA	61,3
Aatrazine 2 hydroxy,	35,4
DEA	30,7
Acetochlore ESA	26,7
Nicosulfuron	22,6
Metolachlore	11,4
Terbutylazine desethyl	14,6
Atrazine	8,1
Simazine	8,9



Atrazine banned since 2003
Restricted use for diuron since 2008

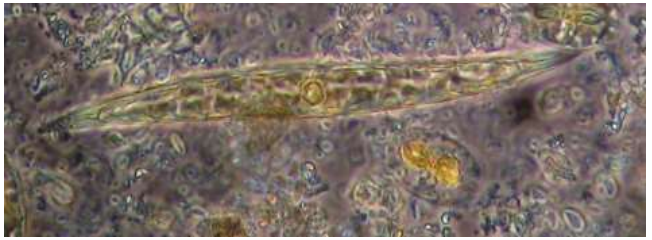


- **Bays and lagoons from Mediterranean Sea,** (Munaron et al., 2012): 16 pesticides detected out of 27 investigated. Diuron detected in all samples, followed by terbuthylazine (92%), atrazine (85%), irgarol (77%) and simazine (77%)

Toxicity for marine organisms: ecotoxicologicaly relevant species

Biological models to investigate pesticide toxicity
High interest working on marine phytoplankton

- Unicellular organism, cultivable at lab : study at individual, population and community level (monospecific cultures → complex natural communities collected in the field)
- Short life cycle: long term exposure on several generations at lab (multigenerational effects, adaptative response to chemical stress)



Choice of biological models
High interest working on marine phytoplankton

- **Major ecological role in the functioning of marine ecosytems**:
  - primary photosynthetic producer at the base of trophic networks
  - role in carbon cycle

Phytoplankton is responsible for the majority of CO_2 transfer from the atmosphere to the ocean

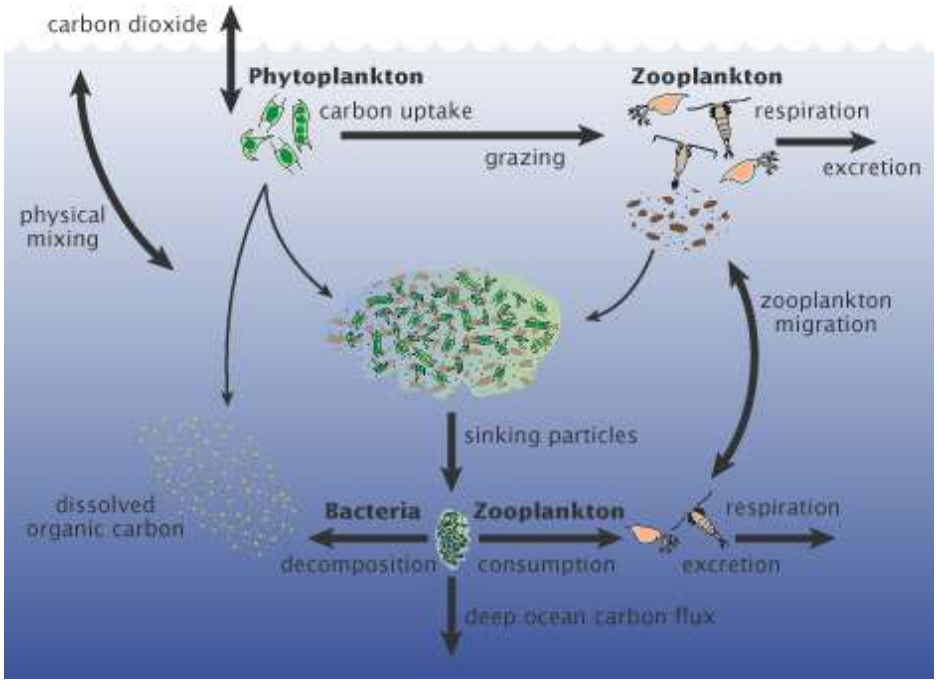
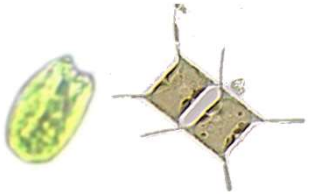


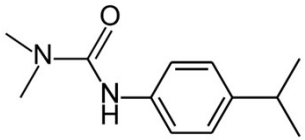
Illustration adapted from A New Wave of Ocean Science,U.S. JGOFS



Microalgae can be particularly concerned by pesticide exposure

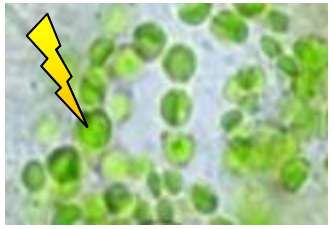
- ❑ **Herbicides represent the majority of pesticide input in coastal seawater**
- ❑ **Herbicides have the potential to damage plant photosystem**

Herbicides



crop weeds

microalgae



Herbicide	Chemical class	Log K_{ow}	Water solubility (mg l^{-1})	CAS number
Diuron	phenylurea	2.6	37.4	330-54-1
Fluometuron	Phenylurea	2.4	110	2164-17-2
Tebuthiuron	Phenylurea	1.8	2,500	34014-18-1
Atrazine	s-triazine	2.5	29,800	1912-24-9
Ametryn	s-triazine	2.6	200	834-12-8
Metribuzin	s-triazine	1.6	1050	21087-64-9
Simazine	s-triazine	2.1	6.2	122-34-9
Prometryn	s-triazine	3.1	33	7287-19-6
Bromacil	uracil	1.9	807	317-40-9
Hexazinone	triazinone	1.2	33,000	51235-04-2

SCIENTIFIC REPORTS

OPEN

Acute and additive toxicity of ten photosystem-II herbicides to seagrass

Received: 02 September 2015
Accepted: 29 October 2015

Adam D. Wilkinson[1,2], Catherine J. Collier[1,3], Florita Flores[2] & Andrew P. Negri[2]

Biological models to investigate pesticide toxicity
High interest working on marine bivalves

- **Bioindicators for marine pollution biomonitoring and key species for ecotoxicological studies :**
  - Sessil filter-feeders
  - External reproduction: exposed to waterborne contaminants during their all life cycle
  - Knowledge and control of their all life cycle (experimental hatcheries)
  - Sequenced genomes (Zhang et al., 2012, Murgarella et al., 2016)

- **Exploited marine species of socio-economical interests**
  - production area under high anthropic pressure
  - specific research questions on Aquaculture Environment interactions (bivalve mortality outbreaks)

Acute toxicity testing based on bioassays

In Phytoplankton

Next presentation of Valentin Dupraz

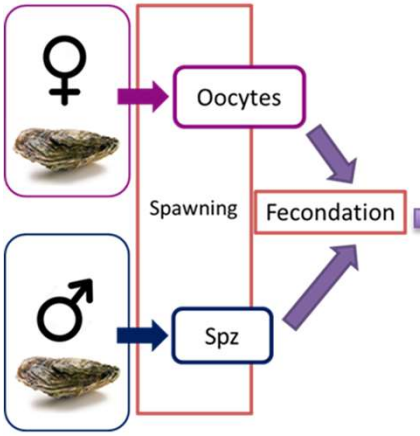
Ph.D at LEX

« Comment évaluer la toxicité des mélanges complexes de pesticides pour le phytoplancton marin ?: une approche combinant échantillonnage passif, bio-essais, modélisation et analyse non ciblée » ESTIVAL ROCCH, 18 novembre 2019.

