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Une collaboration scientifique croissante entre la France et l'État de São Paulo

MARCO ANTONIO ZAGO — président de la FAPESP



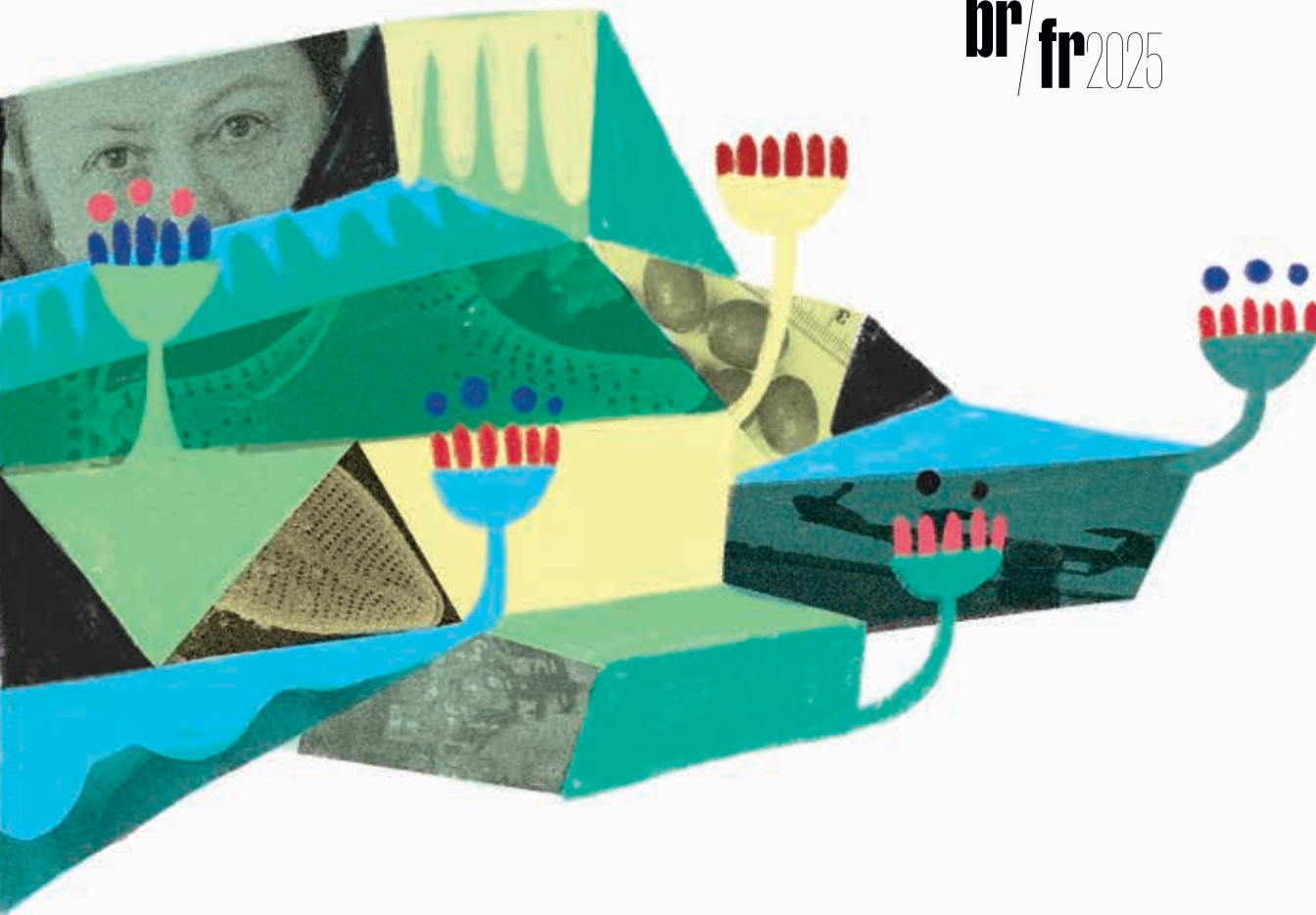
Plus grand exportateur au monde de café, le Brésil produit chaque année environ 40 % du total mondial de près de 170 millions de sacs de 60 kg, desquels 60 % sont de l'espèce *Coffea arabica*. Le séquençage du génome de *C. arabica* et de ses deux espèces ancestrales (une étude publiée dans la revue *Nature* de l'an dernier) a permis de rechercher, par exemple, des variétés plus résistantes aux changements climatiques. Il s'agit d'une réalisation majeure de la collaboration scientifique internationale entre des scientifiques de 18 pays, parmi lesquels l'Institut de recherche pour le développement (IRD) de France et l'École supérieure d'agriculture Luiz de Queiroz de l'Université de São Paulo (Esalq-USP) ; la recherche est financée par l'Agence française de la recherche (ANR) et la FAPESP de l'État de São Paulo.

Dans la zone sud de la ville de São Paulo, il existe un cratère de 3,6 kilomètres de diamètre, provoqué par l'impact d'une météorite qui a frappé la région entre 30 et 5 millions d'années auparavant. L'étude paléobiologique des pollens fossiles, qui permet de reconstituer la flore et le milieu anciens de la région, est un autre exemple de coopération scientifique réussie entre la France et le Brésil. Il concerne

à l'origine trois chercheuses de l'Université fédérale du Paraná, de l'Institut de recherches environnementales de São Paulo et de l'Université de Montpellier.

Ces deux exemples de coopération scientifique et technologique entre l'État de São Paulo et la France sont présentés dans l'édition spéciale de la revue FAPESP publiée pour commémorer les événements organisés par São Paulo en France en juin de cette année : la 25e édition de la FAPESP Week à Toulouse, la participation à VivaTech 2025 à Paris, le Forum des forêts au Muséum national d'histoire naturelle et la Journée de la muséologie au Musée de l'Homme, également à Paris. Les startups soutenues par la FAPESP et sélectionnées pour participer à VivaTech font l'objet d'un reportage sur la stratégie de la Fondation de soutien des petites entreprises *deeptech* par l'intermédiaire du programme Pipe.

D'autres sujets abordés portent sur l'évolution actuelle de recherches conjointes entre l'Institut de physique de l'USP et l'Université Paris-Sud. C'est notamment le cas d'une stratégie de refroidissement de molécules à l'aide d'un faisceau laser. Ou des innovations de l'aéronautique brésilienne avec la production d'eVTOLs (communément appelés voitures volantes) par EVE Mobility Air, une filiale d'Embraer, et le travail du Centre de



recherche en ingénierie pour la mobilité aérienne du futur, soutenu par Embraer et la FAPESP.

Des entretiens avec trois personnalités au cœur des relations actuelles entre São Paulo et la France complètent l'édition française : Christiane Taubira, ancienne ministre de la Justice du gouvernement français, aujourd'hui titulaire de la chaire José Bonifácio de l'USP, dont le thème de recherche porte sur les sociétés amazoniennes ; Paola Minoprio, directrice de l'Institut Pasteur de São Paulo, l'un des 33 centres internationaux appartenant au réseau Pasteur, basé à Paris, qui s'exprime sur les résultats déjà obtenus depuis 2020 et les perspectives d'avenir ; et Liviu Nicu, directeur du bureau du Centre national de la recherche scientifique (CNRS) en Amérique latine et directeur scientifique du Centre international de recherche « Transitions », un partenariat entre la FAPESP, l'USP et le CNRS.

La revue *Pesquisa FAPESP* a complété 25 années de publication continue en octobre 2024 avec le numéro 344. Créée pour rapprocher le monde de la recherche et l'opinion publique, elle est devenue une source privilégiée de lignes directrices, de consultations et de reportages pour les éditoriaux scientifiques des journaux, magazines, stations de radio, télévision et agences de presse.

Tirée à 28 000 exemplaires par mois et largement diffusée dans la communauté scientifique, elle est aussi disponible sur Internet, avec un afflux croissant d'un million de visiteurs en juillet 2024. Elle est citée en moyenne une centaine de fois par mois dans la presse et une soixantaine de fois par an à l'étranger.

En plus des textes produits pour commémorer les événements en France, cette édition spéciale propose en anglais une sélection d'articles originellement publiés en portugais par la revue dans ses éditions régulières du second semestre 2024. Ces articles s'intéressent à la réduction des émissions de gaz à effet de serre par le Brésil ; la mise au point d'une méthode de purification de l'argon liquide pour l'expérience internationale Dune, afin de détecter les mystérieux neutrinos ; l'identification de lésions caractéristiques de la maladie d'Alzheimer dans le cerveau de singes capucins ; et la reprise de l'activité de recherche après la pandémie de coronavirus.

En somme, cette édition spéciale de *Pesquisa FAPESP* célèbre le grand essor de la science dans l'État de São Paulo et dans le monde entier et illustre la solidité de nos échanges avec les communautés scientifiques internationales.

De l'oxygène à la naissance

Le programme Pipe de la FAPESP a déjà financé plus de 2 000 startups technologiques à leurs débuts

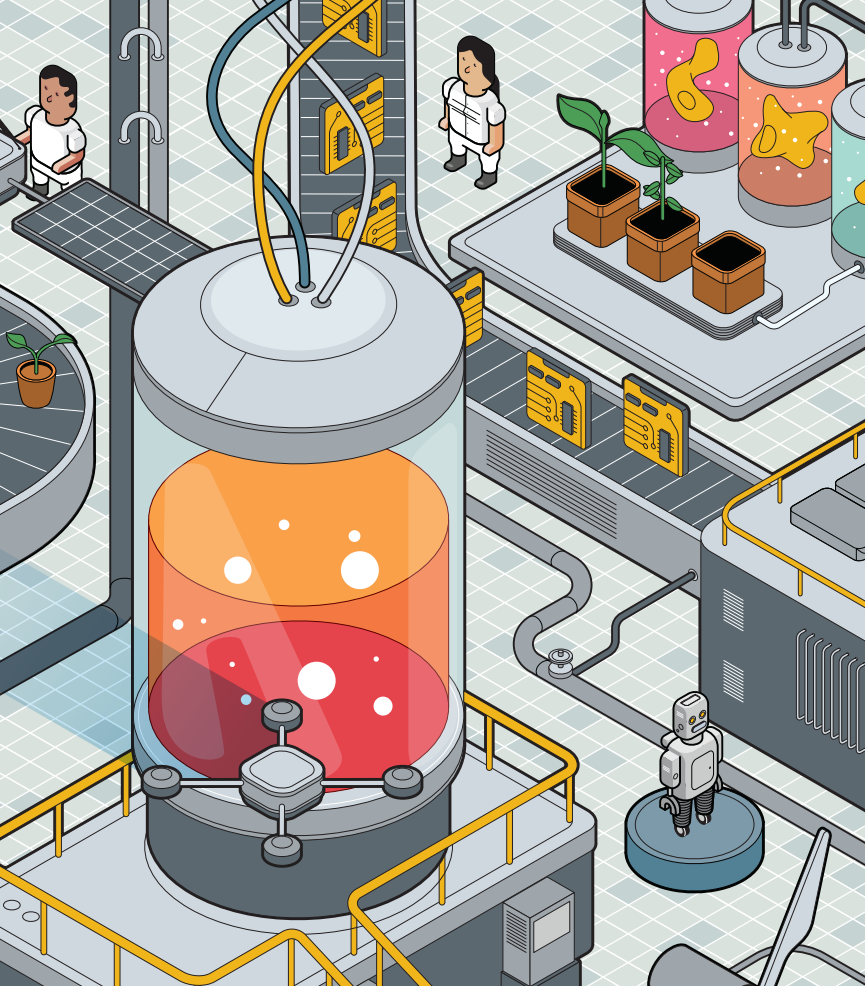
FABRICIO MARQUES



L'État de São Paulo représente 30 % du produit intérieur brut (PIB) du Brésil, mais il concentre 55 % des 875 entreprises brésiliennes de technologie profonde (*deep techs*), des startups de base scientifique fondées sur l'innovation de rupture. La donnée provient d'une enquête réalisée en 2024 par le cabinet de consultation Emerge Brasil. Selon cette enquête, l'agglomération est due à une plus grande disponibilité des soutiens financiers pour l'innovation des nouvelles entreprises à São Paulo par rapport à d'autres États du pays, l'accent étant mis sur le Programme de recherche innovante dans les petites entreprises (Pipe) de la FAPESP. Cette initiative soutient les projets de recherche des entrepreneurs qui souhaitent analyser la viabilité d'une innovation (Pipe-phase 1), mettre en place une technologie ou un processus innovant (phase 2) ou développer leurs produits et services (phase 3). Depuis 1997, le Pipe a déjà financé plus de 2 000 entreprises, dont 28 % des *deep techs* recensées dans le pays par Emerge Brasil.

