SAÉ 54 · START UP'

LACSENS

Voir les antibiotiques dans l'eau.

Remonter jusqu'à la source.



Houssam Chait

L3 Sciences de la Vie, parcours BGB · Université de Toulon

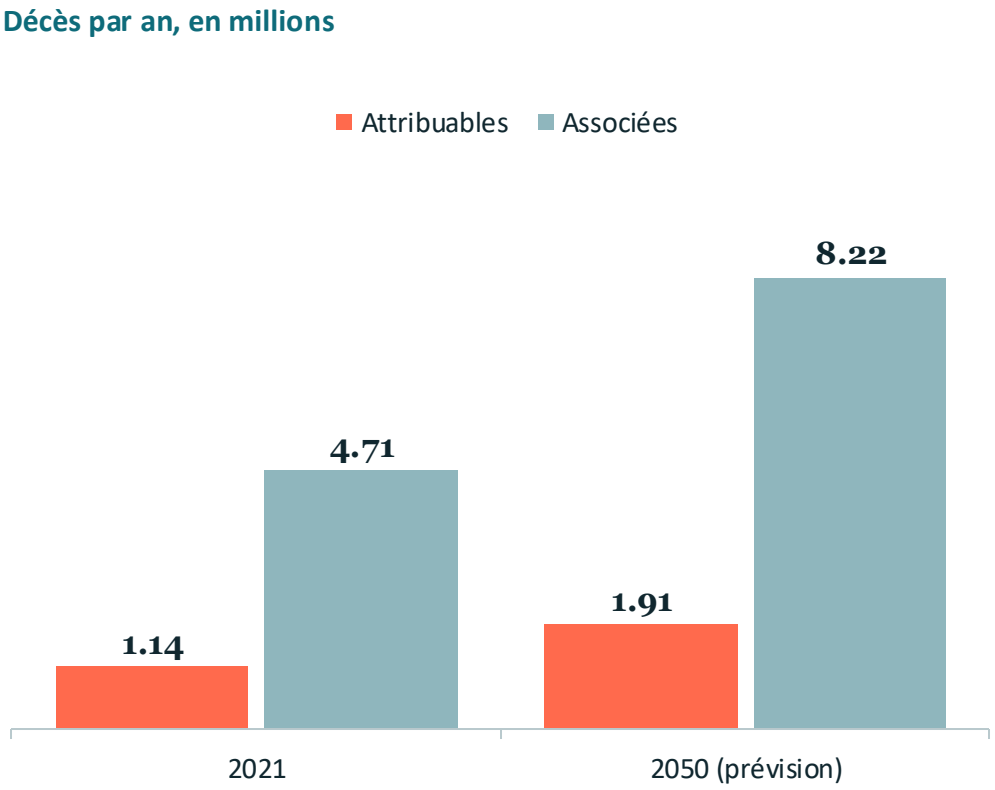
Une menace sanitaire mondiale

39,1

millions de morts

attribuables à la résistance aux antibiotiques, cumulées de 2025 à 2050. En moyenne, près de 3 morts par minute.

Et ça se joue aussi dans l'eau.



Attribuables : décès évités si les infections résistantes devenaient sensibles. Associées : si elles n'existaient pas.

THE LANCET · 2024 · GBD 2021 Antimicrobial Resistance Collaborators · doi:10.1016/S0140-6736(24)01867-1

D'où vient la résistance

Rejets

Hôpitaux, élevages, industries, stations d'épuration

Rivières

Des antibiotiques à très faible dose, en continu

Bactéries

Exposées sans être tuées, elles s'adaptent

Nous

Les résistances finissent par revenir jusqu'à l'humain

Pas besoin de tuer une bactérie pour la rendre résistante : une petite dose suffit.

Gullberg et al.
PLoS Pathogens, 2011

Un capteur de terrain, à bas coût

AUJOURD'HUI

On mesure trop peu pour agir

- ✕ Échantillon envoyé au laboratoire
- ✕ Chromatographie + spectrométrie de masse
- ✕ Matériel coûteux, personnel spécialisé
- ✕ Résultat différé, peu de points mesurés

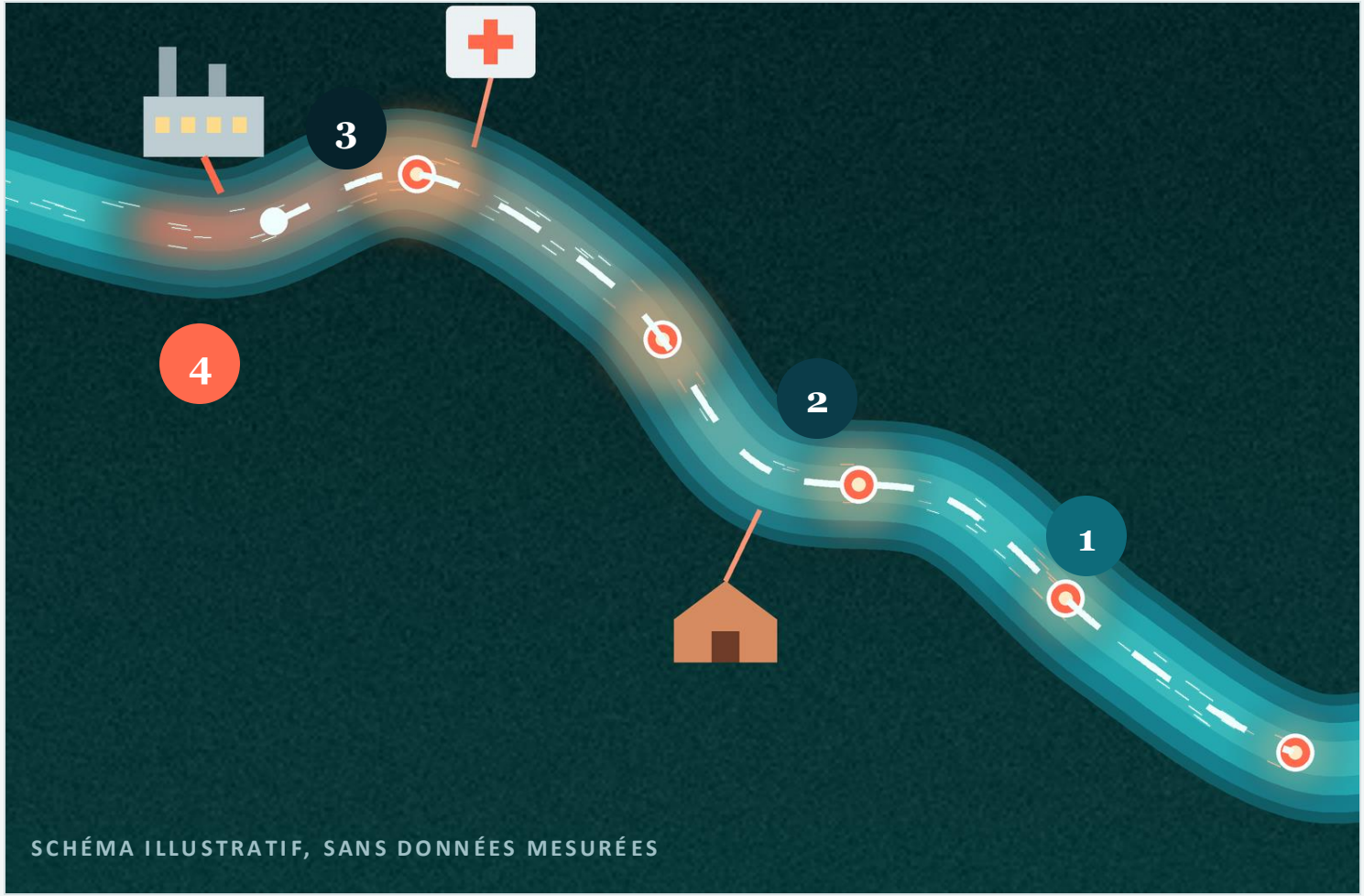
AVEC LACSENS

Mesurer sur place, partout

- ✓ Mesure directement sur le terrain
- ✓ Aucune batterie : le capteur s'alimente seul
- ✓ Bas coût, facile à multiplier
- ✓ Assez de points pour remonter jusqu'au rejet

LACSENS dépiste. L'analyse officielle en laboratoire confirme.