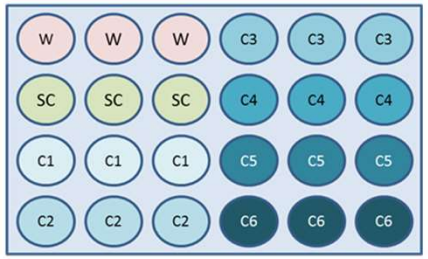
In the Pacific oyster

Use of the embryo-larval bioassay
for the screening of pesticide (embryo)toxicity in bivalves

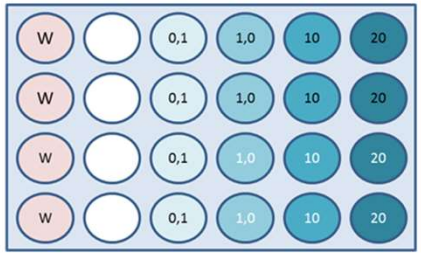
Use of the embryo-larval bioassay for the screening of pesticide (embryo)toxicity in bivalves



24-well microplate inocculation, 100 embryo/mL)

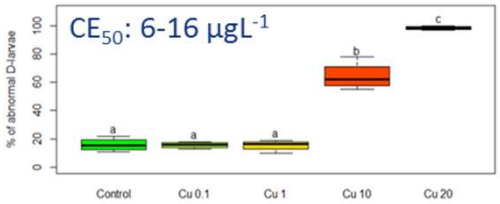


W: SW control, SC; solvant control, C1-6: tested [C]



W: SW control, [$CuSO_4$] μgL^{-1}

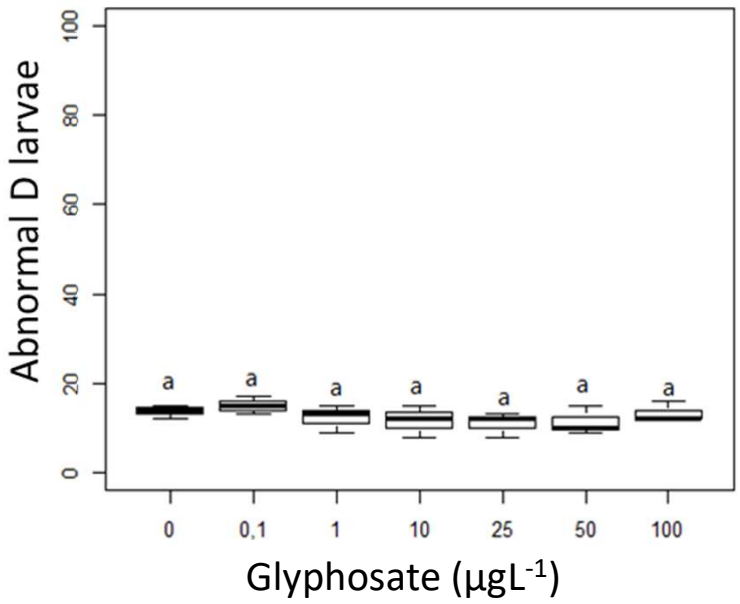
24h exposure, 24°C, dark → fixation (8% formol) → Microscopic observation (N = 400)

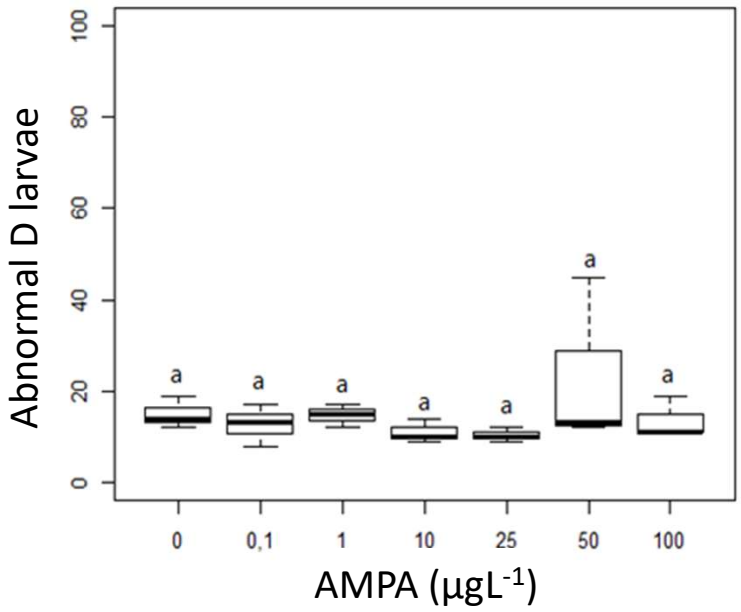


Developmental abnormalities

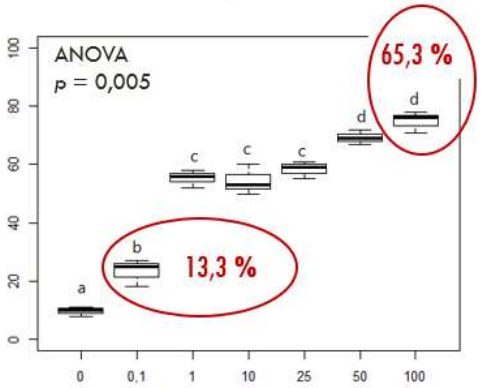
Normal D Larvae | Shell abnormality | Mantle abnormality | Arrested embryonic development