Un exemple est Onkos Diagnósticos Moleculares, une startup spécialisée dans la biologie moléculaire et l'intelligence artificielle pour l'oncologie. Créée en 2015 dans la ville de Ribeirão

Preto (région de São Paulo), elle a déjà eu cinq projets de recherche financés par le programme : des projets visant le développement de tests de diagnostic pour le cancer de la thyroïde et de la prostate et, plus récemment, la localisation de l'origine du cancer chez les patients atteints de métastases. Le produit phare de l'entreprise est un test de diagnostic et de pronostic des nodules thyroïdiens, utilisé par plus de 7 000 personnes dans 30 pays, qui a été conçu et perfectionné avec le soutien de trois projets Pipe. Marcos Tadeu dos Santos, biologiste moléculaire, fondateur et PDG d'Onkos qui emploie aujourd'hui 42 personnes, explique que « le premier Pipe que nous avons reçu nous a donné la possibilité de développer et de finaliser le test en seulement neuf mois. Ensuite, un deuxième projet a permis de réaliser un essai clinique avec environ 400 patients, au cours duquel l'utilité clinique de la méthode a été démontrée ; cela a permis de réduire d'environ 75 % les opérations inutiles de la thyroïde ». Un troisième projet Pipe, dans le cadre d'un appel d'offres en partenariat avec le Sebrae, a permis à l'entreprise d'élaborer un plan d'affaires et d'investir dans des outils de marketing. Aujourd'hui, l'entreprise envisage de solliciter un financement du Pipe pour rendre viable son processus d'internationalisation en Europe.



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Le test vise à éviter les opérations chirurgicales inutiles de retrait de la thyroïde suite à des soupçons infondés de présence de tumeurs. Le diagnostic conventionnel du cancer de la thyroïde est fait à partir de biopsies analysées par des pathologistes et jusqu'à 30 % des nodules sont classés comme « indéterminés ». Pour des raisons de sécurité, la procédure standard dans ces cas est l'extraction de la thyroïde, qui oblige le patient à prendre un traitement hormonal substitutif pour le reste de sa vie. Or, seul un cas sur quatre cas incertains se révèle malin : cela signifie que trois chirurgies sur quatre dans les cas indéterminés sont inutiles. Le test créé par Onkos analyse les micro-ARN, de petites molécules régulatrices de l'acide ribonucléique (ARN), à l'aide d'un algorithme, et voit si le profil de l'échantillon prélevé s'apparente à celui d'un nodule bénin ou malin. Lorsqu'il conclut qu'il ne s'agit pas d'un cancer, il a raison dans 96 % des cas. « Jusqu'à présent, notre test a permis d'éviter au moins 4 000 opérations inutiles de la thyroïde », affirme le docteur Santos. Lorsqu'il indique qu'il s'agit d'un cancer, le taux de résultat positif est de 80 %.

Onkos a récemment fait les premiers pas pour produire et offrir le test en Europe. Après avoir participé à la *FAPESP Week Spain*, un symposium organisé par la FAPESP en novembre 2024 à

l'Université Complutense de Madrid, Santos s'est inscrit et a été sélectionné pour un programme proposé par La Nave, le principal accélérateur de startups en Espagne : « Une publication de l'European Thyroid Association (ETA) a recommandé le type de test que nous faisons, mais personne en Europe ne répond à la demande. En plus de nous, trois autres entreprises américaines explorent ce type de technologie ». Santos est actuellement en train de rassembler et de produire la documentation nécessaire pour répondre aux normes réglementaires européennes. Il y a peu de temps, un projet de l'entreprise a été approuvé par l'Agence de financement d'études et de projets (Finep). L'objectif est de développer un test avec une technologie similaire à celle de la thyroïde, capable d'analyser la signature génétique de la tumeur du sein et d'identifier si le nodule est d'un type qui peut être combattu par des médicaments de chimiothérapie. L'idée est d'éviter que ce type de traitement soit utilisé sur des patientes qui n'en bénéficieront pas.

Le Pipe a également soutenu des entreprises telles que XMobots, qui est aujourd'hui l'un des principaux fabricants latino-américains de véhicules aériens sans pilote, ou drones. L'entreprise est basée à São Carlos, une ville située à 240 kilomètres de São Paulo. Elle a réussi à monter son premier drone pour le tester après l'approbation d'un projet Pipe phase 1 en 2009. Par la suite, trois autres projets ont été approuvés dans le cadre du programme pour développer des applications de drones à usage civil et militaire. Spécialisée dans le développement et la fabrication de drones qui décollent et atterrissent verticalement, l'entreprise est aujourd'hui active dans l'agriculture de précision et les géotechnologies de logiciels, défense et environnement. En 2022, Embraer a acquis une participation minoritaire de XMobots.

Autaza, une entreprise basée dans le parc technologique de São José dos Campos, à 90 kilomètres de São Paulo, développe des solutions basées sur l'intelligence artificielle avancée pour l'inspection de qualité. Avec le soutien du Pipe, elle a créé des systèmes pour analyser des surfaces et contrôler la qualité de différents types de pièces, des tôles embouties aux peintures automobiles, en passant par les fuselages d'avion. « Notre logiciel inspecte et contrôle en garantissant une analyse précise et standardisée, sans dépendre de la perception humaine », explique Renan Padovani, associé d'Autaza. Issue d'un projet en partenariat avec General Motors et l'Institut technologique de l'aéronautique (ITA), l'entreprise a étendu ses activités à d'autres seg-

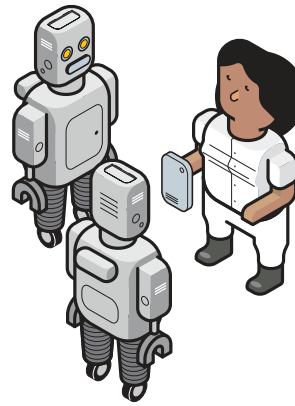
ments tels que l'odontologie, les peintures et la beauté. Un exemple est Colorize, un colorimètre qui utilise l'intelligence artificielle pour mesurer avec précision les tons de la peau et de surfaces ; il offre des solutions innovantes pour différentes industries. « Nous offrons des systèmes personnalisés pour répondre aux demandes spécifiques de chaque secteur », ajoute Padovani.

Selon l'économiste Carlos Américo Pacheco, directeur président du conseil technico-administratif de la FAPESP, la Fondation joue le rôle de principale agence publique de financement pour les entreprises technologiques du pays, en intervenant dans les phases initiales : « Au début, elles n'ont pas encore de recette. Au Brésil et dans de nombreuses autres parties du monde, le marché ne fonctionne pas dans ce segment, car il est difficile d'évaluer l'entreprise pour procéder à un apport de capital ». Le programme a créé d'autres initiatives, comme le Pipe Start, qui soutient les entrepreneurs dans le processus de validation initiale de solutions technologiques innovantes, et le Pipe-TC, qui encourage les startups à effectuer une preuve de concept de recherches provenant d'établissements d'enseignement supérieur ou de recherche. Un autre développement récent est l'apport de ressources par la FAPESP d'un fonds d'investissement (FIP) en partenariat avec la Banque brésilienne de développement économique et social (BNDES) et d'autres institutions financières. « Nous travaillons actuellement avec cinq FIP, qui financent des entreprises issues du Pipe. Nous avons aussi sélectionné deux groupes d'investisseurs providentiels et deux plateformes d'investissement participatif (*crowdfunding*) pour lever des fonds et contribuer aux entreprises qui font partie du Pipe. Ce sont des moyens d'aller au-delà du financement de la recherche, pour soutenir ces entreprises dans leurs phases de croissance », précise Pacheco.

Généralement, les bénéficiaires du programme développent des technologies ou des innovations dérivées d'une connaissance produite dans les universités ; l'État de São Paulo est connu pour créer des environnements d'innovation autour de ses six grandes universités publiques, de l'Institut technologique de l'aéronautique (ITA) et d'institutions de recherche comme le Centre national de recherche sur l'énergie et les matériaux (CN-PEM) et l'Institut de recherche technologique (IPT). IdeeLab, une startup de biotechnologie appliquée à l'agriculture installée dans le parc technologique de Piracicaba (région de São Paulo) a été fondée par deux biologistes qui se sont

éloignés du milieu universitaire : le phytopathologiste Sérgio Pascholati, chercheur retraité de l'École supérieure d'agriculture Luiz de Queiroz de l'Université de São Paulo (Esalq-USP), et Ronaldo Dalio, qui avait déjà effectué trois stages postdoctoraux, le dernier sous la supervision de Pascholati. En travaillant ensemble sur des micro-organismes capables de produire des bio-intrants pour l'agriculture, ils ont remarqué un intérêt croissant de la part des entreprises pour la formation de partenariats et y ont vu une opportunité d'entrepreneuriat. « Nous sommes le pays qui utilise le plus de bio-intrants dans l'agriculture, comme engrais ou pour lutter contre les parasites, et nous avons le potentiel pour développer des innovations dans ce domaine », déclare Dalio.