Détecter ne suffit pas : LACSENS sert à agir



1 — Détecter
Le capteur réagit dans l'eau

2 — Localiser
On remonte le cours d'eau jusqu'au rejet

3 — Alerter
On prévient les autorités et le site

4 — Réguler
Le traitement est corrigé à la source

Mon rôle de chef de projet

Houssam Chait

Chef de projet et responsable scientifique

- BTS Biotechnologies
- Stages en biologie moléculaire au CNRS
- Laccase manipulée en stage
- L3 Sciences de la Vie, parcours BGB

Mes missions

Stratégie scientifique

Je pilote la stratégie scientifique du projet

Coordination

Je coordonne l'équipe : décisions à l'unanimité

Budget et financements

Je gère le budget et je cherche les financements

Partenaires

Je porte le projet auprès des partenaires

Pour aller plus loin, j'ai besoin de trois profils.

On recrute : trois postes

01

Ingénieur(e) d'études en électrochimie

Tu fabriques les électrodes et tu fais parler le capteur : assemblage, mesures, seuil de détection.

ÉLECTROCHIMIE

02

Ingénieur(e) d'études en biologie moléculaire

Tu produis l'enzyme et tu la modifies pour qu'elle s'accroche dans le bon sens sur l'électrode. C'est le cœur technique du projet.

BIOLOGIE MOLÉCULAIRE

03

Chargé(e) relations entreprises et réglementation

Tu fais le lien avec les industriels et les autorités : accès aux sites, cadre légal, plan d'action. Tu transformes une mesure en action.

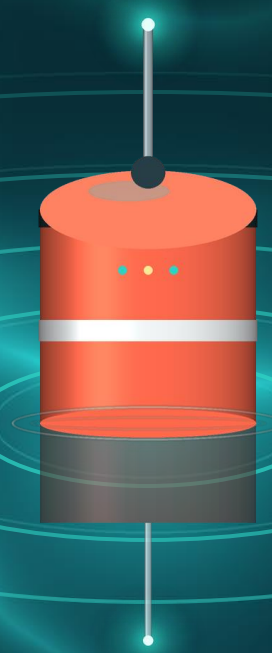
RÉGLEMENTATION

Prise de poste : 1er mars 2027

CDD 18 mois

Université de Toulon · campus de La Garde

Mesurer aujourd'hui pour freiner la résistance demain.



Rejoins LACSENS · postes 01 · 02 · 03

Houssam Chait

houssam.chait.etudiant@gmail.com

ANNEXE

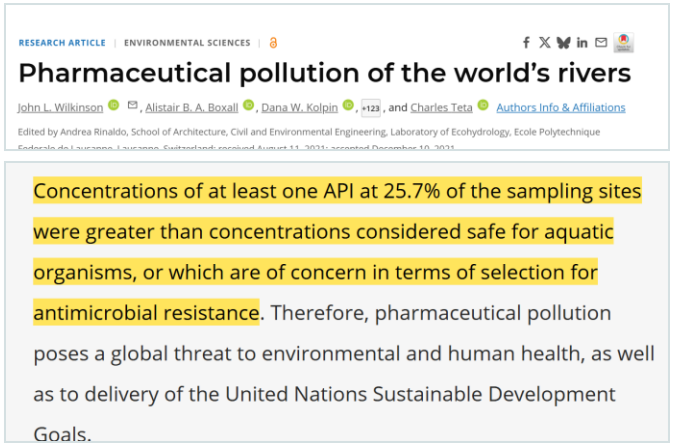
Résultats, preuves et questions du jury

Cette partie n'est pas présentée à l'oral. Elle contient les résultats chiffrés des articles, les captures qui prouvent chaque chiffre, les réponses aux questions du jury et les références.

Ce n'est pas une hypothèse

25,7 %

des 1 052 sites étudiés (258 rivières, 104 pays) dépassent un seuil de sécurité pour au moins un médicament.



RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES

Pharmaceutical pollution of the world's rivers

John L. Wilkinson, Alistair B. A. Boxall, Dana W. Kolpin, +123, and Charles Teta Authors Info & Affiliations

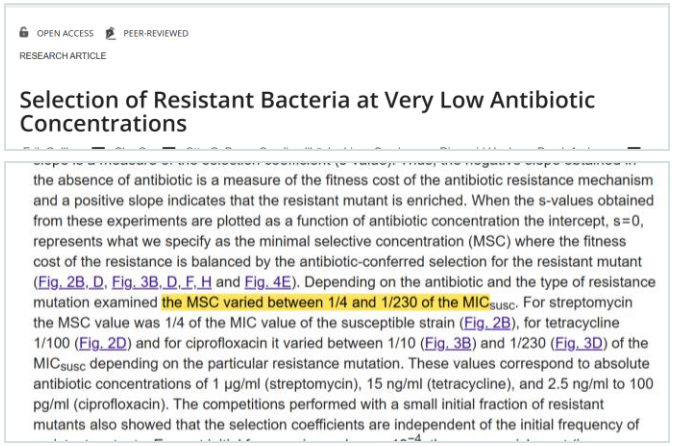
Edited by Andrea Rinaldo, School of Architecture, Civil and Environmental Engineering, Laboratory of Ecohydrology, Ecole Polytechnique

Concentrations of at least one API at 25.7% of the sampling sites were greater than concentrations considered safe for aquatic organisms, or which are of concern in terms of selection for antimicrobial resistance. Therefore, pharmaceutical pollution poses a global threat to environmental and human health, as well as to delivery of the United Nations Sustainable Development Goals.

PNAS · 2022 · Wilkinson et al.

1/230

Jusqu'à 230 fois moins que la dose qui bloque la bactérie : cela suffit à sélectionner des résistantes (ciprofloxacine).



OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

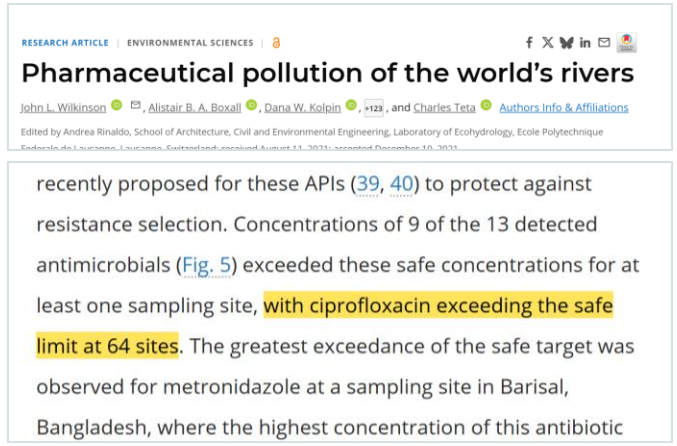
Selection of Resistant Bacteria at Very Low Antibiotic Concentrations

the absence of antibiotic is a measure of the fitness cost of the antibiotic resistance mechanism and a positive slope indicates that the resistant mutant is enriched. When the s-values obtained from these experiments are plotted as a function of antibiotic concentration the intercept, s=0, represents what we specify as the minimal selective concentration (MSC) where the fitness cost of the resistance is balanced by the antibiotic-conferred selection for the resistant mutant (Fig. 2B, D, Fig. 3B, D, F, H and Fig. 4E). Depending on the antibiotic and the type of resistance mutation examined the MSC varied between 1/4 and 1/230 of the MIC_{susc}. For streptomycin the MSC value was 1/4 of the MIC value of the susceptible strain (Fig. 2B), for tetracycline 1/100 (Fig. 2D) and for ciprofloxacin it varied between 1/10 (Fig. 3B) and 1/230 (Fig. 3D) of the MIC_{susc} depending on the particular resistance mutation. These values correspond to absolute antibiotic concentrations of 1 μg/ml (streptomycin), 15 ng/ml (tetracycline), and 2.5 ng/ml to 100 pg/ml (ciprofloxacin). The competitions performed with a small initial fraction of resistant mutants also showed that the selection coefficients are independent of the initial frequency of

PLoS Pathogens · 2011 · Gullberg et al.

64 sites

où la ciprofloxacine dépasse le seuil de sélection de résistance (seuil proposé : 64 ng/L).



RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES

Pharmaceutical pollution of the world's rivers

John L. Wilkinson, Alistair B. A. Boxall, Dana W. Kolpin, +123, and Charles Teta Authors Info & Affiliations

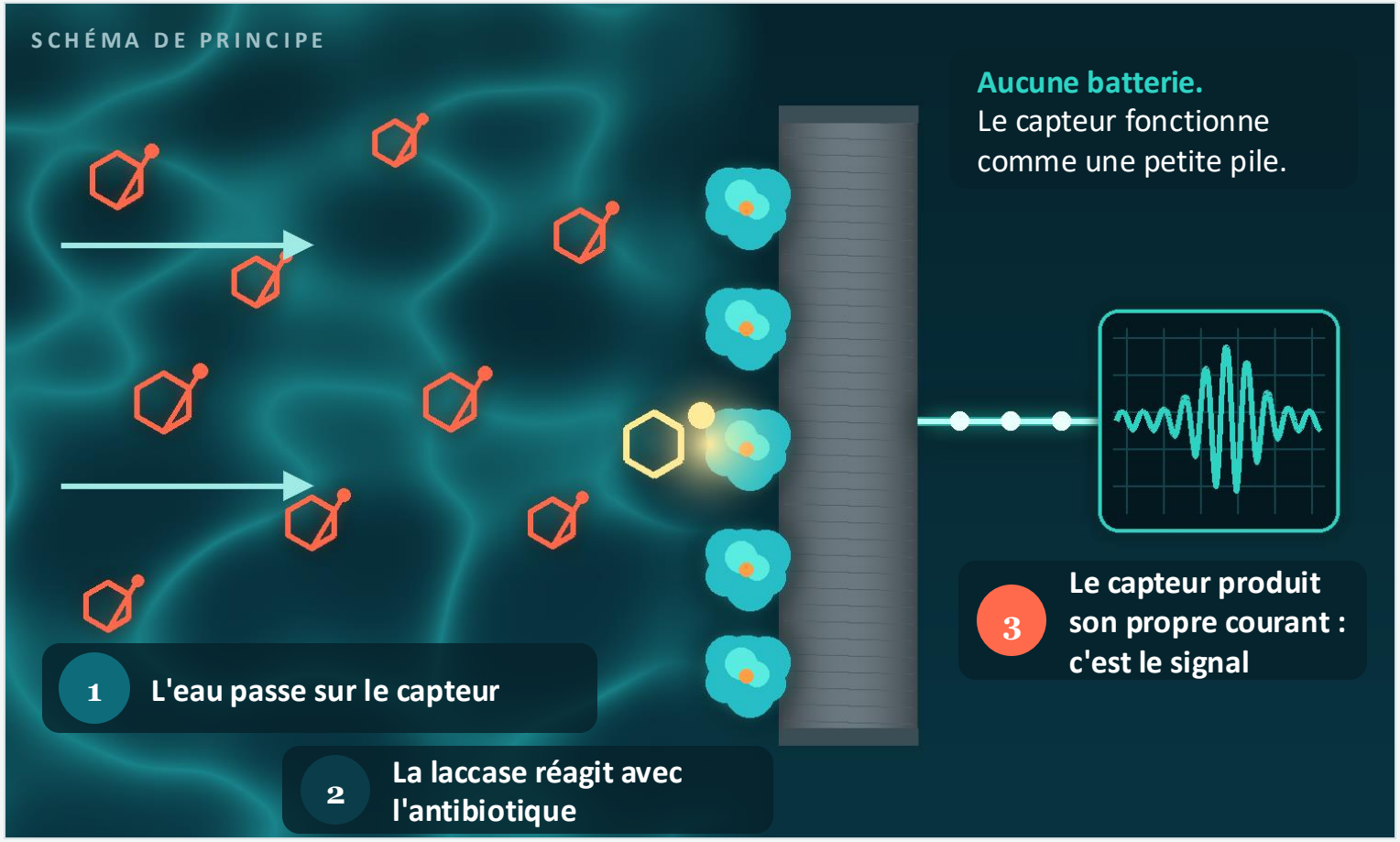
Edited by Andrea Rinaldo, School of Architecture, Civil and Environmental Engineering, Laboratory of Ecohydrology, Ecole Polytechnique

recently proposed for these APIs (39, 40) to protect against resistance selection. Concentrations of 9 of the 13 detected antimicrobials (Fig. 5) exceeded these safe concentrations for at least one sampling site, with ciprofloxacin exceeding the safe limit at 64 sites. The greatest exceedance of the safe target was observed for metronidazole at a sampling site in Barisal, Bangladesh, where the highest concentration of this antibiotic

PNAS · 2022 · seuil : Bengtsson-Palme & Larsson 2016

Transformer une enzyme en capteur

L'enzyme qui détruit l'antibiotique devient le capteur.



Réaction déjà prouvée

transformation and degradation of these antibiotic compounds are being sought. Herein, we review the impact of sustainable fungal laccase-based bioremediation strategies. Fungal laccase enzyme is considered one of the most active enzymes for biotransformation and biodegradation of antibiotic residue in vitro. For industrial applications, the low laccase yields in natural and genetically modified hosts may constitute a bottleneck. Methods to screen for high-laccase-producing sources, optimizing cultivation conditions, and identifying key genes and metabolites involved in extracellular laccase activity are reviewed. These include advanced transcriptomics, proteomics, and metagenomics technologies, as well as diverse laccase-immobilization

Biomolecules · 2025 · Ezra, Vanti & Masaphy

Cathode à laccase stable

rational attachment of a blue copper oxidase to a graphite surface.

Attachment of substrate-like anthracene based units to the surface of pyrolytic graphite greatly enhances the adsorption of high-potential fungal laccases, 'blue' Cu enzymes that catalyse the four-electron reduction of O(2), providing a stable cathode for enzymatic biological fuel cells and electrochemical studies.

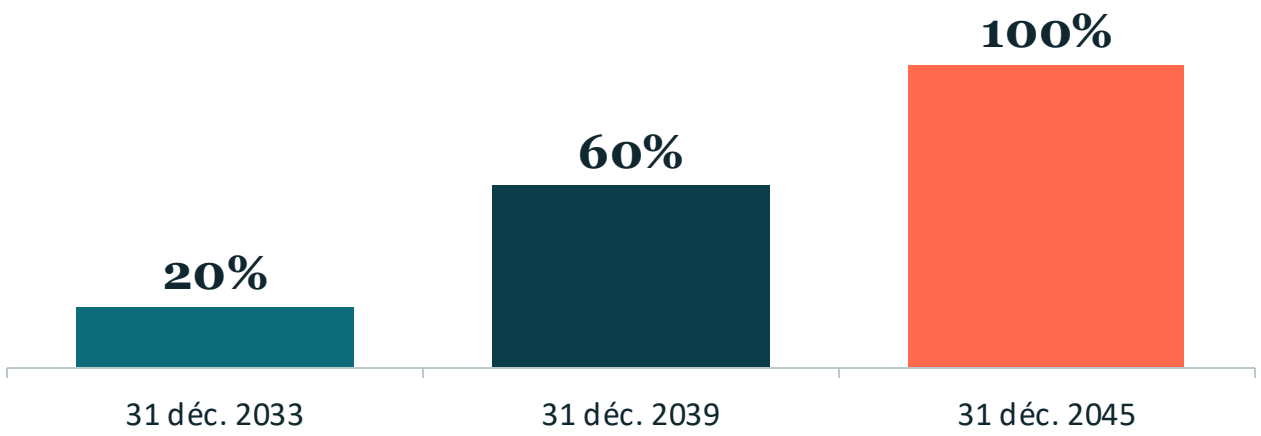
Published

Email Share Cite Print

Chem. Commun. · 2007 · Blanford, Heath & Armstrong

L'Europe impose de traiter les micropolluants

Grandes stations d'épuration (150 000 éq.-hab. et plus) soumises au traitement des micropolluants, article 8



≥ 80 %

des coûts payés par les producteurs de médicaments et cosmétiques (avant fin 2028)

100 000

éq.-hab. et plus : suivi de la résistance aux antibiotiques dans les eaux usées

2026

méthode harmonisée de mesure de la résistance, fixée par la Commission (juillet)

Quaternary treatment

. Member States shall ensure that discharges from urban wastewater treatment plants treating urban wastewater with a load of 50 000 p.e. and above satisfy, before being discharged into receiving waters, the relevant requirements of quaternary treatment set ut in Part B and Table 3 of Annex I in accordance with the methods of monitoring and evaluation of results laid down in Part C of nnex I by:

) 31 December 2033 for discharges from 20 % of those urban wastewater treatment plants;

) 31 December 2039 for discharges from 60 % of those urban wastewater treatment plants;

) 31 December 2045 for all discharges from those urban wastewater treatment plants.

he maximum permitted number of samples which fail to conform to the parametric values of Table 3 of Annex I is set out in Part and Table 4 of Annex I.