Herbicides	Insecticides	Fongicides
~~AMPA~~		
~~Diquat~~	Acrinathrine	
Diuron	Chlorpyrifos	Azoxystrobine
Flazasulfuron	~~Chlorpyrifos-méthyl~~	Krésoxim-méthyl
~~Glyphosate~~	~~Fipronil~~	~~Quinoxyfen~~
Isoproturon	~~Imidaclopride~~	Spiroxamine
Métazachlore	~~α-cyperméthrine~~	
S-métolachlore		

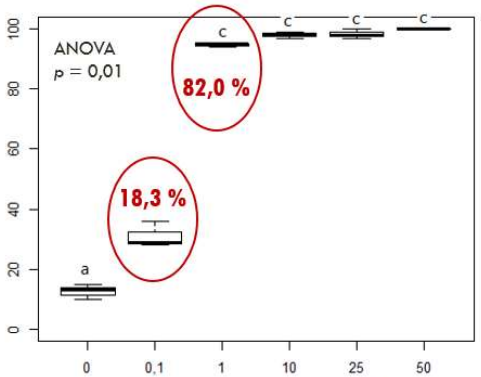




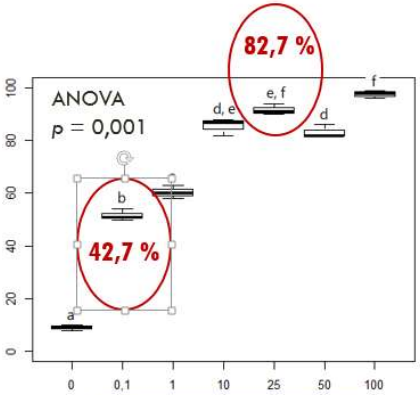
Herbicides	Insecticides	Fongicides
Diuron	Acrinathrine	Spiroxamine
Flazasulfuron	Chlorpyrifos	Azoxystrobine
Isoproturon		Krésoxim-méthyl
Métazachlore		
S-métolachlore		



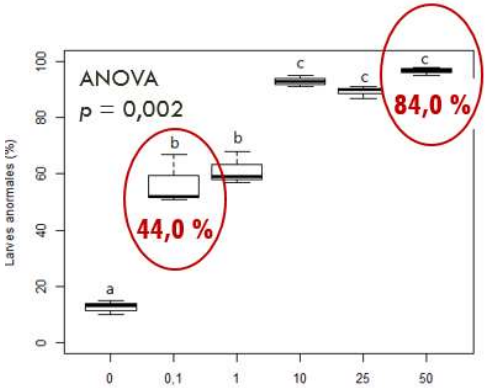
DIURON (µg.L-1)



ACRINATHRINE (µg.L-1)

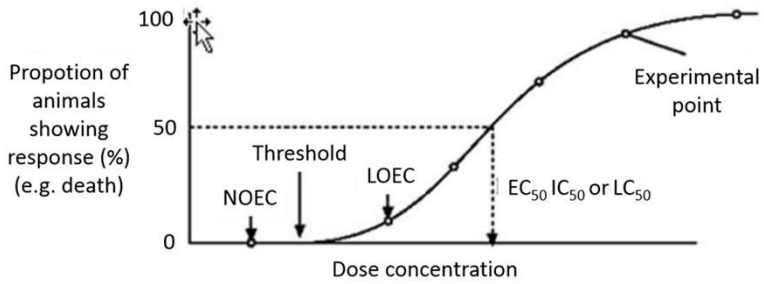


SPIROXAMINE (µg.L-1)



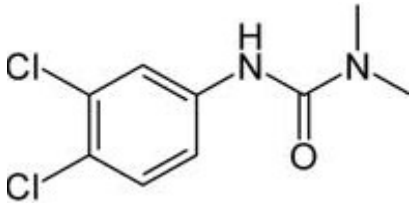
AZOXYSTROBINE (µg.L-1)

CE50 based on Weibull Model



Pesticides	Embryotoxicity	
	LOEC (µg.L-1)	CE50 (µg.L-1)
Azoxystrobine	0,10	0,11
Acrinathrine	0,10	0,21
Spiroxamine	0,10	0,31
Diuron	0,10	1,00
Kresoxim-méthyl	5,00	15,80
Métazachlore	0,10	29,30
S-métolachlore	10,00	-

Lieu/période d'échantillonnage	Concentration ($ng \cdot L^{-1}$)	Références
Europe		
Allemagne		
Mer Baltique (2009)	131[a]	Nödler et al. 2014
Espagne		
Mer Méditerrannée (1998-1999)	2000	Martínez et al. 2000
Grande Canarie (2008-2009)	2.3 - 203	Sánchez-Rodríguez et al. 2011
France		
Bretagne (2006)	115	Caquet et al. 2013
Mer Méditerrannée (2008)	33[a]	Munaron et al. 2012
Normandie (2006)	15 - 132	Buisson et al. 2008
Grèce		
Marinas de Kalamata/Patras et ports de Mytilene/Molyvos (2002)	30-560	Gatidou et al. 2005
Mer Egée et Dardanelles (Grèce et Turquie, 2010)	31[a]	Nödler et al. 2014
Italie		
Nord de la mer Adriatique (2010)	6.1[a]	Nödler et al. 2014
Venise (2010)	80[a]	Nödler et al. 2014
Nord de la mer Adriatique (Italie, 2011)	1.957[a]	Loos et al. 2013
Lagoon water (Italy)	42000	Gennaro et al. 1995
Golfe de Naples (2005-2006)	<1-1380	Di Landa et al. 2009
Golfe de Naples (2004)	6,2-475	Di Landa et al. 2006
Pays-Bas		
Marinas (2000)	90 - 1130	Lamoree et al. 2002
Royaume-Uni		
Marina (1998-1999)	10.5 - 768	Boxall et al. 2000
Port Shoreham/ Marina Brighton (2003-2004)	< 7 - 366	Gatidou et al. 2007
Estuaries/Southampton (1998)	4 - 6742	Thomas 2001
Asie		
Corée du Sud		
Baie Jinhae et ports (2009-2010)	13-1360	Kim et al. 2014
Israel		
Mer Méditerrannée (Israel, 2009 & 2011)	211[a]	Nödler et al. 2014
Japon		
Mer intérieure de Seto (2008-2009)	<10-62	Balakrishnan et al. 2012
Mer intérieure de Seto (2009)	30-3050	Okamura et al. 2003
Port d'Osaka (2002-2003)	<0.8–267	Harino et al. 2005
Récifs coralliens Okinawa (2007-2009)	0.06-90	Sheikh et al. 2009
Malaisie		
Malaisie (2011-2012)	285[a]	Ali et al. 2014



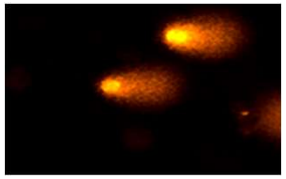
DIURON
Systemic substituted phenylurea herbicide