Le début des opérations en 2020 a été rendu possible par la concession quasi simultanée de deux projets du programme Pipe pour le développement de produits biotechnologiques : l'un basé sur le champignon *Memnoniella levispora*, pour le contrôle des parasites, et l'autre, un bio-fertilisant basé sur un type de bactérie que l'on trouve dans différents types de plantes. Dalio signale que les projets leur « ont permis d'embaucher des étudiants boursiers qui ont contribué au développement des premières innovations ». Cinq ans plus tard, IdeeLab est toujours basée à Piracicaba, mais elle a ouvert une filiale à Londrina, dans l'État du Paraná. Ses clients sont d'autres entreprises : elle développe des ensembles biotechnologiques sur commande et les transfère à ses clients. Elle est rémunérée pour son travail et peut également recevoir des royalties pour l'exploitation économique de ses solutions. En cinq ans, elle a licencié au moins 30 produits, dont des engrais, des herbicides, des insecticides et des bactéries qui favorisent l'équilibre nutritionnel des plantes. Elle emploie actuellement 32 personnes et vient de s'associer à un responsable développement (*business developer*) aux États-Unis pour se lancer sur le marché nord-américain. ●

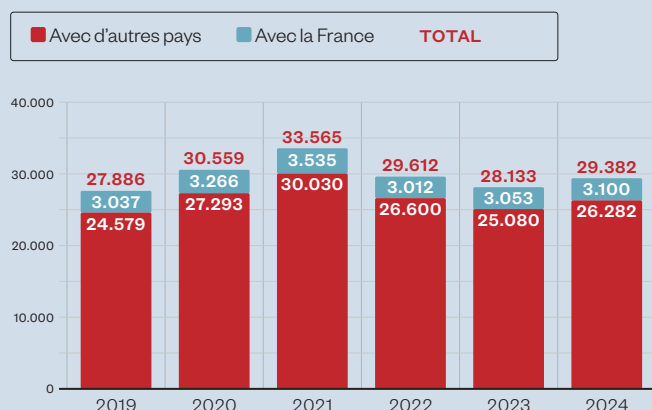


- Des études sur la dynamique de la production scientifique indiquent que les collaborations entre des auteurs de différents pays augmentent le nombre de citations
- Les graphiques ci-dessous montrent les nombres de publications scientifiques¹ du Brésil et de São Paulo écrites en collaboration avec des coauteurs internationaux², et plus spécifiquement avec la France. En termes relatifs, ces collaborations sont plus nombreuses avec São Paulo qu'avec le Brésil pendant toute la période concernée ; en 2024, elles étaient de 11,7 % pour São Paulo et 10,6 % pour le Brésil
- Les données générales montrent que 45,6 % des publications du Brésil en collaboration avec des auteurs internationaux incluent des auteurs originaires de São Paulo. Ce nombre passe à 51,8 % lorsqu'on tient compte uniquement des coauteurs vivant en France, indiquant par-là le rôle important de ce pays dans les collaborations de São Paulo

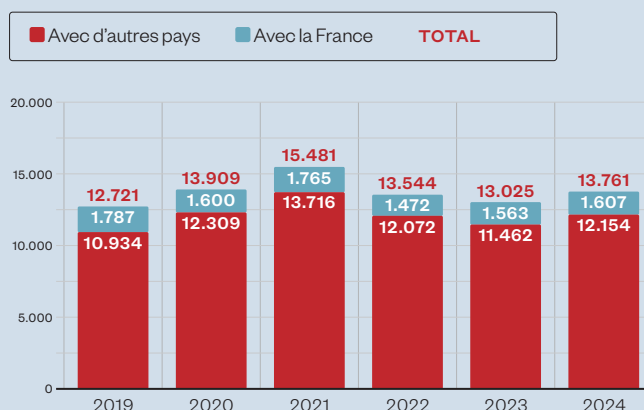
Publications en collaboration avec des auteurs internationaux

BRÉSIL ET SÃO PAULO - TOTAL, AVEC D'AUTRES PAYS ET AVEC LA FRANCE

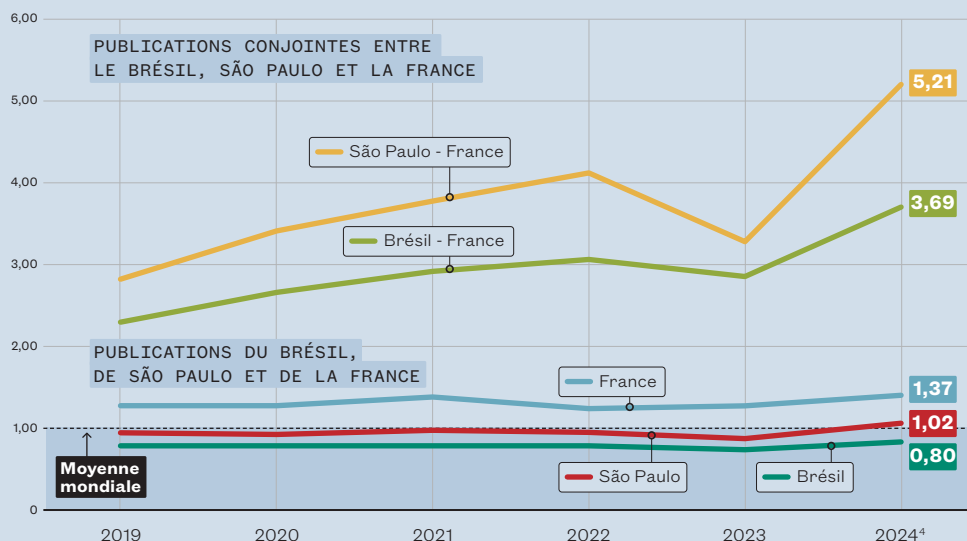
BRÉSIL



SÃO PAULO



Facteur d'impact de citations par catégories



- Concernant le lien entre les collaborations internationales et les citations par publication, le graphique de gauche montre que les valeurs de cet indicateur³ sont beaucoup plus élevées quand il est tenu compte des partenariats entre des domaines géographiques par rapport aux valeurs de l'indicateur pour toutes les publications de chaque pays/région
- Pour les publications conjointes entre le Brésil et la France, le facteur d'impact était proche de 3 en 2023. Pour celles qui concernent São Paulo et la France, il était situé entre 3 et 4 la même année, signe que les collaborations internationales influencent positivement les facteurs d'impact, y compris pour des pays comme la France où les systèmes de recherche sont matures

NOTES (1) PUBLICATIONS DU TYPE « ARTICLE », « PROCEEDINGS PAPER » ET « REVIEW » DE LA BASE DE DONNÉES WEB OF SCIENCE, CLARIVATE. (2) PUBLICATIONS AVEC DES COAUTEURS SITUÉS DANS PLUS D'UN PAYS. (3) L'INDICATEUR UTILISÉ EST LE « CATEGORY NORMALIZED CITATION IMPACT » DE LA PLATEFORME INCITES, CLARIVATE. IL CONSIDÈRE LA MOYENNE DE CITATIONS PAR PUBLICATION, POUR UN ENSEMBLE DE PUBLICATIONS, EN TENANT COMPTE DE L'ANNÉE DU DOMAINE ET DU TYPE DE PUBLICATION. IL EST NORMALISÉ PAR LA MOYENNE MONDIALE QUI PREND LA VALEUR DE 1,0. (4) COMME LE NOMBRE DE CITATIONS PREND UN CERTAIN TEMPS AVANT DE SE STABILISER, LES DONNÉES DE 2024 DOIVENT ÊTRE ENVISAGÉES COMME DES DONNÉES PRÉLIMINAIRES.

SOURCE CLARIVATE/INCITES PRÉPARATION FAPESP/DPCTA/GIP

Décollage à l'horizon

Embraer va prochainement débiter les essais en vol de sa voiture volante, dont l'opération commerciale est prévue pour 2027

YURI VASCONCELOS

Quatre ans et demi après avoir créé l'entreprise Eve Air Mobility pour projeter et construire sa voiture volante, le brésilien Embraer – troisième constructeur mondial d'avions – devrait bientôt commencer les essais en vol de l'aéronef, une étape fondamentale dans le développement et la certification de l'appareil auprès des autorités réglementaires. Connues sous le nom de véhicules électriques à décollage et atterrissage vertical (eVTOL), les voitures volantes sont considérées comme une alternative plus durable pour la mobilité aérienne dans les prochaines décennies. Conçues pour des trajets rapides dans les villes ou sur de courtes distances entre les centres urbains, elles sont alimentées par des batteries et des moteurs électriques qui n'émettent pas de gaz polluants pendant leur fonctionnement.

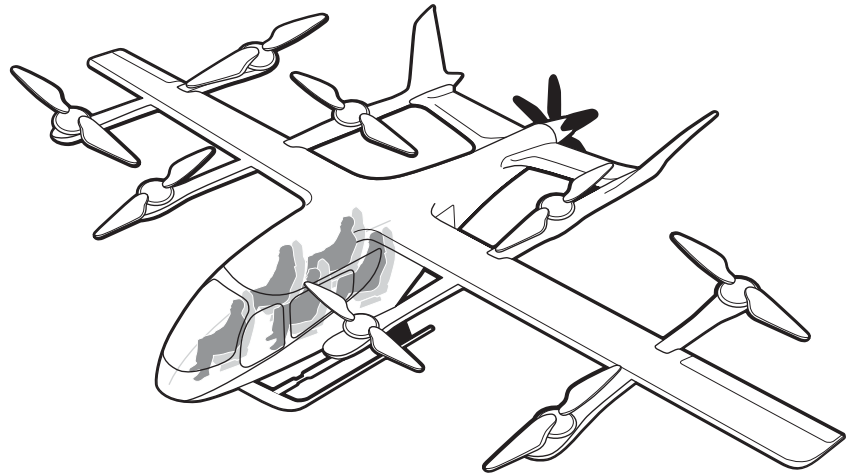
Lors de la campagne d'essais en vol, l'entreprise vérifiera si ce qui a été projeté dans ses laboratoires correspond à ce qui a été produit. William Roberto

Le prototype d'Eve Air Mobility présenté au 45^e Farnborough International Airshow, Angleterre, en juillet 2024



Comme se présente l'eVTOL ?

L'appareil a été projeté pour des déplacements rapides en ville



Capacité
1 pilote et 4 passagers



Portée
100 km



Vitesse maximale
185 km/h



Motorisation
100% électrique

SOURCE EMBRAER/EVE AIR MOBILITY

Wolf, ingénieur aéronautique de l'Université d'État de Campinas (Unicamp), explique : « En plus d'analyser la performance, la sécurité et la manœuvrabilité de l'appareil, l'entreprise verra également s'il est conforme aux réglementations en matière de pollution et d'émissions sonores, entre autres. »

Le premier prototype grandeur nature de l'eVTOL d'Eve Air Mobility a été présenté l'année dernière. L'avion est doté de huit rotors (ensemble formé par le moteur et l'hélice) pour le vol vertical, le décollage et l'atterrissage, et d'ailes fixes pour la croisière (cf. infographie ci-contre). « Dans le cadre de notre campagne d'essais au sol, nous avons réalisé en janvier le premier essai du *pusher* [moteur situé dans la queue de l'avion], qui est responsable de la propulsion en vol de croisière », a déclaré Johann Bordais, PDG d'Eve Air Mobility, à *Pesquisa FAPESP*.

Avec un carnet de commandes de plus de 2 800 intentions d'achat, le plus important du secteur, Embraer espère devenir un concurrent important dans ce nouveau segment aéronautique. « L'entreprise a un avantage. Elle a déjà conçu plusieurs modèles d'avions et possède une grande expertise en aéronautique. En combinant rotors et ailes, le projet d'Eve Air Mobility donnera plus d'autonomie à l'appareil, ce qui ajoute de la valeur au projet », précise Wolf.

Entre ingénieurs, techniciens et chercheurs, près d'un millier de personnes travaillent à plein temps au développement de l'eVTOL. Les appareils seront produits dans une usine à Taubaté, dans la région de São Paulo. Bordais prévoit « une production initiale de 120 unités par an, avec une expansion modulaire en fonction de la demande du marché. La capacité maximale sera de 480 unités par an. »

Plusieurs entreprises dans le monde ont des programmes eVTOL en cours. La société américaine Joby Aviation espère débiter l'opération commerciale de ses voitures volantes en 2026. Eve Air Mobility prévoit que son eVTOL commence à transporter des passagers l'année suivante. En janvier, Airbus a interrompu le projet CityAirbus NextGen, qui avait fait son premier vol d'essai en 2024. L'entreprise a notamment parlé de problèmes liés aux batteries.

Domingos Alves Rade est ingénieur en mécanique de l'Institut technologique

de l'aéronautique (ITA) de São José dos Campos (dans la région de São Paulo), la même ville qui abrite le siège d'Embraer. Il estime que « la grande majorité des entreprises ayant des projets dans ce domaine ont peu de chances de survivre. [...] En plus de la difficulté inhérente à la conception d'un nouvel avion, le processus de certification est complexe et coûteux. »

Rade dirige le Centre de recherche en ingénierie pour la mobilité aérienne du futur, connu sous le nom de Flymov, créé en 2023 par la FAPESP et Embraer. Son objectif est de développer des études sur des sujets innovants qui contribuent à la compétitivité de l'industrie aéronautique brésilienne. Outre l'ITA et Embraer, l'Unicamp et l'école d'ingénieurs São Carlos de l'Université de São Paulo (USP) participent à l'initiative.