Extended producer responsibility

. Member States shall take measures to ensure that by 31 December 2028, producers who place any of the products listed in nnex III on the market have extended producer responsibility.

uch measures shall ensure that those producers cover:

) at least 80 % of the full costs for complying with the requirements set out in Article 8, including the investment and operational costs for the quaternary treatment of urban wastewater to remove micropollutants resulting from the products they place on the market and from the residues of those products, and for the monitoring of micropollutants referred to in Article 21(1), point (a);

) the costs for gathering and verifying data on products placed on the market; and

) other costs required to exercise their extended producer responsibility.

by that competent authority.

To determine whether there is a public health emergency, the competent authority shall consider Commission decisions adopted pursuant to Article 23(1) of Regulation (EU) 2022/2371, assessments of the ECDC, and decisions of the WHO taken in accordance with the International Health Regulations.

3. For agglomerations of 100 000 p.e. and above, Member States shall, by the last day of the second year from the date of adoption of the implementing act in the second subparagraph, ensure that antimicrobial resistance is monitored in urban wastewater.

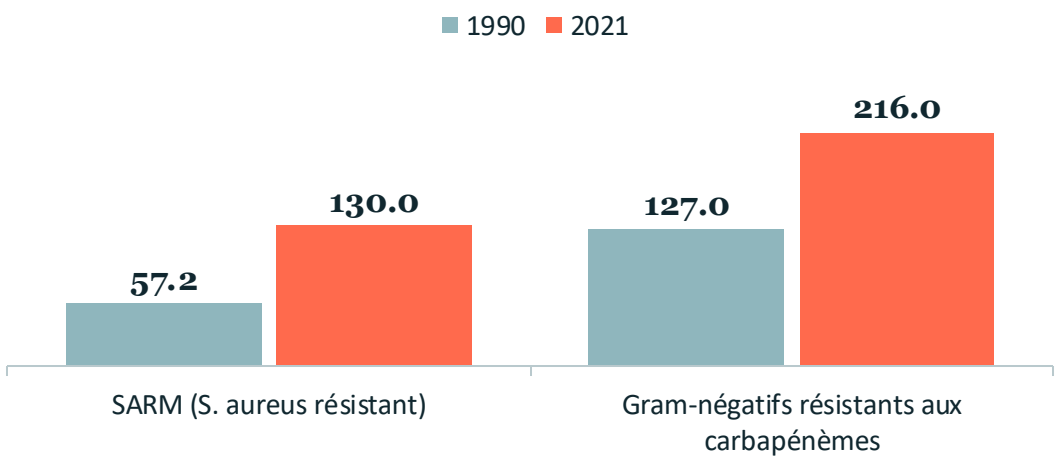
By 2 July 2026, the Commission shall adopt implementing acts in order to establish a minimum frequency of sampling and a harmonised methodology for measuring antimicrobial resistance in urban wastewater, taking into account at least all available data from national public health authorities and national authorities responsible for monitoring antimicrobial resistance. Those implementing acts shall be adopted in accordance with the examination procedure referred to in Article 28(2).

4. Results from the monitoring referred to in this Article shall be reported in accordance with Article 22(1), point (h).

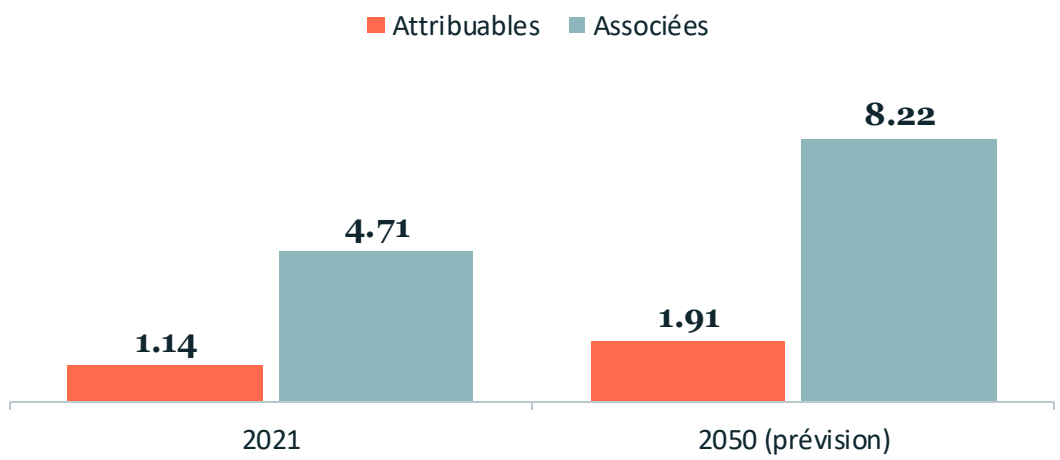
Directive (UE) 2024/3019 · EUR-Lex
articles 8 (échéances), 9 (80 %) et 17 (résistance)

Les chiffres de la résistance

Décès attribuables par an, en milliers



Décès par an, en millions



Indicateur	Valeur	Intervalle d'incertitude à 95 %
Décès attribuables, 2021	1,14 million	1,00 à 1,28
Décès associés, 2021	4,71 millions	4,23 à 5,19
Décès attribuables, 2050 (prévision)	1,91 million	1,56 à 2,26
Décès associés, 2050 (prévision)	8,22 millions	6,85 à 9,65
Décès attribuables cumulés, 2025-2050	**39,1 millions**	**33,0 à 46,0**
Décès évitables avec de meilleurs soins, 2025-2050	92,0 millions	82,8 à 102,0

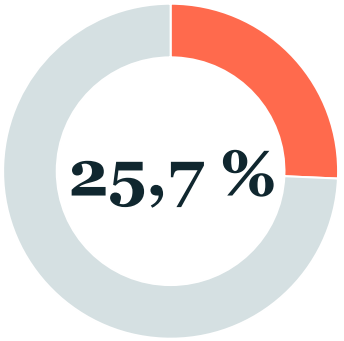
GBD 2021 Antimicrobial Resistance Collaborators · The Lancet 2024 ; 404 : 1199-1226 · valeurs relevées dans le texte de l'article

RÉSULTATS R2 · PNAS 2022

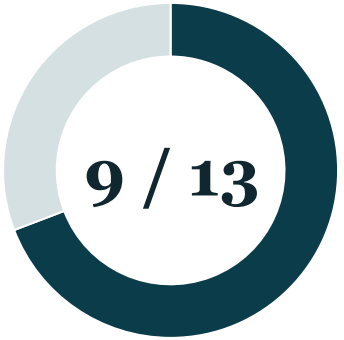
L'étude mondiale en chiffres

Indicateur	Valeur
Rivières étudiées	258
Sites d'échantillonnage	1 052
Pays (dont 36 jamais étudiés pour ce sujet)	104
Population représentée	471,4 millions
Régions géographiques	137
Molécules pharmaceutiques analysées	61
Antimicrobiens détectés	13
Concentration maximale observée (paracétamol)	227 µg/L
Antimicrobiens au-dessus du seuil de résistance, sur au moins un site	**9 sur 13**

Molécules les plus détectées : carbamazépine, metformine et caféine, sur plus de la moitié des sites. Les concentrations les plus élevées : Afrique subsaharienne, Asie du Sud et Amérique du Sud.



des sites (270 sur 1 052) dépassent un seuil de sécurité : organismes aquatiques ou sélection de résistance

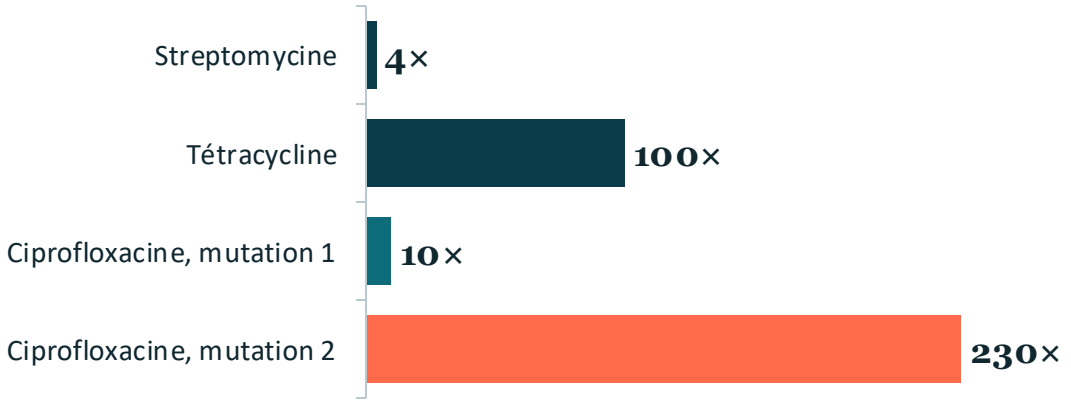


antimicrobiens détectés dépassent le seuil de résistance sur au moins un site ; ciprofloxacine : 64 sites