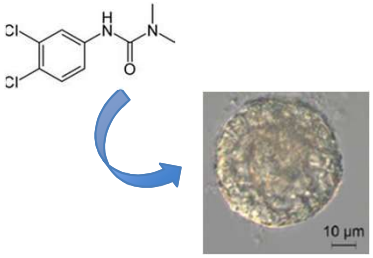
LOEC: 0,1 μgL^{-1}
EC_{50}: 1 μgL^{-1}

Risk for oyster recruitment

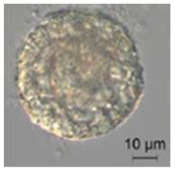
Which mechanisms involved in embryotoxicity ? e.g diuron

- Oyster is able to biotranform diuron at all development stage (Akcha et al., unpublished)
- The embryotoxic effects of diuron and its metabolites involved ROS production (Behrens et al., 2016):
  - Demonstration of diuron-induced ROS production by flow cytometry (H2DCF-DA)
  - Decreased embryotoxicity in presence of a ROS scavenger (ascorbic acid)
- Diuron is genotoxic in oyster (Akcha et al., 2012, Barranger et al., 2014)





ROS



Damaged DNA

Change in developmental gene expression and methylation pattern

Diuron (a)

DCPMU (b)

DCPU (c)

3, 4 DCA (d)

Aquatic Toxicology 175 (2016) 249–259

Contents lists available at ScienceDirect

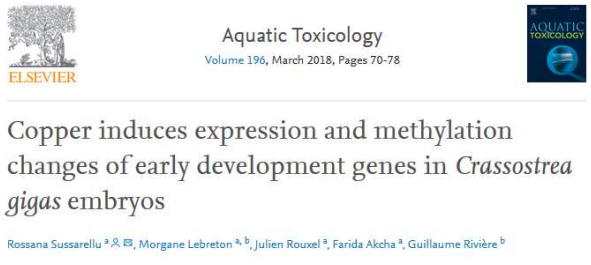
Aquatic Toxicology

journal homepage: www.elsevier.com/locate/aquatox

Comparative embryotoxicity and genotoxicity of the herbicide diuron and its metabolites in early life stages of *Crassostrea gigas*: Implication of reactive oxygen species production

Daphné Behrens, Julien Rouxel, Thierry Burgeot, Farida Akcha*

Ifremer, Laboratoire d'Ecotoxicologie, Rue de l'Ile d'Yeu, BP21105, 44311 Nantes, cedex 03, France


Aquatic Toxicology

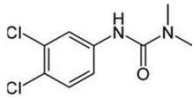
Volume 196, March 2018, Pages 70-78

Copper induces expression and methylation changes of early development genes in *Crassostrea gigas* embryos

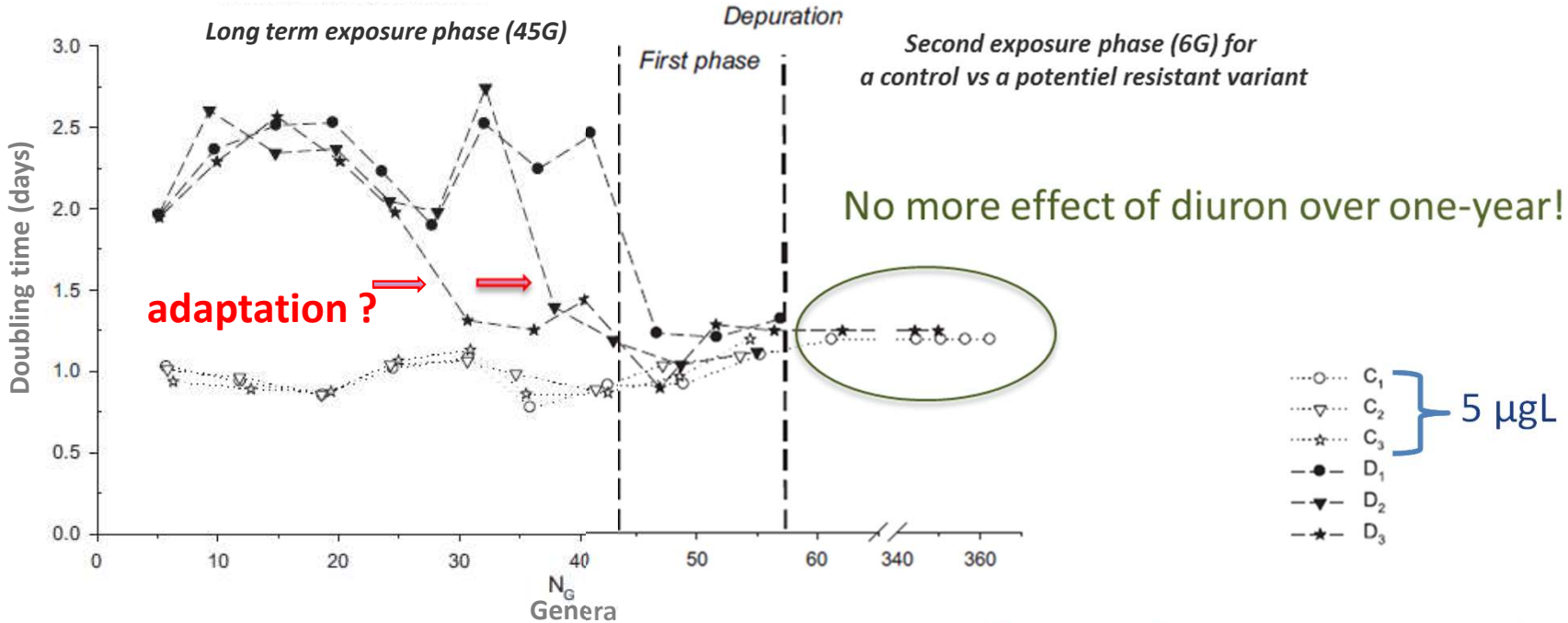
Rossana Sussarellu [a], Morgane Lebreton [a, b], Julien Rouxel [a], Farida Akcha [a], Guillaume Rivière [b]

Subchronic and multigenerational effects of pesticides

Axe 3: Long term effects of diuron exposure on the chlorophyta *Tetraselmis suecica*



- Exposure for 45 generations to 5 μgL^{-1} of diuron (EC50: 4.20 ± 0.12 μgL^{-1})
- During first 25 generations, diuron-exposed cultures have a lower growth (2-2,5 fold lower than the controls)
- After 25–32 generations, two culture replicates seem to adapt to diuron