Les recherches de Flymov sont menées dans trois domaines d'intérêt pour Embraer : aviation à faible émission de carbone, systèmes autonomes et fabrication avancée. Le développement du premier domaine est dû au fait que l'aviation a besoin de réduire les émissions de gaz à effet de serre (GES), en particulier le dioxyde de carbone. Rade précise que « le secteur représente entre deux

et trois pour cent des émissions de gaz à effet de serre. »

L'un des axes de recherche porte sur la propulsion électrique des avions. Le chercheur de l'ITA signale que « le fonctionnement d'un moteur électrique est très différent de celui d'un moteur à combustion interne ou d'une turbine à gaz. [...] Cela exige la production d'un très grand nombre de connaissances sur le fonctionnement et la sécurité que ces machines vont offrir. »

Sur les près de 120 chercheurs qui font partie de Flymov, certains sont des ingénieurs d'Embraer. Ils étudient aussi la capacité du véhicule aérien à effectuer certaines opérations et à prendre des décisions sans intervention humaine. Plusieurs eVTOL en cours de développement ont pour objectif à long terme de devenir des véhicules autonomes, sans pilote dans le cockpit.

Rade estime que « la synergie entre les connaissances [générées] et les intérêts commerciaux d'Embraer est importante. [...] Le projet d'Eve Air Mobility s'inscrit clairement dans la proposition de mobilité aérienne du futur, le thème central de Flymov. Nous sommes sûrs qu'une partie de nos études pourra être utilisée par Embraer dans le projet de leur eVTOL. » ●

Le projet consulté pour ce reportage figure dans la version en ligne.

La consolidation d'un institut

En 6 ans, la biomédecin de São Paulo a équipé et mis en œuvre l'unité de l'Institut Pasteur à São Paulo

RICARDO ZORZETTO



Après 30 ans passés à l'Institut Pasteur de Paris, Paola Minoprio, biomédecin originaire de São Paulo et spécialiste des maladies causées par les protozoaires, s'est vu confier en 2014 la mission d'accroître la collaboration entre l'institution française centenaire et le Brésil. Quelques années plus tôt, elle avait déjà créé un réseau de coopération entre l'institut et des universités et institutions de recherche en Argentine, en Uruguay, au Paraguay, au Chili et au Brésil. Elle est parvenue en un an à formaliser un accord entre Pasteur, l'Université de São Paulo (USP) et la Fondation Oswaldo Cruz (Fiocruz), qui prévoyait la mise en place d'une plateforme scientifique entre l'institut français et l'Université de São Paulo. Inaugurée en 2019, à la veille de la pandémie, la plateforme a permis de séquencer des variétés du nouveau coronavirus et de développer des tests de diagnostic. Forte de son succès, la plateforme est devenue en 2023 l'Institut Pasteur de São Paulo (IPSP), inauguré l'année suivante.

L'IPSP a ouvert ses portes il y a un an. Qu'avez-vous gagné avec cette nouvelle phase ?

Nous avons gagné en visibilité. Et nous avons rejoint le réseau international de l'Institut Pasteur en France, ce qui permet d'obtenir des financements du groupe pour envoyer des étudiants en formation à l'étranger ou faire venir des chercheurs de l'extérieur pour passer un temps dans notre unité. En installant la plateforme puis l'unité Pasteur sur son campus, l'USP a fait avancer les collaborations internationales. En mars 2024, lorsque le président Emmanuel Macron est venu à São Paulo pour inaugurer l'unité de l'Institut Pasteur, le recteur de l'USP, Carlos Carlotti, a signé un accord pour faire venir le bureau sud-américain du CNRS [Centre national de la recherche scientifique, la plus grande agence française de recherche fondamentale] à l'université. Comme Pasteur et le CNRS interagissent déjà en France, il est possible de créer des chaires et des laboratoires mixtes à l'IPSP.

Cela facilitera la coopération scientifique.

Absolument. Avec le passage de la plateforme scientifique à l'institut, nous ne dépendons plus de l'USP pour régler les questions administratives. Désormais, notre équipe doit faire face aux obstacles bureaucratiques, passer des accords avec des agences de développement et obtenir les autorisations de l'Anvisa [l'Agence nationale de surveillance sanitaire] et du ministère de l'Agriculture et de l'Élevage pour fonctionner. Nous avons également dû mettre en place le conseil d'administration et les comités d'éthique et de recherche. Comme l'Institut Pasteur de São Paulo est une association privée d'intérêt public à but non lucratif, nous devons toujours rechercher des fonds pour fonctionner et mener à bien nos recherches.

Comment sont organisés les équipes et les laboratoires ?

Nous disposons d'une surface de 2 000 m² (mètres carrés), qui peut accueillir jusqu'à 10 équipes. Elle est équipée à 75 %. Les laboratoires et les appareils sont multi-utilisateurs. Nous avons sept chefs de groupe, dont quatre sont également professeurs à l'USP. Dans le cadre

de l'accord, ils ont monté une équipe de recherche à l'IPSP et y consacrent 30 à 50 % de leur temps tout en conservant leur laboratoire d'origine. En 2021, l'USP et l'Institut Pasteur ont signé un accord avec la FAPESP pour financer quatre jeunes chercheurs pendant quatre ans. Au terme de cette période, ils pourront concourir pour un poste permanent à l'Institut Pasteur de São Paulo. Deux sont en activité et nous sommes en train d'en recruter un troisième. En ajoutant les techniciens, les doctorants et les stagiaires postdoctoraux, nous sommes presque 45 personnes. Je souhaite atteindre les 80 personnes.

Quels ont été les résultats les plus importants pendant ces six années ?

Durant la pandémie, nous avons séquencé les variantes du coronavirus (dont l'une pour la première fois dans le pays) et mis au point des tests de diagnostic. Nous avons aussi créé des modèles biologiques pour étudier des maladies. Nous allons publier quelque chose d'important sur la trypanosomiase africaine, la maladie du sommeil courante en Afrique qui est également présente au Brésil. Comme elle touche aussi le bétail, c'est un problème important dans l'élevage. La vache maigrit, produit moins de lait et fait des fausses couches. Nous n'avions pas de modèle pour travailler *in vitro* et étudier l'effet de la maladie sur le cerveau. La neuroscientifique Patrícia Beltrão Braga et moi-même avons obtenu des échantillons de cellules souches bovines auprès de la faculté de médecine vétérinaire et de zootechnie du campus de Pirassununga de l'USP, avec la chercheuse Fabiana Fernandes Bressan. Nous avons créé des mini-cerveaux bovins en laboratoire, quelque chose d'inédit dans le monde. Mais un problème s'est posé. Comment infecter les mini-cerveaux si le parasite n'envahit pas les cellules, s'il ne circule qu'à l'intérieur des vaisseaux sanguins et

si nos mini-cerveaux n'ont pas de vaisseaux sanguins ?

Comment avez-vous résolu le problème ?

J'ai envoyé une chercheuse de mon groupe, qui fait un postdoctorat avec le soutien de la FAPESP, suivre un cours sur la néovascularisation en Espagne. Elle est revenue deux semaines plus tard en sachant comment fabriquer des organoïdes de vaisseaux. Elle a ensuite fusionné les organoïdes vasculaires avec les mini-cerveaux bovins. Aujourd'hui, nous avons des mini-cerveaux bovins vascularisés. Nous devons publier dans les prochains mois. J'essaie d'établir à l'IPSP une culture commune en Europe. Quand on ne sait pas comment faire, on apprend avec ceux qui savent. Comme cela on ne perd pas de temps à essayer de répondre à des questions scientifiques. Nous incitons également des personnes qui n'ont jamais collaboré auparavant à travailler ensemble pour résoudre des problèmes spécifiques.

Vous avez obtenu des résultats ?

Sergio Costa, spécialiste en vaccins, et Luís Carlos de Souza Ferreira, qui travaille également sur les vaccins, ont testé des formulations de nouveaux immunisants contre le Sars-CoV-2 sur des animaux dans nos laboratoires. Ils ont très bien fonctionné.

Comment se passent les échanges avec les autres unités du Pasteur ?

Très bien. Le fait d'appartenir au réseau nous permet de participer à des appels internationaux pour les pays à moyens et faibles revenus. Nous venons de soumettre un projet à l'ANRS-MIE (Agence nationale de recherche sur le sida et les hépatites virales - maladies infectieuses émergentes) en partenariat avec un postdoctorant qui a travaillé avec moi et qui est devenu chercheur

permanent à l'Institut Pasteur de Paris, Guilherme Dias de Melo. Nous voulons étudier le rôle des co-infections par le virus Sars-CoV-2 et le virus de la grippe dans le développement de problèmes neurologiques tels que les maladies d'Alzheimer et de Parkinson. Vont participer à la recherche l'équipe d'Anna Pepe, de l'Institut Pasteur de Paris, qui travaille sur la cryomicroscopie électronique, et l'équipe de Luiz Roberto Giorgetti de Britto, de l'USP, qui étudie la neurophysiologie. Pendant la pandémie, nous avons collaboré avec les groupes d'immunité et vaccination et neurosciences de l'Institut Pasteur de Paris. En octobre, nous emmenons 15 étudiants collecter des échantillons d'eau et d'animaux sauvages en Amazonie. Ils viendront ensuite à l'IPSP pour les analyser à la recherche de virus émergents. Nous organiserons ensuite un forum sur la santé mondiale à São Paulo avec des chercheurs de l'Institut Pasteur de Paris, du Cameroun, du Sénégal, de la Guyane française, de la Guadeloupe et de l'université de Guyane.

Quels sont les défis pour l'avenir ?

Faire progresser deux de nos nouveaux laboratoires, le laboratoire d'éco-épidémiologie, diversité et évolution des virus émergents et le laboratoire de surveillance génomique et innovation en matière de vaccins. Dans le premier, Luiz Bentim Góes étudie les virus chez les chauves-souris et les rongeurs de la forêt atlantique brésilienne, à la recherche de variétés susceptibles de se propager à l'espèce humaine. Dans le deuxième, Rúbens Alves dos Santos travaille au développement de nouveaux vaccins à ARNm contre la grippe. En collaboration avec les hôpitaux, nous voulons développer la médecine translationnelle et transformer les résultats de la recherche fondamentale en nouveaux traitements. ●



Montage des lasers utilisés à l'IFSC pour refroidir des molécules

Arrêter des atomes

Un projet conjoint de chercheurs brésiliens et français développe des techniques pour refroidir et capturer des molécules ultrafroides

MARCOS PIVETTA

En 1992, alors qu'il était doctorant en stage à l'Université nord-américaine de Maryland, le physicien brésilien Luis Marcassa a fait la connaissance d'Olivier Dulieu, un collègue français qui se trouvait pour un temps au National Institute of Standards and Technology (NIST) sur le campus de Gaithersburg, une ville voisine de l'université. Les deux hommes se sont liés d'amitié et sont devenus de proches collaborateurs. Dans les années 1990, ils ont publié ensemble quelques articles scientifiques sur les collisions de molécules et d'atomes ultrafroids, maintenus à des températures proches du zéro absolu ou zéro Kelvin ($-273,15^{\circ}\text{C}$).

Au fil du temps, la collaboration est devenue occasionnelle et les travaux communs plus rares. Marcassa a poursuivi sa carrière à l'Institut de physique de São Carlos de l'Université de São Paulo (IFSC-USP). D'ailleurs, il a continué ses recherches au Laboratoire Aimé Cotton (LAC) de l'Université Paris-Saclay, dont il est aujourd'hui le directeur. Mais au début de la dernière décennie, les deux chercheurs ont repris leur ancien partenariat, désormais de manière plus systématique.