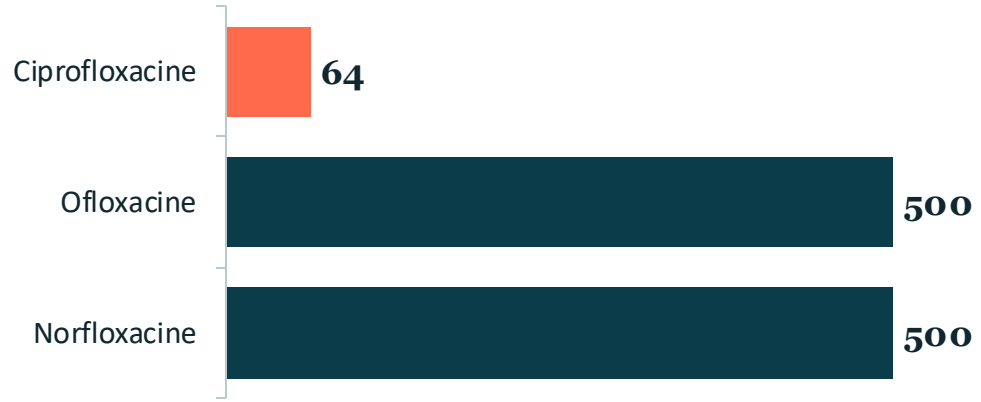
Wilkinson et al. · PNAS 2022 ; 119(8) : e2113947119 · valeurs relevées dans le texte de l'article

Une petite dose sélectionne des résistants

À combien de fois sous la CMI la sélection commence-t-elle ?



Seuils prédits sans effet pour la sélection de résistance, en ng/L



Antibiotique	Fraction de la CMI	Concentration
Streptomycine	1/4	1 µg/ml
Tétracycline	1/100	15 ng/ml
Ciprofloxacine	**1/10 à 1/230**	**2,5 ng/ml à 100 pg/ml**

Gullberg et al. · PLoS Pathogens 2011 · concentration minimale sélective (MSC)

7,8×

plus puissante : 64 ng/L pour la ciprofloxacine contre 500 pour l'ofloxacine

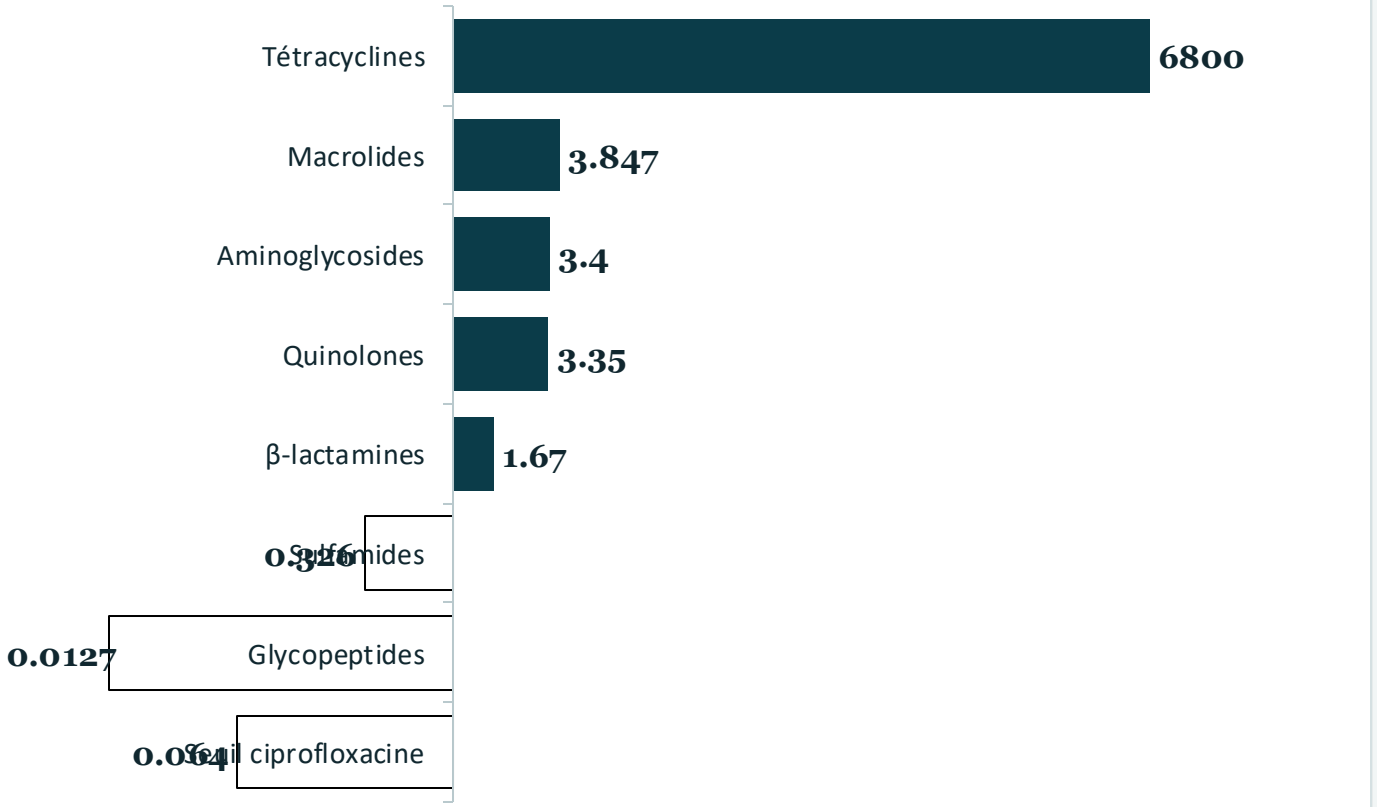
111

antibiotiques étudiés ; seuils de 8 ng/L à 64 µg/L

Bengtsson-Palme & Larsson · Environ Int 2016 · valeurs de l'article, citées dans PMC6726141

Les concentrations d'antibiotiques rapportées

Concentration rapportée par famille, en µg/L (échelle logarithmique)



Famille	Valeur	Milieu
Tétracyclines	6,8 mg/L	—
Macrolides	3,847 µg/L	station d'épuration
Aminoglycosides	3,4 µg/L	—
Quinolones	3,35 µg/L	effluent
β-lactamines	1,67 µg/L	effluent
Sulfamides	0,326 µg/L	eau de rivière
Glycopeptides	0,0127 µg/L	—

Ordre de grandeur, pas une comparaison directe.
Quinolones dans un effluent : 3,35 µg/L, soit environ 52 fois le seuil de risque de la ciprofloxacine (0,064 µg/L). Calcul à partir de deux sources, milieux différents.

Ezra, Vanti & Masaphy · Biomolecules 2025 ; 15(8) : 1138, tableau 1 · seuil : Bengtsson-Palme & Larsson 2016 (64 ng/L)

Quelles laccases dégradent quels antibiotiques

Champignon	Support ou méthode	Molécule(s) étudiée(s)
Pleurotus eryngii	Microcapsule (encapsulation)	Tétracycline
Aspergillus oryzae	Charbon actif granulaire (adsorption)	Sulfaméthoxazole
Trametes versicolor	Microbilles de silice magnétiques (liaison covalente)	Paracétamol
Trametes versicolor	Membrane nanofibreuse polyacrylonitrile-biochar (adsorption)	Chlortétracycline
Cerrena unicolor	Nanoparticules magnétiques (liaison covalente)	Tétracycline, oxytétracycline, ampicilline, sulfaméthoxazole, érythromycine
Phanerochaete chrysosporium	Sans support (réacteur discontinu)	Tétracycline, sulfathiazole
Trametes versicolor	Biochar et stévensite (liaison covalente)	Tétracycline
Trametes versicolor	Matériau mésoporeux dérivé de bentonite (adsorption)	Tétracycline
Trametes versicolor	Billes de chitosane-tripolyphosphate (liaison covalente)	Tétracycline
Pycnoporus sp.	Sans support (culture discontinue)	Tétracycline
Trametes hirsuta	Sans support (culture discontinue)	Chloramphénicol
Coriolopsis gallica	Milieux solide et liquide	Lévofloxacine

Ezra, Vanti & Masaphy · Biomolecules 2025 ; 15(8) : 1138, tableau 4

La tétracycline revient le plus souvent : c'est la famille la plus étudiée avec la laccase dans ce tableau.