ELSEVIER

Multigenerational exposure of the microalga *Tetraselmis suecica* to diuron leads to spontaneous long-term strain adaptation

Sabine Stachowski-Haberkorn[a], Marc Jérôme[b], Julien Rouxel[a], Célia Khelifi[a], Maéva Rincé[a], Thierry Burgeot[a]

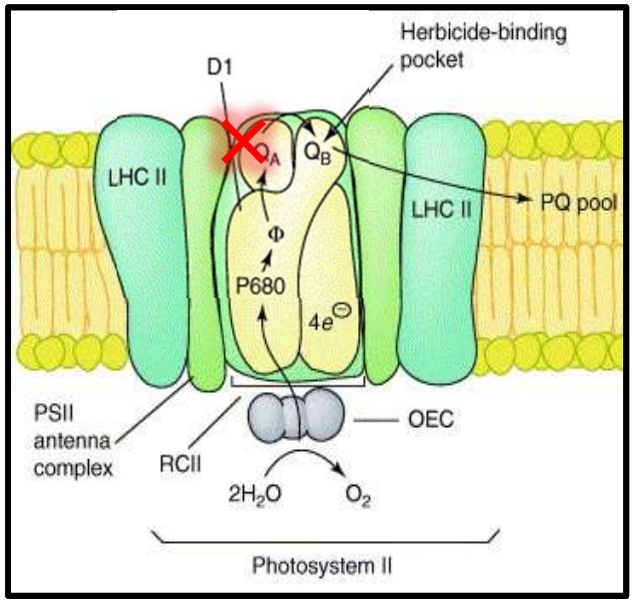
selection of a resistant variant ?

- A mutation found in the *psbA* gene coding sequence of the diuron-resistant strain
- The diuron-resistant strain is still sensitive to irgarol

PSII inhibitor binds on Q_B site on D_1 protein coded by psbA gene

→ Electron flux blockage

→ Photosynthesis inhibition



(Galloway and Mets 1984, Erickson et al., 1985, 1989)

ELSEVIER

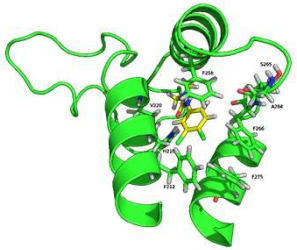
Chemosphere

Volume 151, May 2016, Pages 241-252

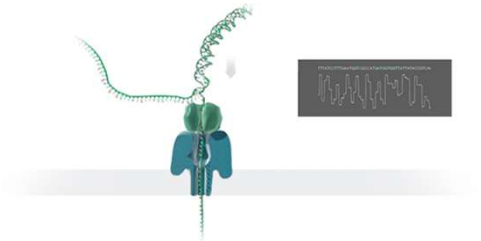
Microalgal sensitivity varies between a diuron-resistant strain and two wild strains when exposed to diuron and irgarol, alone and in mixtures

Valentin Dupraz [a, 1], Nathalie Coquillé [a, b, c, d, 1], Dominique Ménard [a], Rossana Sussarell
Larissa Haugarreau [a], Sabine Stachowski-Haberkorn [a]

Further investigations

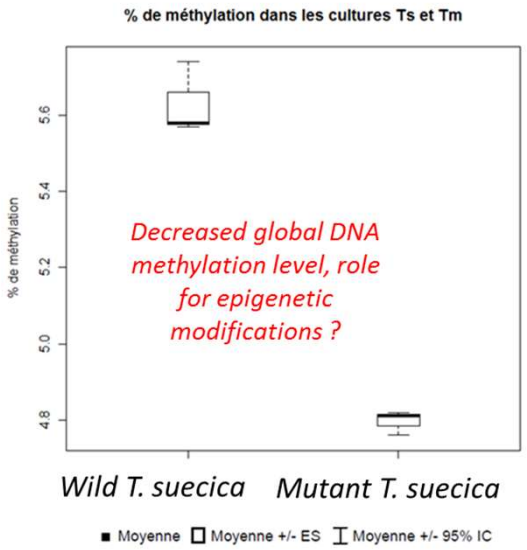


- Modelling protein/biocide interactions in the PSII at the atomic scale (CEISAM, University of Nantes)*



- Wild vs resistant: comparison of transcriptomic and physiological responses , genome comparison (Nanopore sequencing)*

- Epigenetic worth to be explored



**Projet Projet DS Intercentre EMIHP (2017-2018)*

Genotoxicity, IMmunotoxicity and rEprotoxicity of Pesticides in *Crassostrea gigas* (GIMEPEC 2012-2015)

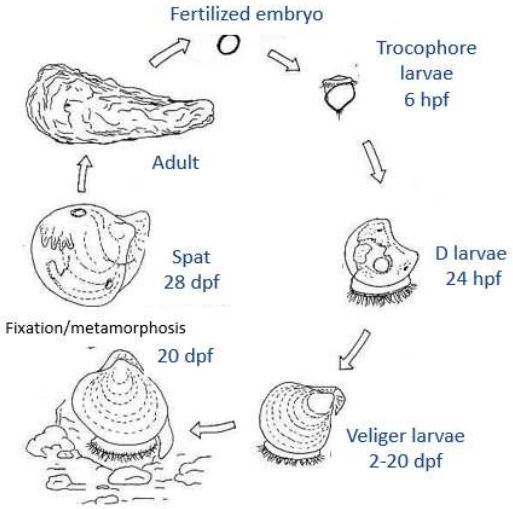
Lots of pesticides are genotoxic and carcinogens in human (Benedetti et al., 2014, Kaur and Kaur, 2018) but also in marine organisms (Akcha et al., 2012, Srivastava et al., 2016,)

Multigenerational effects of an environmentally realistic diuron exposure: a focus on genotoxicity

2a. Can DNA lesions be transmitted to the next generation ?

2b. Is the transmission of damaged DNA concomitantly observed with:

- functional genome alterations (epigenome and transcriptome) ?
- physiological impairment ?

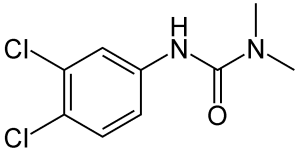


Genome structure (DNA damage) → **Genome expression** (change in transcriptome & epigenome) → **Physiological performances** (impact on development, growth, reproduction, survival..)

The herbicide diuron as a model substance

Biotransformed[1]

genotoxic, embryotoxic, immunotoxic..)[2]



ROS-mediated toxicity[3]

Quite persistent[4]

Frequently detected[5]

A priority substance (EU WFD)

(1) Is diuron genotoxic at environmental concentrations ?