La coopération repose sur une division du travail qui s'appuie sur le point fort des deux groupes. Les expérimentations sont faites à São Carlos et la partie théorique des études à Paris. Marcassa coordonne actuellement un projet en partenariat avec les membres du LAC : « Ils nous aident à concevoir les expériences et à interpréter les résultats. [...] C'est l'un des meilleurs groupes de physique théorique sur les molécules et les atomes froids au monde ».

Dans le cadre de cette coopération, la partie des études réalisée à l'IFSC est financée par la FAPESP et celle réalisée au laboratoire de Paris par l'Agence nationale de la recherche (ANR). La physicienne Nadia Bouloufa-Maafa, du LAC, coordonne la partie française du projet : « L'équipe de Marcassa a une longue tradition d'expériences dans le domaine des collisions froides. [...] Nos groupes ont des compétences complémentaires. »

L'objectif principal du projet commun est de créer de nouvelles techniques laser et perfectionner celles déjà connues pour refroidir et piéger des molécules composées de deux atomes de rubidium (Rb_2), un métal alcalin extrêmement réactif, dans ce que l'on appelle l'état fondamental. En mécanique quantique, la théorie qui décrit le comportement de la lumière et de la matière à l'échelle atomique et subatomique, cet état correspond à l'énergie la plus basse qu'un système puisse présenter.

Dans cette condition, les molécules et les atomes ne sont pas excités (activés). Ils n'ont pas d'excès d'énergie et réduisent au maximum deux types de mouvements : la vibration et la rotation. Pour atteindre cet état également appelé équilibre stationnaire, dans lequel le système n'a pas d'énergie supplémentaire à perdre sous forme de chaleur ou de lumière, la molécule de rubidium doit être refroidie à des températures d'environ 10 milliardièmes de degrés au-dessus du zéro absolu.

Conserver des molécules dans leur état fondamental va stimuler les études sur la nature complexe des collisions entre atomes ultrafroids et révéler les propriétés des réactions chimiques au niveau quantique. « Nous pourrions voir comment les réactifs interagissent et génèrent le produit de ces réactions. C'est un domaine que nous appe-

lons la superchimie », explique Marcassa. En plus de gains potentiels en termes de connaissances fondamentales, ce stade de moindre énergie d'un système peut être une plate-forme utile pour le développement d'applications dans les champs de la communication et de l'informatique quantique.

Au cours des dix dernières années, les groupes de São Carlos et du LAC ont publié ensemble 14 articles, dont certains ont été écrits avant même la formalisation du projet actuel. En 2019, par exemple, ils ont publié dans *Physical Review Letters* un article sur le développement d'une stratégie plus simple pour refroidir les molécules de rubidium, qui n'utilise pas plusieurs faisceaux laser (mais un seul) ou des équipements coûteux.

Lors de l'expérience, qui a servi de test initial, les chercheurs ont réussi à abaisser la température de 74 % des 10 000 molécules de rubidium à des valeurs très proches du zéro absolu. En rapprochant les molécules de cet élément de leur état fondamental, la stratégie a pratiquement annulé la vibration des particules. En revanche, le résultat est moins significatif en ce qui concerne le mouvement de rotation.

La plupart des travaux des deux groupes visent à développer des techniques de piégeage et de refroidissement des molécules de rubidium, le système classique qui concentre la quasi-totalité des expériences du secteur. Actuellement, par exemple, les Brésiliens et les Français travaillent au développement d'une source capable de générer un laser puissant, mais avec un faisceau plus large que le laser standard. Ce type d'appareil pourrait produire des résultats plus significatifs dans des travaux avec des molécules de rubidium.

Parallèlement, le partenariat envisage de lancer des études et de tester des schémas de refroidissement avec d'autres composés diatomiques que le rubidium. Cette classe de molécules est formée par la liaison de deux atomes seulement, qui peuvent provenir du même élément chimique ou d'éléments différents. C'est le cas, respectivement, des molécules de césium (Cs_2) et du monofluorure de baryum (BaF), qui ont fait l'objet d'études récentes dans ce domaine. D'après Bouloufa-Maafa, « développer des techniques de refroidissement et de piégeage pouvant être appliquées à des molécules diatomiques 'chaudes' (qui sont à des températures plus élevées que le rubidium) pourrait être intéressant pour plusieurs domaines de la physique ». ●

Le projet et l'article scientifique consultés pour ce reportage figurent dans la version en ligne.

Une Amazonienne qui parle au monde

Après avoir été députée et ministre en France, l'économiste guyanaise s'apprête à contribuer à la COP 30 avec une étude sur la diversité des populations locales

MARIA GUIMARÃES



Lisez l'entretien complet

Née en Guyane, économiste de formation, Christiane Taubira a été députée française pendant 19 ans ainsi que députée européenne pendant cinq ans. Entre 2012 et 2016, sous le président François Hollande, elle a été garde des Sceaux, ministre de la Justice. Actuellement, à 73 ans, elle vit à Cayenne, sa ville natale.

Depuis octobre 2024, Mme. Taubira occupe la chaire José Bonifácio de l'Université de São Paulo (USP), au Brésil, attribuée chaque année à une personnalité ibéro-américaine pour conduire des études à propos d'un sujet brûlant d'actualité. Elle est la première titulaire francophone. Sa recherche, intitulée « Sociétés amazoniennes : des réalités plurielles, un destin commun ? », sera présentée à la conférence sur les changements climatiques (COP 30) qui se tiendra à Belém, au nord du Brésil, en novembre prochain.

Fin mars, Mme. Taubira a trouvé un créneau parmi des engagements à l'Université Fédérale du Pará et à l'Université de l'État du Pará pour accorder cet entretien à *Pesquisa FAPESP*, par appel vidéo.

Vous avez occupé la chaire José Bonifácio en octobre, avec un projet sur les sociétés d'Amazonie. Quels sont les buts de ce projet ?

J'ai accepté d'être titulaire de la *cadeira* José Bonifácio pour une année académique à cause de la nature de cette chaire, c'est-à-dire, de son ouverture sur des problématiques qui touchent les Amériques et, principalement, l'Amérique du Sud et Centrale. Je les ai intéressés davantage en tant que personnalité internationale : ancienne ministre de la Justice française, ancienne députée à l'Assemblée Nationale et au Parlement Européen. Pour moi, mon enracinement Amazonien faisait sens. J'ai donc choisi de travailler sur les Amazonies, dont je souhaite rappeler qu'elles sont plurielles, indépendamment de l'unité géographique.

L'ouvrage avec ces travaux sera-t-il présenté à la COP 30 ?

Oui. Je me rendrai à la conférence. C'est une des raisons pour lesquelles je passe quelques jours à Belém en ce moment. Je travaille avec les deux universités, la fédérale et celle de l'état du Pará. Je prends également des contacts institutionnels

avec les autorités de Belém et je m'inscris dans les trajectoires d'un certain nombre d'événements qui seront préparés pour ce sommet international. C'est pour cela que le livre doit être prêt en septembre.

À propos de la COP 30, la participation des peuples amazoniens est très discutée. Est-ce possible ?

Si ce n'est pas possible, ce sera un scandale. Ça ne se fait pas de venir chez les autres, de s'installer dans leur salon, de parler fort, de boire, de manger, de salir et de s'en aller ! Nous y serons nombreux, les associations se mobilisent. Il y aura aussi le sommet social, une zone verte, des espaces où des paroles plus libres pourront s'exprimer. Moi, j'ai quand même la possibilité de parler fort en tant que haute personnalité internationale, j'ai des opportunités d'expression dans des médias internationaux, et je dirai, à haute voix : « Attention à votre comportement, attention à votre expression, à ne pas être indifférent à ce qui se passe là où vous arrivez. » L'ONU [Organisation des Nations Unies] a été créée à un moment où le monde était impérialiste, à la sortie de la Deuxième Guerre Mondiale. L'Empire

Mme. Taubira lors
d'une visite chez
FAPESP, en mars

cheurs de s'interroger sur l'imaginaire multilatéral dans le projet sur l'Amazonie, de poser la question des Amazoniens dans leur unité géographique, de leur pluralité liée à l'histoire devenue nationale, de s'interroger sur la verticalité des relations entre les pays amazoniens et les anciennes métropoles coloniales, de leurs rapports avec l'ONU, les instances multilatérales, mais aussi de la perception que les instances multilatérales ont de l'Amazonie. Il est important d'admettre que les Amazonies sont diverses, contradictoires, multiples. Ce sont des communautés indigènes qui sont là depuis des milliers d'années et qui ont construit des réseaux urbains très denses. Ces communautés ont traversé des continents et se sont affrontées entre elles. Avec l'arrivée des Européens il y a eu, très vite, la traite et l'esclavage d'êtres humains, donc de nouvelles réalités sociales, de nouvelles communautés, tels les quilombolas ou les communautés de marrons dans mon Amérique à moi. Cette histoire a mené à des conflits, mais elle a aussi suscité des rencontres. Des mariages ou des métisages ont été réalisés, des échanges de connaissances ont eu lieu. Par conséquent, il y a des noms sur les végétaux, sur les lieux physiques, les collines ou les rivières qui sont « indigènes » et d'autres qui sont d'origine africaine. Il y a des noms créoles chez moi. Je souhaite que nous soyons capables de décrire les Amazonies telles qu'elles sont : indigènes, mais aussi des communautés métisses, des sociétés urbaines très sophistiquées, avec des constructions architecturales à forte influence européenne, comme l'Opéra de Manaus. Lorsque l'ONU dit qu'il faut sauver l'Amazonie, « le poumon vert de la Terre », c'est elle qui a un problème. Il faut qu'elle accepte que les gens qui y vivent sont conscients de ces réalités composites et que ces personnes, à travers leurs relations millénaires avec la forêt, connaissent cette biodiversité, savent établir des relations avec un rapport d'équilibre et de préservation. ●

Français existe encore, avec les territoires d'outre-mer, l'Empire Britannique aussi. On se bat toujours contre les métropoles coloniales. Donc, ce que je demande, c'est qu'on s'interroge sur cette empreinte qui existe dans l'imaginaire multilatéral.

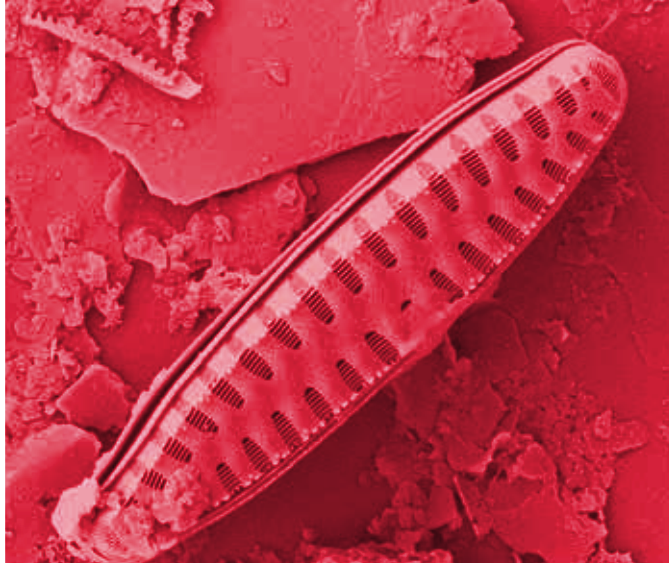
Vous avez cette position d'être, en même temps, européenne et amazonienne. Comment ces deux mondes se rejoignent-ils ?