Le calendrier de la directive

2 juillet 2026

La Commission fixe la méthode de mesure de la résistance

ART. 17

31 décembre 2028

Responsabilité élargie des producteurs en place (au moins 80 % des coûts)

ART. 9

31 décembre 2030

Liste des zones à risque pour les micropolluants établie

ART. 8

31 décembre 2033

20 % des grandes stations traitent les micropolluants

ART. 8

31 décembre 2039

60 % des grandes stations

ART. 8

31 décembre 2045

Toutes les grandes stations

ART. 8

Stations de 150 000 éq.-hab. et plus pour le traitement des micropolluants (art. 8) ; agglomérations de 100 000 éq.-hab. et plus pour le suivi de la résistance (art. 17).

Directive (UE) 2024/3019 du 27 novembre 2024 · texte consolidé EUR-Lex · dates relevées dans les articles 8, 9 et 17

Preuves : la charge mondiale de la résistance

ARTICLES · Volume 404, Issue 10459, P1199-1226, September 28, 2024 · *Open Access* Download Full Issue

Global burden of bacterial antimicrobial resistance 1990–2021: a

In 2021, we estimated 4·71 million (95% UI 4·23–5·19) deaths were associated with bacterial AMR, including 1·14 million (1·00–1·28) deaths attributable to bacterial AMR. Trends in AMR mortality over the past 31 years varied substantially by age and location. From 1990 to 2021, deaths from AMR decreased by more than 50% among children

deaths (82 100–171 000) in 1990, to 216 000 (168 000–264 000) attributable deaths in 2021. There was a notable decrease in non-COVID-related infectious disease in 2020 and 2021. Our forecasts show that an estimated 1·91 million (1·56–2·26) deaths attributable to AMR and 8·22 million (6·85–9·65) deaths associated with AMR could occur globally in 2050. Super-regions with the highest all-age AMR mortality rate in 2050 are forecasted to be

attributable to AMR globally and 8·22 million (6·85–9·65) annual deaths associated with AMR (table 3; figure 6). Cumulatively from 2025 to 2050, our reference scenario forecasts 39·1 million (33·0–46·0) deaths attributable to AMR and 169 million (145–196) deaths associated with AMR (appendix 1 pp 114–115). DALYs attributable to AMR are forecasted to increase from 42·6 million (35·5–52·5) in 2022 to 46·5 million (37·7–57·3) in 2050. The all-

GBD 2021 Antimicrobial Resistance Collaborators · Lancet 2024 ; 404 : 1199-1226 · doi:10.1016/S0140-6736(24)01867-1

Comment lire ces chiffres

1,14 M décès attribuables à la résistance en 2021.

1,91 M par an en 2050, dans le scénario de référence.

39,1 M cumulés de 2025 à 2050 (33,0 à 46,0).

Attribuables : décès évités si les infections résistantes devenaient sensibles.

Associés : décès où la résistance est présente.

Preuves : 1 052 sites, 258 rivières, 104 pays

RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES |

Pharmaceutical pollution of the world's rivers

Concentrations of at least one API at 25.7% of the sampling sites were greater than concentrations considered safe for aquatic organisms, or which are of concern in terms of selection for antimicrobial resistance. Therefore, pharmaceutical pollution antimicrobials (Fig. 5) exceeded these safe concentrations for at least one sampling site, with ciprofloxacin exceeding the safe limit at 64 sites. The greatest exceedance of the safe target was observed for metronidazole at a sampling site in Barisal,

Wilkinson et al. · PNAS 2022 ; 119(8) : e2113947119 · doi:10.1073/pnas.2113947119

Comment lire ces chiffres

25,7 % des sites : au moins une molécule au-dessus d'un seuil, pour les organismes aquatiques ou pour la sélection de résistance.

64 sites : ciprofloxacine au-dessus du seuil de sélection de résistance.

Plus de 300 fois le seuil pour le métronidazole sur un site du Bangladesh.

Preuves : une petite dose suffit à sélectionner

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Selection of Resistant Bacteria at Very Low Antibiotic Concentrations

Erik Gullberg, Sha Cao, Otto G. Berg, Carolina Ilbäck, Linus Sandegren, Diarmaid Hughes, Dan I. Andersson

antibiotic concentrations present in many environments plays in selection remains largely unclear. Here we show using highly sensitive competition experiments that selection of resistant bacteria occurs at extremely low antibiotic concentrations. Thus, for three clinically important antibiotics, drug concentrations up to several hundred-fold below the minimal inhibitory concentration of susceptible bacteria could enrich for resistant bacteria, even when present at a very low initial fraction. We also show that *de novo* mutants can be selected at sub-MIC concentrations of antibiotics, and we provide a mathematical model predicting how rapidly such mutants would take over in a susceptible population. These results add another dimension to

from these experiments are plotted as a function of antibiotic concentration the intercept, s=0, represents what we specify as the minimal selective concentration (MSC) where the fitness cost of the resistance is balanced by the antibiotic-conferred selection for the resistant mutant (Fig. 2B, D, Fig. 3B, D, F, H and Fig. 4E). Depending on the antibiotic and the type of resistance mutation examined the MSC varied between 1/4 and 1/230 of the MIC_{susc}. For streptomycin the MSC value was 1/4 of the MIC value of the susceptible strain (Fig. 2B), for tetracycline 1/100 (Fig. 2D) and for ciprofloxacin it varied between 1/10 (Fig. 3B) and 1/230 (Fig. 3D) of the MIC_{susc} depending on the particular resistance mutation. These values correspond to absolute antibiotic concentrations of 1 μg/ml (streptomycin), 15 ng/ml (tetracycline), and 2.5 ng/ml to 100

Gullberg et al. · PLoS Pathogens 2011 ; 7(7) : e1002158 · doi:10.1371/journal.ppat.1002158

Seuils de risque proposés

identified, and to compensate for limited species coverage, predicted lowest MICs adjusted for the number of tested species were extrapolated through modeling. Predicted No Effect Concentrations (PNECs) for resistance selection were then assessed using an assessment factor of 10 to account for differences between MICs and minimal selective concentrations. The resulting PNECs ranged from 8 ng/L to 64 μg/L. Furthermore, the link between taxonomic similarity between species and lowest MIC was weak. This work provides estimated upper boundaries for selective concentrations (lowest MICs) and PNECs for resistance selection for all common antibiotics. In most cases, PNECs for selection of resistance were below available PNECs for ecotoxicological effects. The generated PNECs can guide implementation of

In this model, we applied any reductions in antibiotic prescribing, i.e., 4 or 20%, uniformly across all antibiotics within the class. However, the use of antibiotics within a class are unlikely to be uniformly reduced. As a result, some reductions in prescribing could delay or hasten the time to achieve 'low risk'. For example, ciprofloxacin is the most 'potent' fluoroquinolone in its class, with a PNEC of 64 ng/L; ofloxacin and norfloxacin are less 'potent', with a PNEC of 500 ng/L. In other words, ciprofloxacin is 7.8 times more potent than ofloxacin and norfloxacin. Hence, the benefit gained from reducing 1 unit of ciprofloxacin necessitates a reduction in 7.8 units of ofloxacin or norfloxacin. As ciprofloxacin represents the majority of fluoroquinolone prescribed (96.9%; Table 2), any reduction in ciprofloxacin

Bengtsson-Palme & Larsson · Environ Int 2016 ; 86 : 140-149
doi:10.1016/j.envint.2015.10.015 · seuil 64 ng/L cité dans PMC6726141

Preuves : ce qui est prouvé, et ses limites

Laccase et antibiotiques



Review 7 August 2025 25 Pages

Sustainable, Targeted, and Cost-Effective Laccase-Based Bioremediation Technologies for Antibiotic Residues in the Ecosystem: A Comprehensive Review