(2) Can DNA lesions be transmitted to the next generation ?

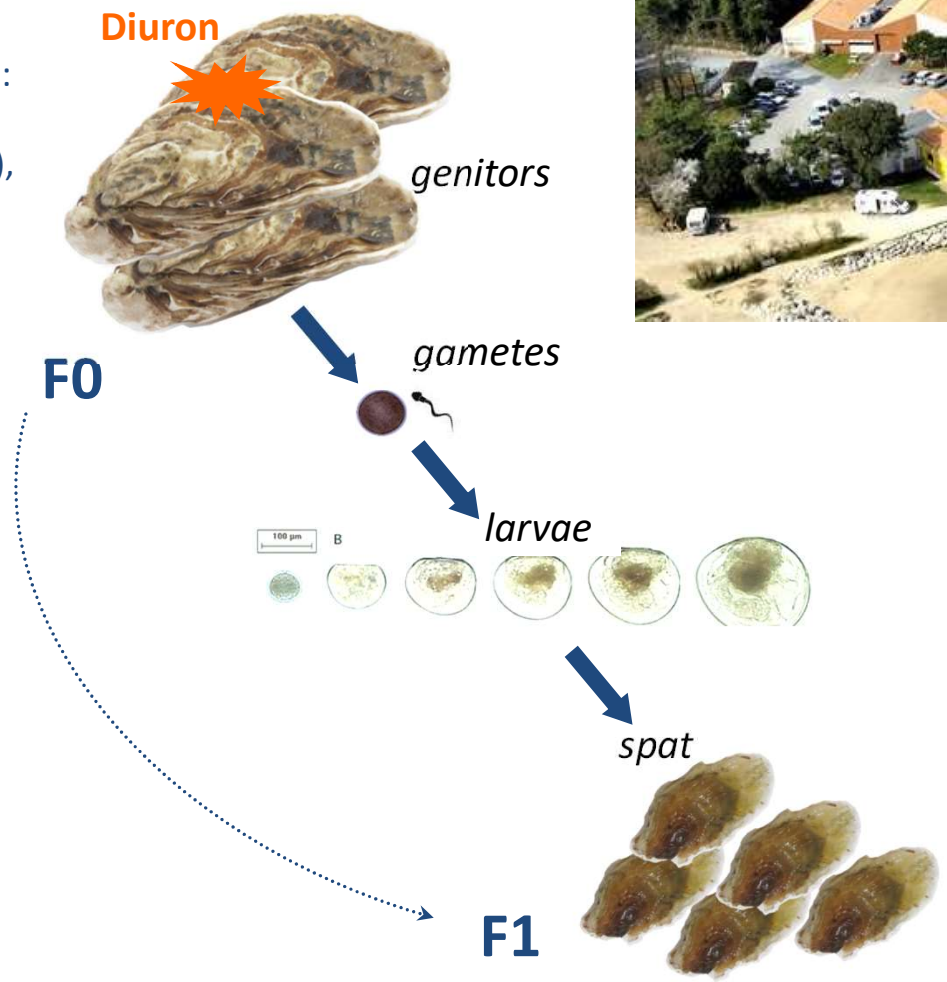
(3) Which consequences on genome expression and physiology of the offspring ?

[1]Behrens et al. (2016), 2 Akcha et al. (2012), Bouilly et al. (2007), [3]Behrens et al. (in prep), [4]Thomas et al. (2002),[5]Munaron et al. (2012)

Parental exposure to diuron (Barranger et al., 2014)

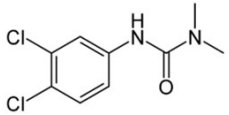
- Two 7 day-exposure pulses (*0.2-0.3 µgL^{-1}, POCIS), start and half course of gametogenesis
- 3 groups (720 ind/group):
  - SWC
  - SC (0.005% acetonitrile),
  - D

*0.02-0.20 µgL^{-1} (Sánchez-Rodríguez *et al.*, 2011), 0.16 µgL^{-1} (Caquet et al., 2013), 1.9 µgL^{-1} (Loos et al., 2013)



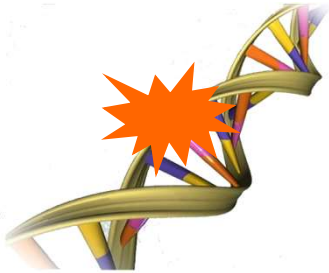
Vertical transmission of diuron-induced DNA damages in oyster: Which impact on physiological performances ?

ANR CESA 2011



2 pulses of 7 day-exposure to diuron (0.2-0.3 µgL^{-1})

Oyster genitors in gametogenesis



DNA damage
- somatic cells
- germ cells
- reproductive cells

Contents lists available at ScienceDirect
Comparative Biochemistry and Physiology, Part C
journal homepage: www.elsevier.com/locate/cbpc

Parental exposure to the herbicide diuron results in oxidative DNA damage to germinal cells of the Pacific oyster *Crassostrea gigas*

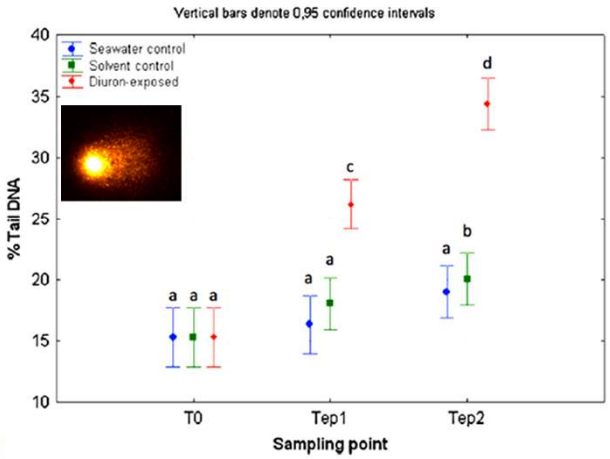
Audrey Barranger [a,b,*], Clothilde Heude-Berthelin [c], Julien Rouxel [a], Béatrice Adeline [c], Abdellah Benabdelmouna [b], Thierry Burgeot [a], Farida Akcha [a,**]

Contents lists available at ScienceDirect
Aquatic Toxicology
journal homepage: www.elsevier.com/locate/aquatox