Je prétendrais même - heureusement - qu'il y a plusieurs mondes en moi, et c'est ce qui fait un peu l'intérêt de ma présence dans des endroits très différents : je suis profondément amazonienne. Je suis également ce qu'on appelle une créole, guyanaise. Et aussi française sans aucun tourment, ni dans ma tête, ni dans mon cœur. J'ai accumulé une expérience de travail importante en Europe, mais je n'ai jamais cessé de circuler dans le monde en tant que responsable politique, dé-

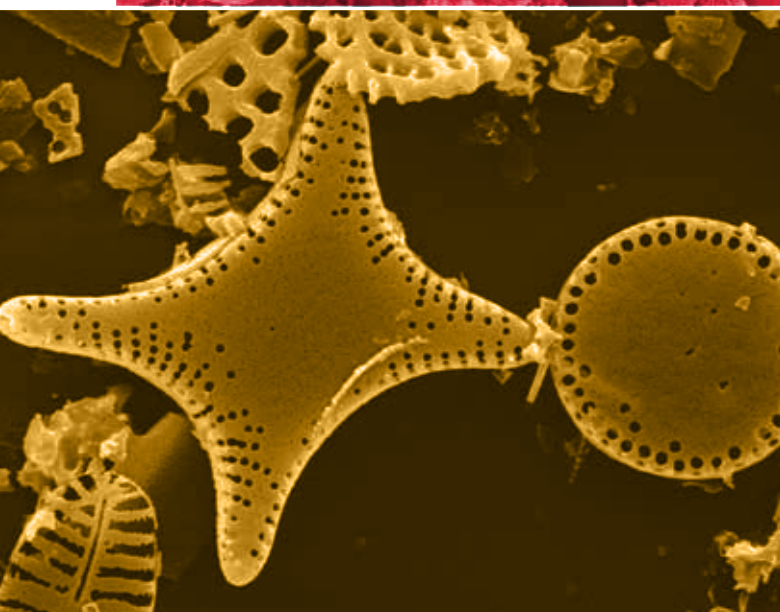
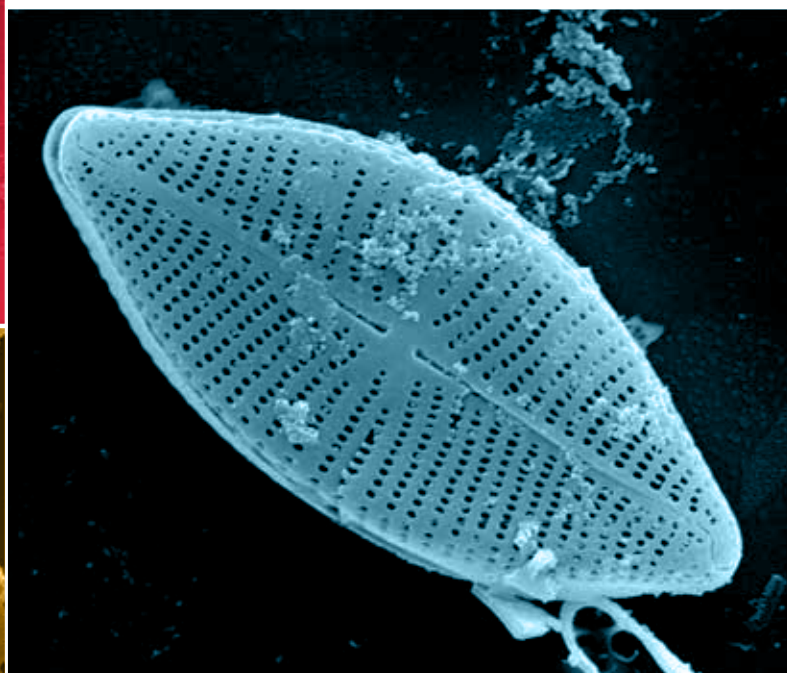
putée en France, députée au Parlement Européen. En 2008 j'ai rédigé, pour la présidence française de l'Union Européenne, un rapport sur les accords de partenariats économiques entre l'Union Européenne et les pays d'Afrique, des Caraïbes et du Pacifique. Cette très grande diversité d'expériences m'a rendue de plus en plus consciente de ce que venir d'Amazonie représente. Cela m'enracine aussi dans le monde : à force de traverser les sociétés, les continents, les périodes et les sujets, j'appartiens complètement à l'humanité. J'ai une conscience aigüe, permanente de cette appartenance.

Quand on parle de sauver l'Amazonie, on pense à l'intérêt global, on ne parle pas des réalités locales, culturelles. Comment peut-on les intégrer aux autres réalités ?

C'est tout à fait exact, et c'est pour ça que je demande aux chercheuses et aux cher-



Les assemblages de diatomées aident à la reconstruction de l'écologie ancienne de Colônia



PALÉOÉCOLOGIE

500 000 ans d'histoire environnementale

La coopération franco-brésilienne révèle des transformations environnementales dans la dépression de Colônia et forme de nouvelles générations de chercheurs

GUILHERME COSTA

Le Brésil était encore sur le chemin du retour à un régime démocratique lorsque la paléoécologue française Marie-Pierre Ledru y est venue pour la première fois. En 1985, alors qu'elle était encore étudiante de master à Paris, elle a été invitée par un professeur français à participer à des fouilles archéologiques. L'expérience a éveillé son intérêt pour la paléoécologie (l'étude des écosystèmes du passé à partir des preuves conservées dans les sédiments, les fossiles et autres archives naturelles) et l'histoire climatique des paysages tropicaux.

Depuis, elle est venue au Brésil à de nombreuses reprises. Pour donner des conférences, participer à des événements et, surtout, pour du travail de terrain. « Nous n'avons plus ce rapport à la recherche de terrain comme les Brésiliens. En France, il y a moins de nature, tout est urbanisé et on reste beaucoup dans les laboratoires. Or, quand je suis à la campagne, j'aime aller voir la végétation, l'espace, les communautés », explique la chercheuse sénior de l'Institut de recherche pour le développement (IRD), actuellement basé à Montpellier.

Au cours des 40 dernières années, Marie-Pierre Ledru a travaillé dans les universités de São Paulo, Brasília et Fortaleza ; elle a établi un réseau de coopération qui a donné lieu à plus de 200

articles universitaires. L'un d'entre eux, publié en décembre 2024 dans la revue *Palaeogeography, Palaeoclimatology, Palaeoecology*, étudie les changements environnementaux survenus au cours de centaines de milliers d'années dans la dépression de Colônia, située au sud de la ville de São Paulo. Il s'agit d'un cratère circulaire de 3,6 kilomètres (km) de diamètre qui s'est formé entre 30 et 5 millions d'années auparavant, probablement après l'impact d'une météorite.

« Nous avons découvert que la transformation du lac en tourbière dans la dépression de Colônia s'est déroulée en plusieurs phases, en commençant par le bord et en atteignant ensuite le centre », explique Gisele Marquardt, biologiste et première auteure de l'article, de l'Université fédérale du Paraná (UFPR). « Cela indique qu'il s'agit d'un processus plus ancien que ce que nous pensions – les données remontent à 500 000 ans – et plus complexe qu'une simple réponse aux changements climatiques ».

Le passage de lac à tourbière, un terrain détrempé semblable à un marais, aurait été influencé par des facteurs locaux tels que la géologie, les sédiments et la végétation, indiquant par là que les écosystèmes tropicaux peuvent réagir de manière variée aux changements climatiques. D'après la chercheuse, cela serait crucial pour identifier les changements futurs dans les zones inondées, ainsi que pour renforcer l'importance de la gestion adéquate de ces environnements.

Marquardt et Ledru travaillent ensemble depuis cinq ans, lorsque la Brésilienne faisait une recherche postdoctorale à l'Institut botanique de São Paulo, qui a été intégré en 2021 à l'Institut de recherches environnementales (IPA). Financé par la FAPESP, le projet visait à évaluer les changements des assemblages de diatomées (micro-algues unicellulaires à paroi cellulaire siliceuse) et à les utiliser comme marqueurs biologiques pour la reconstruction paléoenvironnementale dans la dépression de Colônia. C'est la botaniste Denise Bicudo, de l'IPA, qui a fait le lien entre les deux.

Actuellement à la retraite, Denise Bicudo a beaucoup travaillé sur l'étude des lacs et des milieux aquatiques anciens à partir des sédiments accumulés au fond de ces plans d'eau, un domaine universitaire appelé paléolimnologie. En 2017, alors qu'elle participait à un projet thématique également financé par la FAPESP sur la reconstruction environnementale des milieux aquatiques, elle a été invitée par un collègue de l'Institut des géosciences de l'Université de São Paulo (IGc-USP), l'hydrogéologue André Oliveira Sawakuchi, à participer à un travail à Colônia avec Ledru.

Selon Bicudo, « la possibilité d'analyser une carotte de sédiments de 50 mètres et de plus de 1,5 million d'années est une opportunité rare ». La

principale contribution de son équipe à l'époque a été d'introduire un front de recherche qui n'avait pas encore été envisagé, en utilisant les diatomées comme bioindicateurs. Le groupe a pu identifier les changements d'alcalinité, d'acidité et de salinité de l'eau, ainsi que des variations du régime hydrologique et de la qualité de l'eau au fil du temps.

L'approche a permis d'envisager le lac de la dépression de Colônia comme un capteur de ce système environnemental, capable de refléter les changements dans l'environnement terrestre, l'atmosphère et les conditions écologiques du plan d'eau lui-même. « Les données étant nombreuses et complexes, nous avons dû procéder à une interprétation conjointe. Et la coopération entre notre équipe et celle de Madame Ledru s'est très bien déroulée, ce qui nous a permis d'avancer dans les analyses », explique Bicudo.

La collègue française souligne que dans les études de reconstruction environnementale, il est nécessaire de rassembler tous les indicateurs possibles. Et le travail sur les diatomées mené par l'équipe brésilienne a été fondamental pour comprendre les étapes de transformation du lac en tourbière dans le cas de Colônia : « C'est important pour nous aider à comprendre l'avenir. Avec le changement climatique actuel et l'utilisation intensive de l'eau pour l'irrigation, de nombreux lacs s'évaporent.

En plus d'aboutir à des publications significatives et de faire avancer le domaine de la paléoécologie, le partenariat entre les chercheuses a également joué un rôle décisif dans la formation de nouveaux scientifiques, comme Gisele Marquardt. « Le projet de Colônia m'a donné une base solide », souligne-t-elle. L'impact sur la formation de jeunes chercheurs souligne l'importance des initiatives de coopération telles que les projets franco-brésiliens, en particulier dans des domaines hautement spécialisés. Dans le cas de la paléolimnologie – un domaine multidisciplinaire qui nécessite des connaissances en chimie, climatologie, taxonomie et écologie –, les possibilités d'emploi au Brésil sont encore très limitées.

Bicudo regrette qu'« il y [ait] très peu de spécialistes et [qu'ils soient] de moins en moins nombreux, presque en voie d'extinction. [...] Depuis que j'ai commencé la paléoécologie, j'ai formé des professionnels qui sont devenus très compétents. Le problème, c'est qu'ils ne trouvent pas toujours de travail. C'est aussi pour cette raison que ces coopérations sont importantes ».

Les projets et l'article scientifique consultés pour ce reportage figurent dans la version en ligne.

Un pont scientifique

Le spécialiste des nanotechnologies dirige la représentation du CNRS en Amérique du Sud et coordonne la coopération avec l'USP à travers l'IRC Transitions

GUILHERME COSTA



Liviu Nicu, chercheur en micro et nanotechnologies, est rapidement devenu un fin observateur du paysage académique sud-américain. Arrivé au Brésil en février 2022 pour un projet en collaboration avec l'Université Fédérale de Rio de Janeiro (UFRJ), il est nommé quelques mois plus tard directeur de la représentation du Centre National de la Recherche Scientifique (CNRS) en Amérique du Sud — l'un des 11 bureaux que l'organisme français déploie à l'étranger.