Rinat Ezra [1,2], Gulamnabi Vanti [3] and Segula Masaphy [4,5,*]

[1] Chelmsford Campus, Anglia Ruskin University, Bishop Hall Lane, Chelmsford CM1 1SQ, UK
[2] Rambam Health Care Campus (Medical Center), Haifa 3109601, Israel
[3] Multidisciplinary Research Unit, Karnataka Institute of Medical Sciences, Vidyanagar, Hubli 580021, India
[4] Faculty of Science and Technology, Tel Hai College, Upper Galilee, Kiryat Shmona 12210, Israel

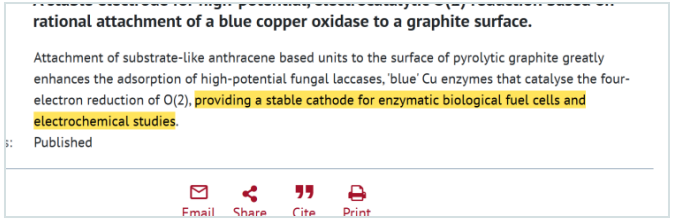
methods and the need for industrial applications pose significant challenges. Hence, environmentally sustainable, green, and readily available approaches for the transformation and degradation of these antibiotic compounds are being sought. Herein, we review the impact of sustainable fungal laccase-based bioremediation strategies. Fungal laccase enzyme is considered one of the most active enzymes for biotransformation and biodegradation of antibiotic residue in vitro. For industrial applications, the low laccase yields in natural and genetically modified hosts may constitute a bottleneck. Methods to screen for high-laccase-producing sources, optimizing cultivation conditions, and identifying key genes and metabolites involved in extracellular laccase activity are reviewed. These include advanced

Apport La laccase fongique figure parmi les enzymes les plus actives pour transformer les antibiotiques in vitro.

Limite Faibles rendements en laccase : un goulot d'étranglement pour l'industrie.

Biomolecules 2025 ; 15(8) : 1138 · doi:10.3390/biom15081138

Cathode à laccase stable



rational attachment of a blue copper oxidase to a graphite surface.

Attachment of substrate-like anthracene based units to the surface of pyrolytic graphite greatly enhances the adsorption of high-potential fungal laccases, 'blue' Cu enzymes that catalyse the four-electron reduction of O(2), providing a stable cathode for enzymatic biological fuel cells and electrochemical studies.

Published

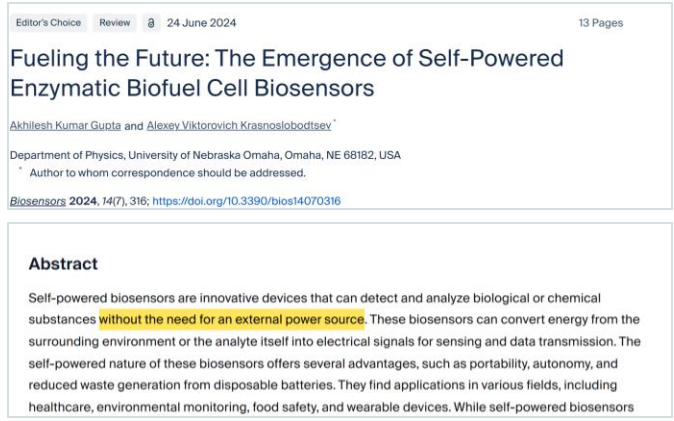
Email Share Cite Print

Apport Une cathode stable, base des piles enzymatiques et des études électrochimiques.

Limite Étude fondamentale de 2007 : à adapter à la détection d'antibiotiques.

Chem. Commun. 2007 : 1710-1712 · doi:10.1039/b703114a

Capteurs auto-alimentés



Editor's Choice Review 24 June 2024 13 Pages

Fueling the Future: The Emergence of Self-Powered Enzymatic Biofuel Cell Biosensors

Akhilesh Kumar Gupta and Alexey Viktorovich Krasnoslobodtsev *

Department of Physics, University of Nebraska Omaha, Omaha, NE 68182, USA
* Author to whom correspondence should be addressed.

Biosensors **2024**, *14*(7), 316; https://doi.org/10.3390/bios14070316

Abstract

Self-powered biosensors are innovative devices that can detect and analyze biological or chemical substances without the need for an external power source. These biosensors can convert energy from the surrounding environment or the analyte itself into electrical signals for sensing and data transmission. The self-powered nature of these biosensors offers several advantages, such as portability, autonomy, and reduced waste generation from disposable batteries. They find applications in various fields, including healthcare, environmental monitoring, food safety, and wearable devices. While self-powered biosensors

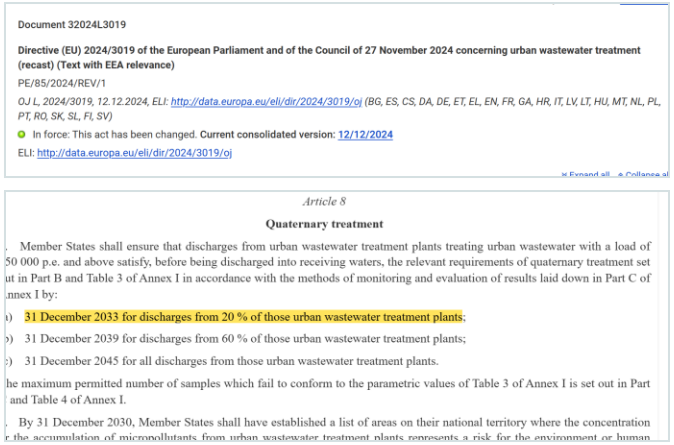
Apport Détection sans source d'énergie externe : portabilité, autonomie, moins de piles jetables.

Limite Défis : efficacité énergétique, sensibilité, stabilité.

Biosensors 2024 ; 14(7) : 316 · doi:10.3390/bios14070316

Preuves : pourquoi c'est le bon moment

Directive (UE) 2024/3019



Document 32024L3019

Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (recast) (Text with EEA relevance)

PE/85/2024/REV/1

OJ L, 2024/3019, 12.12.2024, ELI: http://data.europa.eu/eli/dir/2024/3019/oj (BG, ES, CS, DA, DE, ET, EL, EN, FR, GA, HR, IT, LV, LT, HU, MT, NL, PL, PT, RO, SK, SL, FI, SV)

In force: This act has been changed. **Current consolidated version: 12/12/2024**

ELI: http://data.europa.eu/eli/dir/2024/3019/oj

Article 8

Quaternary treatment

. Member States shall ensure that discharges from urban wastewater treatment plants treating urban wastewater with a load of 50 000 p.e. and above satisfy, before being discharged into receiving waters, the relevant requirements of quaternary treatment set ut in Part B and Table 3 of Annex I in accordance with the methods of monitoring and evaluation of results laid down in Part C of nnex I by:

) 31 December 2033 for discharges from 20 % of those urban wastewater treatment plants;

) 31 December 2039 for discharges from 60 % of those urban wastewater treatment plants;

) 31 December 2045 for all discharges from those urban wastewater treatment plants.

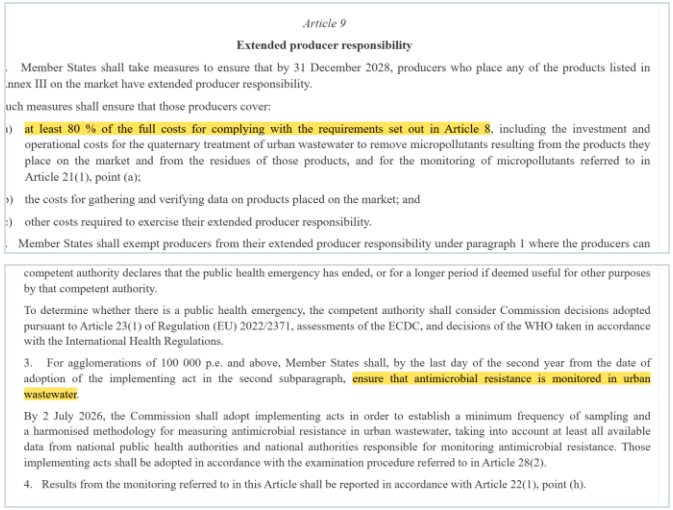
he maximum permitted number of samples which fail to conform to the parametric values of Table 3 of Annex I is set out in Part and Table 4 of Annex I.