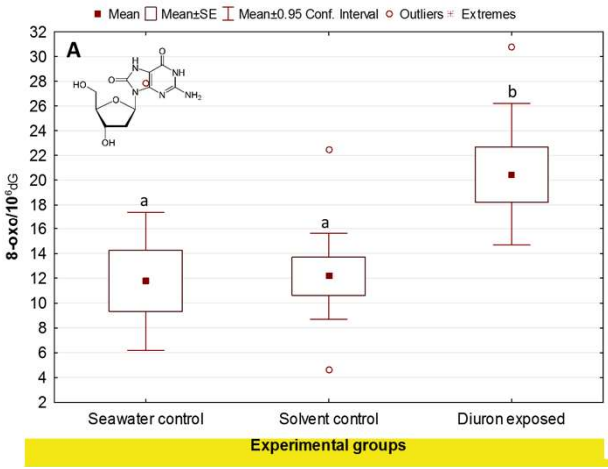
Study of genetic damage in the Japanese oyster induced by an environmentally-relevant exposure to diuron: Evidence of vertical transmission of DNA damage

A. Barranger [a,b], F. Akcha [b,*], J. Rouxel [b], R. Brizard [a], E. Maurouard [a], M. Pallud [b], D. Menard [b], N. Tapie [c], H. Budzinski [c], T. Burgeot [b], A. Benabdelmouna [a]

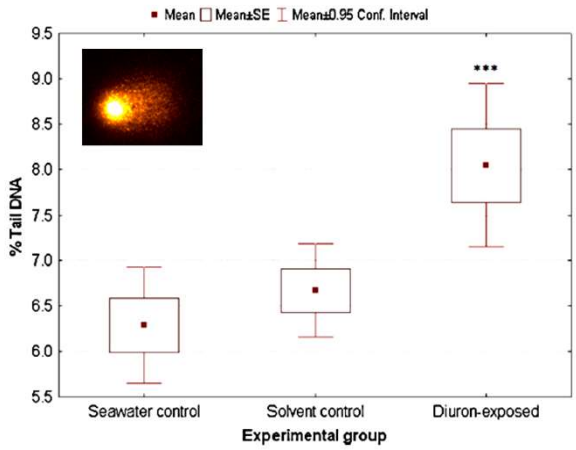
Erythrocytes



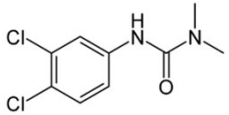
Gonads



Spermatozoides



Vertical transmission of diuron-induced DNA damages in oyster: Which impact on physiological performances ?



2 pulses of 7 day-exposure to diuron (0.2-0.3 µgL^{-1})

DNA damage
- somatic cells
- germ cells
- reproductive cells

Oyster genitors in gametogenesis

Contents lists available at ScienceDirect

Aquatic Toxicology

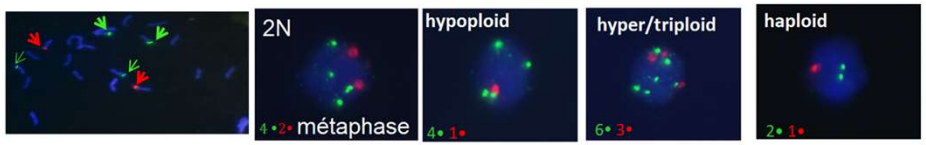
journal homepage: www.elsevier.com/locate/aquatox

Parental exposure to environmental concentrations of diuron leads to aneuploidy in embryos of the Pacific oyster, as evidenced by fluorescent in situ hybridization

Audrey Barranger[a,b,*], Abdellah Benabdelmouna[a,*], Lionel Dégremont[a], Thierry Burgeot[b], Farida Akcha[b]

Larvae

I-FISH analysis



Ploidy level	SWC	SC	Diuron
Aneuploid	7.92 %	9.69 %	**22.20 %**
Hypoploid	6.64 %	5.76 %	**17.82 %**
Hyperploid	1.28 %	3.93 %	**4.38 %**

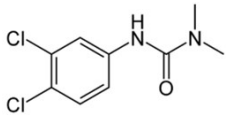
Chr 4, 5, 10 concern by chromosome lost or break

Spat

Chromosome damage
- chromosome breaks, gain or loss of chromosomes (chr 4, 5 and 10)

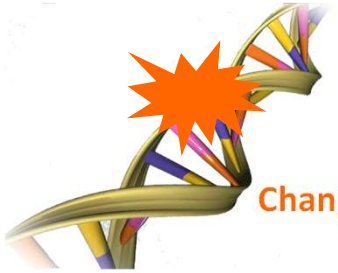
Vertical transmission of diuron-induced DNA damages in oyster: Which impact on physiological performances ?

ANR CESA 2011



2 pulses of 7 day-exposure to diuron (0.2-0.3 µgL^{-1})

Oyster genitors in gametogenesis



DNA damage
- somatic cells
- germ cells
- reproductive cells

Change in DNA methylation (tissue, sperm)
- DNMT gene expression
- DNA methylation level

Larvae

Spat

Chromosome damage
- chromosome breaks, gain or loss of chromosomes (chr 4, 5 and 10)

Change in methylome

ENVIRONMENTAL EPIGENETICS

Environmental Epigenetics, 2017, 1–13

doi: 10.1093/eep/dvx004
Research article

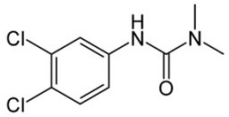
RESEARCH ARTICLE

Effects of a parental exposure to diuron on Pacific oyster spat methylome

Rodolfo Rondon[1,2], Christoph Grunau[2], Manon Fallet[2], Nicolas Charlemagne[3], Rossana Sussarellu[3], Cristian Chaparro[2], Caroline Montagnani[1], Guillaume Mitta[2], Evelyne Bachère[1], Farida Akcha[3] and Céline Cosseau[2,*]

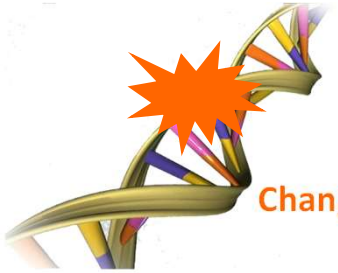
TRANSMISSION TO THE NEXT GENERATION OF MODIFIED GENETIC MATERIAL
(genotoxicity tests, CMF, FISH, comet-FISH, HPLC, BS-Seq)

Vertical transmission of diuron-induced DNA damages in oyster: Which impact on physiological performances ?