En tant que directeur, il contribue activement au développement des coopérations scientifiques entre le CNRS et les pays de la région, en s'appuyant sur les partenariats existants et en explorant de nouvelles opportunités de collaboration. Sa première mission l'a amené à travers

le sud du continent, du Chili à l'Uruguay, à la rencontre de collègues dans des universités partenaires. Il y présentait notamment un dispositif de coopération innovant du CNRS : les centres de recherche internationaux (IRC).

Dans ce contexte, l'Université de São Paulo (USP) est devenue un partenaire clé pour le CNRS, « grâce à la richesse et à la profondeur de ses coopérations pluridisciplinaires ». En mars 2024, l'IRC « Transitions » a été inauguré sur le campus de l'USP, à São Paulo. Il s'agit du cinquième centre de ce type lancé par le CNRS en collaboration avec une université, après ceux créés avec l'Université de l'Arizona et l'Université de Chicago, aux États Unis, l'Imperial College London, en Angleterre, et l'Université de Tokyo, au Japon. Un sixième centre a également été établi à l'Université de Sherbrooke, au Canada.

L'IRC a été inauguré début 2024 au Brésil. Où en sont les travaux de coopération, un an après ?

Nous avançons en trois étapes : d'abord, l'identification des communautés scientifiques dans chacun des sept domaines thématiques définis, comme piliers centraux — sciences humaines et sociales, écologie et environnement, océanographie, immunologie, technologies quantiques, sciences de l'informatique, agriculture et décarbonation. Vient ensuite la consolidation autour de projets financés. Enfin, à plus long terme, l'interaction entre disciplines. Après un an, certains domaines sont déjà bien structurés, avec des projets en cours et des communautés actives. D'autres avancent plus progressivement, selon les dynamiques propres à chaque domaine. L'interdisciplinarité, au cœur de l'ambi-

tion de l'IRC, sera développée dans une perspective de coopération sur dix ans.

Quels résultats concrets peut-on déjà observer ?

Plusieurs workshops ont été organisés, à São Paulo et en France, dans les domaines des sciences sociales, de l'informatique, de l'immunologie et de l'écologie/environnement. Il y a eu aussi un atelier virtuel en technologies quantiques, un workshop présentiel en agriculture et décarbonation, et un autre, en océanographie, est en préparation. Certaines communautés ont déjà soumis des projets, notamment dans le cadre de l'appel commun ANR-FAPESP. Des bourses de doctorat vont bientôt démarrer. Surtout, plusieurs chercheurs du CNRS sont déjà en poste au Brésil : un en immunologie, au campus de l'USP à Ribeirão Preto, trois en sciences humaines et sociales, installés sur le campus Butantã, à São Paulo et moi-même pour la recherche en ingénierie.

Comment l'IRC contribue-t-il à la formation de nouveaux chercheurs ?

Dès son lancement, l'IRC CNRS-USP a eu un effet amplificateur, attirant ainsi l'attention des chercheurs français. Depuis, la participation aux appels à projets franco-brésiliens – notamment ceux de l'ANR – a doublé. Pour soutenir cette dynamique, un programme de doctorat conjoint – le *PhD Joint Programme* – a été mis en place : chaque année, l'USP et le CNRS accordent chacun cinq bourses de thèse, permettant la création de binômes – un chercheur de l'USP et un du CNRS – qui encadrent chacun un doctorant. Ces équipes franco-brésiliennes contribueront à forger une nouvelle génération scientifique, portée par l'esprit collaboratif et interdisciplinaire du centre.

Ce programme de doctorat est-il limité aux sept domaines scientifiques définis par le centre ?

Non. Il a justement été conçu pour aller au-delà du cadre fixe des sept piliers thématiques. L'objectif est de maintenir une structure dynamique et flexible, capable d'évoluer en fonction des besoins de la coopération. Par exemple, même si l'ingénierie ou la physique nucléaire ne figurent pas parmi les domaines actuellement retenus, des projets de thèse dans ces champs peuvent tout à fait être soutenus dans le cadre du programme. Nous avons tout intérêt à collaborer avec d'autres domaines pour aborder ensemble des défis scientifiques de plus en plus complexes auxquels nous ne pouvons plus répondre en restant à l'intérieur de nos frontières (géographiques et disciplinaires) respectives.

Quels sont les engagements financiers respectifs de la FAPESP, de l'USP et du CNRS dans le cadre de ce programme ?

Les trois institutions ont signé un accord prévoyant un investissement de 30 millions de reais BRL par la FAPESP dans l'IRC de l'USP. Cette somme finance des bourses de doctorat et de post-doctorat, des workshops, ainsi que des équipements, exclusivement pour des projets menés à l'USP par des chercheurs du CNRS en collaboration avec leurs collègues brésiliens. Parallèlement, l'USP et le CNRS financent chacun cinq bourses de thèse dans le cadre du *PhD Joint Programme*. Le CNRS mobilise également d'autres instruments de coopération internationale : il soutient des projets internationaux, ainsi que d'autres programmes de recherche bilatéraux. Il prend aussi en charge les salaires des chercheurs français envoyés au Brésil pour des séjours de longue durée, souvent accompagnés de leurs familles.

Ce modèle de l'IRC pourra-t-il s'étendre à d'autres universités de São Paulo ?

Oui, tout à fait. Inspirée par la dynamique créée autour du partenariat CNRS-USP, la FAPESP a décidé d'élargir cette initiative à d'autres institutions. Elle propose désormais à chaque université — comme l'Unifesp [Université Fédérale de São Paulo], l'Unicamp [Université d'État de Campinas] ou d'autres — la possibilité de créer jusqu'à trois centres internationaux de recherche, chacun bénéficiant du même financement de 30 millions de reais BRL. Le Centre CNRS-USP est donc le premier de cette série, mais il ouvre la voie à d'autres partenariats internationaux structurés.

Votre propre recherche porte sur les micro et les nanotechnologies, n'est-ce pas ?

Oui, tout à fait. Même si mes fonctions actuelles sont très prenantes, j'ai tenu à poursuivre une activité scientifique. Je viens d'un laboratoire à Toulouse spécialisé en informatique, robotique, micro et nanotechnologies que j'ai dirigé pendant les six années précédant mon arrivée au Brésil et avec lequel je continue à collaborer. Par ailleurs, ma venue au Brésil en 2022 s'est faite dans le cadre d'un projet de recherche avec une équipe du département de mécanique de l'UFRJ, dans le domaine des métamatériaux mécaniques. Depuis, j'ai commencé à établir des collaborations plus larges avec des chercheurs à São Paulo et à São Carlos. Nous travaillons actuellement à la construction de projets conjoints dans le domaine des microsystèmes électromécaniques. J'y ai rencontré des équipes scientifiques remarquables, à la fois du point de vue théorique et expérimental, avec lesquelles le dialogue est très prometteur. ●

Pari sur les cafés sauvages

Des biologistes séquencent le génome de 33 espèces de ce genre en quête de gènes pouvant aider à faire face au réchauffement climatique prévu pour les années à venir

CARLOS FIORAVANTI

Des groupes de recherche de São Paulo et de France ont travaillé ensemble pour séquencer le génome de *Coffea arabica*, l'espèce de café la plus consommée au monde ; l'étude a été décrite en avril 2024 dans *Nature Genetics*. Désormais, ils se consacrent ensemble à une étude complémentaire : le séquençage et la comparaison des génomes de 33 espèces sauvages dans un premier temps, à la recherche de gènes pouvant être utilisés, par croisement avec des variétés commerciales, pour augmenter la résistance à un climat de plus en plus chaud et sec.

Romain Guyot, généticien de l'Institut français de recherche pour le développement (IRD) a déclaré à la revue *Pesquisa FAPESP* : « Les deux espèces cultivées de café, *C. arabica* et *C. canephora*, sont de plus en plus affectées par le changement climatique ». Le chercheur est responsable de la partie française du projet *Bridges Coffea*, un projet qui a pu voir le jour grâce à un accord de coopération entre la FAPESP et l'Agence nationale de la recherche (ANR). « On estime qu'au cours des 30 prochaines années, jusqu'à 50 %

des zones actuelles de culture du café pourront devenir impropres à la plantation ».

Grâce à ce travail conjoint, le coordinateur du projet au Brésil, le généticien Douglas Silva Domingues de l'École supérieure d'agriculture Luiz de Queiroz de l'Université de São Paulo (Esalq-USP), a reçu en octobre 2024 les données des partenaires français et a commencé à analyser les génomes de trois espèces sauvages. Les échantillons proviennent d'Afrique parce que la législation permet un prélèvement plus facile qu'au Brésil. L'Institut agronomique de Campinas (IAC), qui participe à la recherche, conserve des spécimens de ces espèces qui n'ont pas encore été séquencées et les utilise depuis les années 1950 dans des programmes classiques d'amélioration génétique, en croisant différentes espèces – un travail qui, pour chaque nouvelle variété, peut prendre des décennies. « Ce que nous voulons savoir, c'est quels gènes ont été ou pourraient être utilisés pour améliorer la qualité et la résistance aux maladies », explique Domingues.

L'une de ces espèces, *C. racemosa*, résiste à l'un des principaux fléaux des caféiers, l'insecte

Les esp. *Coffea heterocalyx* (ci-dessus) et *C. liberica* (ci-dessous) sont des exemples des différents formats de fruits des variétés sauvages de café



connu sous le nom de mineuse des feuilles de caféier (*Leucoptera coffeella*) ; elle a été utilisée à l'IAC pour produire un hybride capable de survivre à la maladie. La *C. ramosa* est également intéressante pour une autre raison : elle contient moins de la moitié des teneurs en caféine de la *C. arabica* et un quart de celle de la *C. canephora*. Une autre espèce, *C. liberica*, est résistante à la rouille, une maladie dévastatrice causée par le champignon *Hemileia vastatrix*. Elle produit de gros grains, de la taille d'une cerise, et a fait l'objet d'une attention particulière dans les programmes d'amélioration en Asie parce qu'elle nécessite peu de soins une fois plantée.

À l'inverse, la troisième espèce, *C. stenophylla*, produit des grains petits et en faible quantité, mais elle résiste bien aux températures élevées et à la sécheresse. Domingues pense que la *C. stenophylla* pourrait aussi être utilisée parce que son goût est plus proche de celui de la *C. arabica* de haute qualité : « Le groupe français analyse également d'autres espèces qui ne sont pas présentes au Brésil, comme celles de Madagascar, qui poussent dans des sols sablonneux à des températures supérieures à 35 degrés Celsius ».

Dans son laboratoire, Domingues et la pharmacienne Daisy Sotero Chacon, parcourent 18 fichiers sur l'écran de l'ordinateur. Ils sélectionnent et regroupent les gènes pour savoir d'abord, en fonction de la proportion dans laquelle ils apparaissent, si les génomes sont complets ou s'ils doivent demander plus de lectures.

Ensuite, la comparaison des génomes ne sera pas simple en raison des différences de taille entre eux, qui vont de 470 millions de paires de bases (mpb) à 900 mpb. Utilisée comme support pour les comparaisons parce qu'elle cumule des gènes de deux espèces, la *C. arabica* a 1 276 mpb. Le genre *Coffea* comprend environ 140 espèces, dont 66 sont originaires des îles du sud de l'Afrique. Les espèces sauvages peuvent aussi être consommées ou utilisées dans des programmes d'amélioration génétique.