. By 31 December 2030, Member States shall have established a list of areas on their national territory where the concentration r the accumulation of micropollutants from urban wastewater treatment plants represents a risk for the environment or human

Traitement des micropolluants : 20 % des grandes stations en 2033, 60 % en 2039, toutes en 2045.

EUR-Lex · JO L, 12.12.2024 · articles 8 et 9

Ce que change la directive



Article 9

Extended producer responsibility

. Member States shall take measures to ensure that by 31 December 2028, producers who place any of the products listed in nnex III on the market have extended producer responsibility.

uch measures shall ensure that those producers cover:

) at least 80 % of the full costs for complying with the requirements set out in Article 8, including the investment and operational costs for the quaternary treatment of urban wastewater to remove micropollutants resulting from the products they place on the market and from the residues of those products, and for the monitoring of micropollutants referred to in Article 21(1), point (a);

) the costs for gathering and verifying data on products placed on the market; and

) other costs required to exercise their extended producer responsibility.

. Member States shall exempt producers from their extended producer responsibility under paragraph 1 where the producers can

competent authority declares that the public health emergency has ended, or for a longer period if deemed useful for other purposes by that competent authority.

To determine whether there is a public health emergency, the competent authority shall consider Commission decisions adopted pursuant to Article 23(1) of Regulation (EU) 2022/2371, assessments of the ECDC, and decisions of the WHO taken in accordance with the International Health Regulations.

3. For agglomerations of 100 000 p.e. and above, Member States shall, by the last day of the second year from the date of adoption of the implementing act in the second subparagraph, ensure that antimicrobial resistance is monitored in urban wastewater.

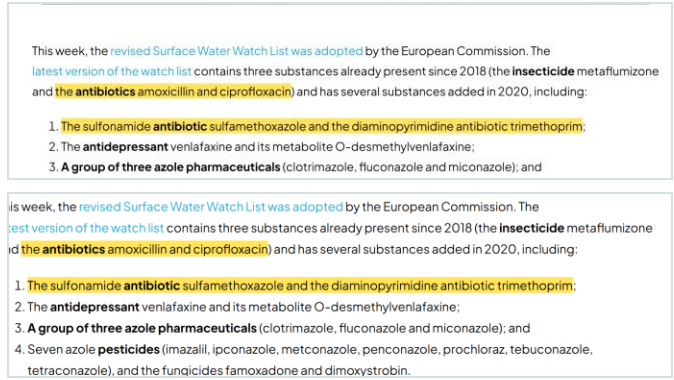
By 2 July 2026, the Commission shall adopt implementing acts in order to establish a minimum frequency of sampling and a harmonised methodology for measuring antimicrobial resistance in urban wastewater, taking into account at least all available data from national public health authorities and national authorities responsible for monitoring antimicrobial resistance. Those implementing acts shall be adopted in accordance with the examination procedure referred to in Article 28(2).

4. Results from the monitoring referred to in this Article shall be reported in accordance with Article 22(1), point (h).

Au moins 80 % des coûts à la charge des producteurs ; suivi de la résistance dans les eaux usées.

EUR-Lex · articles 9 et 17

Liste de vigilance de l'UE



This week, the revised Surface Water Watch List was adopted by the European Commission. The latest version of the watch list contains three substances already present since 2018 (the **insecticide** metaflumizone and the **antibiotics** amoxicillin and ciprofloxacin) and has several substances added in 2020, including:

1. The sulfonamide **antibiotic** sulfamethoxazole and the diaminopyrimidine antibiotic trimethoprim;
2. The **antidepressant** venlafaxine and its metabolite O-desmethylvenlafaxine;
3. **A group of three azole pharmaceuticals** (clotrimazole, fluconazole and miconazole); and

is week, the revised Surface Water Watch List was adopted by the European Commission. The test version of the watch list contains three substances already present since 2018 (the **insecticide** metaflumizone nd the **antibiotics** amoxicillin and ciprofloxacin) and has several substances added in 2020, including:

1. The sulfonamide **antibiotic** sulfamethoxazole and the diaminopyrimidine antibiotic trimethoprim;
2. The **antidepressant** venlafaxine and its metabolite O-desmethylvenlafaxine;
3. **A group of three azole pharmaceuticals** (clotrimazole, fluconazole and miconazole); and
4. Seven azole **pesticides** (imazalil, ipconazole, metconazole, penconazole, prochloraz, tebuconazole, tetraconazole), and the fungicides famoxadone and dimoxystrobin.

Antibiotiques surveillés : amoxicilline, ciprofloxacine, sulfaméthoxazole, triméthoprime.

Water Europe · liste de vigilance des eaux de surface (version 2020)

Le cadre européen crée le besoin : il faudra des outils pour savoir où agir.

Réponses préparées

1 Pourquoi pas la chromatographie ?

Elle reste la référence et confirme. Mais elle exige un laboratoire, du matériel coûteux, et rend un résultat différé : on mesure peu de points. LACSENS dépiste sur place et dit où aller vérifier.

2 Pourquoi la laccase ?

Les revues la décrivent parmi les enzymes les plus actives pour transformer les antibiotiques in vitro (Biomolecules 2025). Et je l'ai déjà manipulée en stage.

3 Que fait-on d'une alerte ?

On remonte le cours d'eau jusqu'au rejet, on alerte les autorités et le site, et le traitement est corrigé à la source. Le poste 03 assure ce lien.

4 Pourquoi maintenant ?

La directive (UE) 2024/3019 impose le traitement des micropolluants (20 % des grandes stations en 2033, 100 % en 2045) et le suivi de la résistance. Il faudra des outils pour savoir où agir.

5 Quelles sont les limites ?

Un capteur dépiste, il ne remplace pas l'analyse officielle. Les revues citent des défis : rendement en laccase, sensibilité et stabilité des biocapteurs. C'est le travail des postes 01 et 02.

6 Qui paie ?

Les producteurs de médicaments et de cosmétiques financent au moins 80 % du traitement avancé (directive, article 9). Le budget et les financements du projet sont gérés par le chef de projet.

Sources et vérification

1. GBD 2021 Antimicrobial Resistance Collaborators. Global burden of bacterial antimicrobial resistance 1990-2021: a systematic analysis with forecasts to 2050. Lancet 2024 ; 404 : 1199-1226. doi:10.1016/S0140-6736(24)01867-1

2. Wilkinson JL, Boxall ABA, Kolpin DW, et al. Pharmaceutical pollution of the world's rivers. PNAS 2022 ; 119(8) : e2113947119. doi:10.1073/pnas.2113947119

3. Gullberg E, Cao S, Berg OG, et al. Selection of resistant bacteria at very low antibiotic concentrations. PLoS Pathog 2011 ; 7(7) : e1002158. doi:10.1371/journal.ppat.1002158

4. Bengtsson-Palme J, Larsson DGJ. Concentrations of antibiotics predicted to select for resistant bacteria: proposed limits for environmental regulation. Environ Int 2016 ; 86 : 140-149. doi:10.1016/j.envint.2015.10.015

5. Ezra R, Vanti G, Masaphy S. Sustainable, targeted, and cost-effective laccase-based bioremediation technologies for antibiotic residues in the ecosystem: a comprehensive review. Biomolecules 2025 ; 15(8) : 1138. doi:10.3390/biom15081138

6. Blanford CF, Heath RS, Armstrong FA. A stable electrode for high-potential, electrocatalytic O2 reduction based on rational attachment of a blue copper oxidase to a graphite surface. Chem Commun 2007 ; (17) : 1710-1712. doi:10.1039/b703114a

7. Gupta AK, Krasnoslobodtsev AV. Fueling the future: the emergence of self-powered enzymatic biofuel cell biosensors. Biosensors 2024 ; 14(7) : 316. doi:10.3390/bios14070316

8. Directive (UE) 2024/3019 du Parlement européen et du Conseil du 27 novembre 2024 relative au traitement des eaux urbaines résiduaires (refonte). JO L, 12.12.2024.

9. Parlement européen. New EU rules to improve urban wastewater treatment and reuse. Communiqué de presse, 10 avril 2024.

10. Water Europe. European Commission adopts revised Surface Water Watch List (amoxicilline, ciprofloxacine, sulfaméthoxazole, triméthoprime).

Vérifié dans les textes : 39,1 M · 1,14 M · 1,91 M (Lancet) · 25,7 % et 64 sites (PNAS) · 1/230 (PLoS) · 20, 60, 100 % et 80 % (directive).