2 pulses of 7 day-exposure to diuron (0.2-0.3 µgL^{-1})

Oyster genitors in gametogenesis



DNA damage
- somatic cells
- germ cells
- reproductive cells

Change in DNA methylation (tissue, sperm)
- DNMT gene expression
- DNA methylation level

Larvae

Spat

Chromosome damage
- chromosome breaks, gain or loss of chromosomes (chr 4, 5 and 10)

Change in methylome

Contents lists available at ScienceDirect

Aquatic Toxicology

journal homepage: www.elsevier.com/locate/aquatox

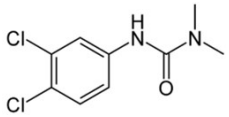
Transcriptional changes in *Crassostrea gigas* oyster spat following a parental exposure to the herbicide diuron

R. Rondon[a,b], F. Akcha[c], P. Alonso[d], D. Menard[c], J. Rouxel[c], C. Montagnani[a,*], G. Mitta[b], C. Cosseau[b], C. Grunau[b]

CHANGE ON OFFSPRING TRANSCRIPTOME

TRANSMISSION TO THE NEXT GENERATION OF MODIFIED GENETIC MATERIAL
(genotoxicity tests, CMF, FISH, comet-FISH, HPLC, BS-Seq)

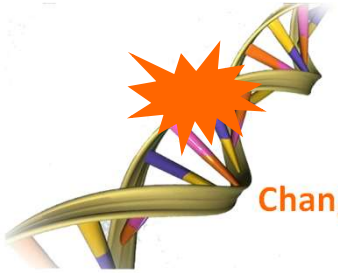
Vertical transmission of diuron-induced DNA damages in oyster: Which impact on physiological performances ?



2 pulses of 7 day-exposure to diuron (0.2-0.3 µgL^{-1})

DNA damage
- somatic cells
- germ cells
- reproductive cells

Decrease in weight ← Oyster genitors in gametogenesis



Change in DNA methylation (tissue, sperm)
- DNMT gene expression
- DNA methylation level

Larvae →
- Developmental abnormalities
- Decrease in hatching rate
- Delayed metamorphosis
- Reduced growth

Chromosome damage
- chromosome breaks, gain or loss of chromosomes (chr 4, 5 and 10)

Change in methylome

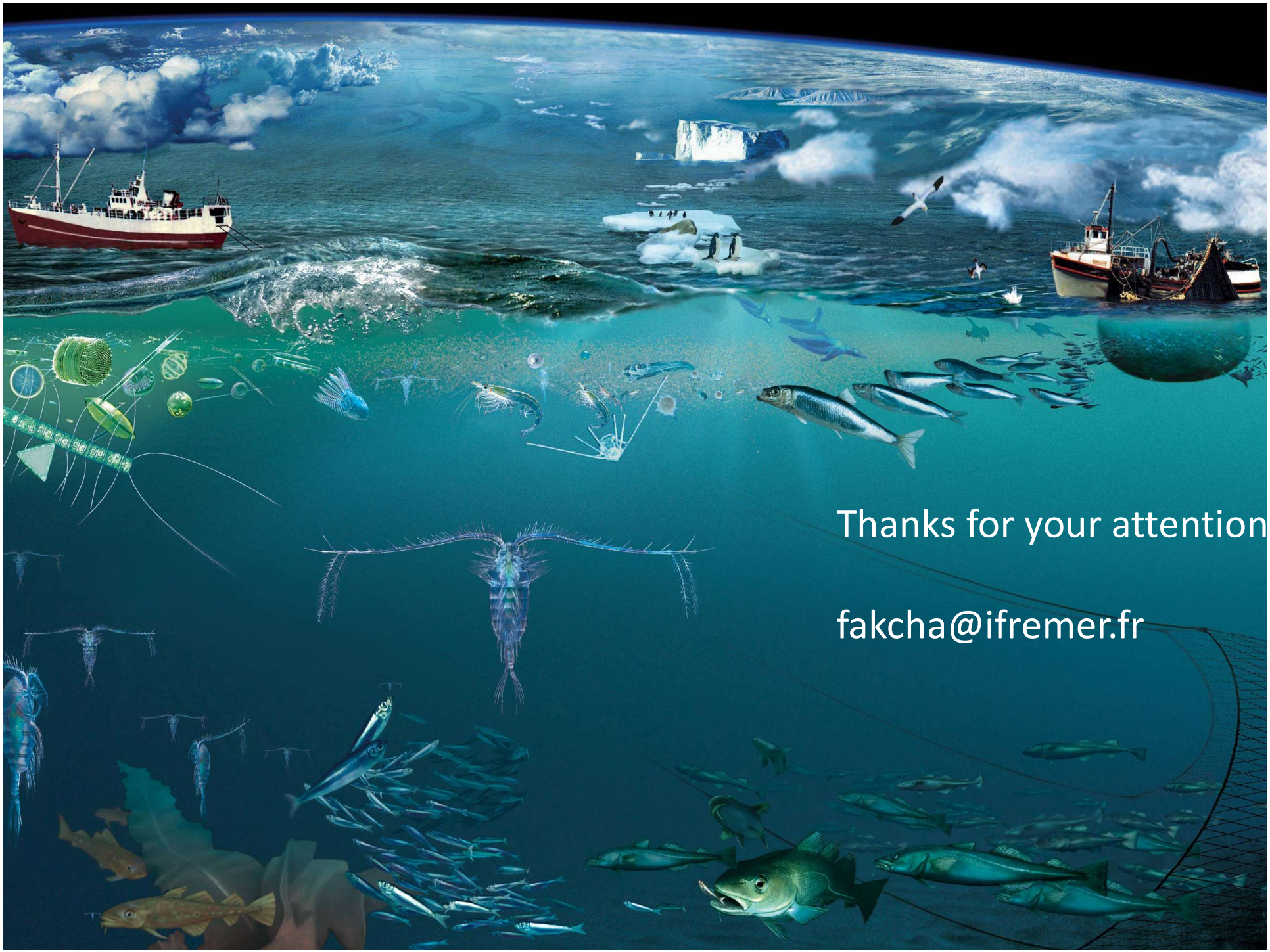
Spat →
- Reduced growth (reversible)
- Difference in survival to field mortality

NEGATIF IMPACT ON OFFSPRING FITNESS ← ? CHANGE ON OFFSPRING TRANSCRIPTOME ← ? TRANSMISSION TO THE NEXT GENERATION OF MODIFIED GENETIC MATERIAL (genotoxicity tests, CMF, FISH, comet-FISH, HPLC, BS-Seq)

Conclusions

- Environmental concentrations of pesticides can be toxic for microalgae and marine bivalves
- Effects can be observed following direct and indirect exposure (e.g parental exposure)
- Pesticides can have genetic and epigenetic effects (adaptation to chemical stress)
- Effects can be multi- and trans-generational

Pesticides can
disturb primary production
Impact marine bivalve recruitment
Impact biodiversity (adaptative responses)



Thanks for your attention

fakcha@ifremer.fr