D'après Domingues, « la comparaison des génomes devrait prendre au moins six mois ». Le généticien est allé étudier en France pour la première fois en 2006, dans le cadre de son doctorat en génétique de la canne à sucre au Centre de coopération internationale en recherche agronomique pour le développement (Cirad) de Montpellier. En 2011, il a reçu un courriel de Guyot l'invitant à participer à des projets de recherche sur la génétique du café. L'année suivante, ils ont obtenu leur premier financement de recherche commune grâce à un appel d'offres du gouvernement fédéral.

« Notre point de départ est toujours basé sur des défis réels au Brésil, tels que le changement climatique et son impact sur la production de café », explique Guyot. « À partir de là, nous formulons des hypothèses et produisons les données nécessaires pour les tester en collaboration avec des instituts agronomiques. La clé de la réussite d'un projet quel qu'il soit consiste à comprendre les défis spécifiques au Brésil et à les aligner avec les besoins scientifiques de nos partenaires ».

Guyot est venu au Brésil en mars dernier. À l'Esalq, il a participé à des analyses de données sur les génomes avec Domingues et son équipe, et il a visité des zones expérimentales telles que l'IAC. Il s'est également rendu à Botucatu et a rencontré le généticien Celso Luís Marino, de l'Université de l'État de São Paulo (Unesp), avec lequel il collabore à un projet de recherche sur la diversité génétique de l'arbre *aroeira* (*Myracrodruon urundeuva*) et ses mécanismes d'adaptation à différents environnements naturels au Brésil. Le généticien français s'est félicité des « échanges [...] très enrichissants pour les deux parties. [...] Ce transfert de connaissances et de formation est extrêmement important pour moi ». ●

Les projets et l'article scientifique consultés pour ce reportage figurent dans la version en ligne.



Les fruits de l'esp. *Coffea racemosa* (ci-contre), avec une faible teneur en caféine, et de *C. humblotiana* (ci-dessus), une autre variété sauvage à séquencer

CLIMATE CHANGE



Global levels rise, while national levels fall



Greenhouse gas emissions are increasing worldwide but are decreasing in Brazil because of reduced deforestation in the Amazon

MARCOS PIVETTA — illustrations ANDRÉ KITAGAWA

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Global greenhouse gas (GHG) emissions reached a record high in 2023, at 57.1 billion tons of carbon dioxide equivalent (CO₂eq). The figure is 1.3% higher than that in the previous year, according to a report released by the United Nations Environment Programme (UNEP) at the end of October. The growth rate was higher than that over the previous decade (from 2010 to 2019), when, before the outbreak of COVID-19, emissions increased by an annual average of 0.8%. In 2020, at the height of the pandemic, the suspension of many activities worldwide caused a decrease of almost 5% in the total emissions, the largest decrease recorded since the 1970s.

This year, global emissions increased in four of the five major GHG-producing sectors: energy, industrial processes, agriculture, and waste treatment. Only the land use, land-use change, and forestry (LULUCF) category exhibited the release of lower greenhouse gas emissions in 2023 than those in the previous year. The process most notably influencing the total emissions of this sector is the removal of vegetation, especially the clearing of forests, to create space for agriculture and livestock.

“The problem in Brazil is that the national inventory underestimates carbon dioxide emissions from forest fires and degradation in vegetation,” noted Luciana Gatti, head of the Greenhouse Gas Laboratory (LaGEE) of the Brazilian National

Institute for Space Research (INPE). Apart from agriculture, in which carbon can be stored in soil (its removal is not usually accounted for in carbon inventories), the LULUCF sector is the only sector that, in addition to producing emissions, can also naturally remove carbon dioxide from the air (other sectors only emit GHGs).

Well-preserved green areas can remove more CO₂ from the atmosphere via photosynthesis, thereby storing carbon in biomass, than they emit through respiration. Owing to its dense tropical vegetation, the Amazon has always been considered an area of the planet that absorbs more carbon than it emits. Recent studies, such as the research of Gatti’s team, have indicated that, owing to deforestation and progressive degradation, parts of the Amazon are losing the capacity to provide this ecosystem service that reduces global warming.

Today, most analyses indicate that the global temperature is at least 1.2 °C higher than the reference values during the preindustrial era in the second half of the nineteenth century. Various studies have revealed that this level of warming has led to deterioration in some of the planet’s vital signs, such as rising sea levels and the intensification of extreme weather events. Since 2023, however, a global temperature increase of 1.5 °C has been recorded several months in a row, although it is still considered a temporary increase.

According to the UNEP report, there has been an increase in the emission of four gases that con-

tribute to global temperature increase: carbon dioxide (CO₂), which alone causes three-quarters of the total global warming, driven primarily by the burning of fossil fuels (oil, gas, and coal); methane (CH₄), which is released mainly through agriculture and leakage during natural gas exploration; nitrous oxide (N₂O), which is present in agricultural fertilizers and animal waste; and hydrofluorocarbons (HFCs), which are used in refrigeration systems.

In statistics, the emissions of methane, nitrous oxide, and HFCs are commonly converted into their equivalents in CO₂. The established conversion equation indicates that in one century, the production of one ton of methane or nitrous oxide heats the atmosphere to the same extent as that due to 25 or 298 tons of CO₂, respectively. For HFCs, which encompass a family of artificially produced gases, the conversion factor often exceeds one thousand.

If the current upward trend in GHG emissions is not reversed, there is zero chance of limiting global warming to 1.5 °C, i.e., the target established by the Paris Agreement in 2015, and the global temperature will increase by an estimated 2.5 °C to 3 °C by the end of the century. This level of warming would be catastrophic, resulting in a very high cost to human life and the global economy. “To achieve a least-cost pathway toward [limiting global warming to] 1.5 °C, emissions must fall 42% by 2030 compared with 2019 levels,” Danish economist Inger Andersen, UNEP’s executive director, said in the document’s foreword. Another way would be to reduce emissions by 7.5% every year from now until 2035.

EMISSIONS IN BRAZIL DECREASE

Unlike most of the planet, GHG emissions in Brazil significantly decreased last year. According to the Greenhouse Gas Emissions and Removals Estimation System (SEEG), which is managed

by a network of nongovernmental organizations known as the Climate Observatory, the country emitted 2.6 billion gross tons (not including removal) of CO₂eq into the atmosphere in 2023, which is 12% less than that in 2022. It was the largest decrease over the last 15 years.

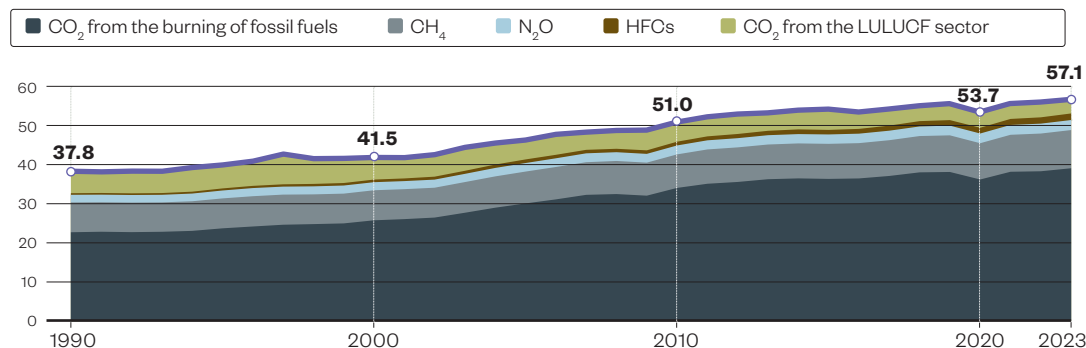
The sector that contributed most to the country’s emissions was land-use change (46%), historically the leader in GHG production in Brazil, followed by agriculture (28%), energy (18%), waste management (4%), and industrial processes (4%). With respect to net emissions (the gross total emissions minus the carbon removed from the atmosphere through the photosynthesis of growing vegetation), the amount of GHGs released into the atmosphere by Brazil in 2023 was approximately 1.6 billion tons of CO₂eq.

The data from SEEG are not official, but they closely follow the methodology recommended by the United Nations Intergovernmental Panel on Climate Change (IPCC). “By the end of this year, we will create a new inventory of net greenhouse gas emissions [considering removal by the LULUCF sector] up to the period of 2022,” said Márcio Rojas, head of climate science and sustainability at the Brazilian Ministry of Science, Technology, and Innovation (MCTI). “Our numbers are usually very similar to the net emission figures calculated by SEEG, which uses the national inventory as a reference.”

The most recent information from the ministry’s National Emissions Registration System (SIRENE) pertains to 2020, the year the pandemic began. Brazil emitted 1.7 billion tons of CO₂eq that year, 38% of which stemmed from the LULUCF sector and 28.5% stemmed from agriculture, according to SIRENE. The energy, industrial processes, and waste management sectors accounted for 23.2%, 6.1%, and 4.2%, respectively, of the total GHG emissions.

All the greenhouse gases

Global emissions of carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons (billions of tons of CO₂eq)



SOURCE UNEP EMISSIONS GAP REPORT 2024





The reduction in emissions in Brazil in 2023 was due to the particular nature of its economic model. The country's total GHG output was lower last year owing exclusively to a 24% decrease in emissions from the land-use change sector. In the other four sectors that release carbon into the atmosphere (energy, agriculture, industrial processes, and waste management), emissions increased in Brazil in 2023, according to SEEG. "In Brazil, land-use change has historically dictated the dominant trend in the production of greenhouse gases," explained David Tsai, a chemical engineer from the Institute for Energy and the Environment (IEMA) and coordinator of SEEG. "It serves as a kind of modulator, a regulator of the intensity of the total emissions."

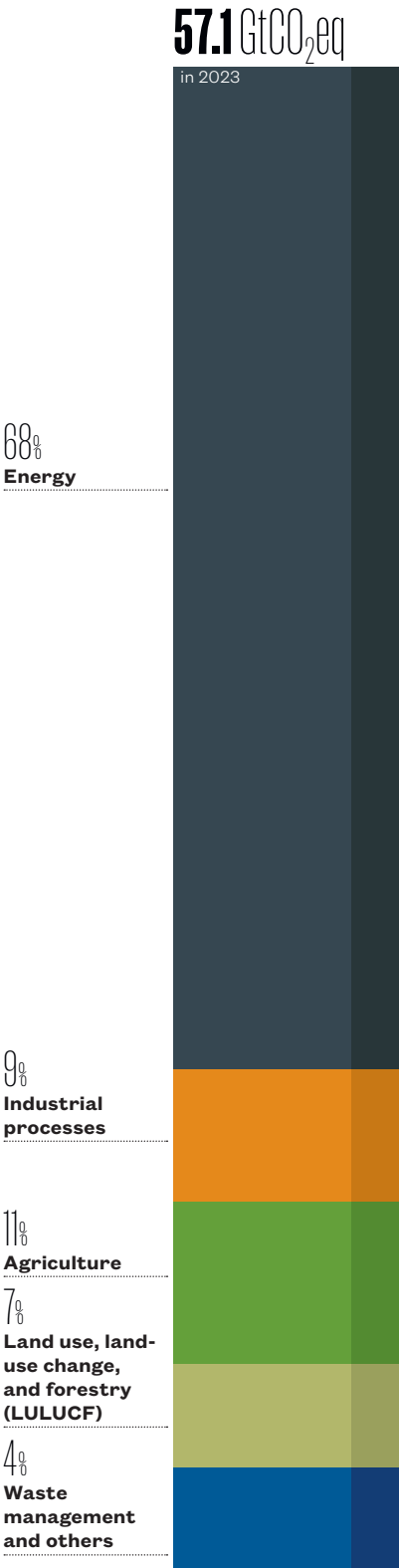
Among the major countries and blocs that currently emit the most GHGs into the atmosphere, such as China (30% of the total emissions), the USA (11%), India (8%), the European Union (6%), and Russia (5%), the sector that accounts for most of the greenhouse gas emissions is, by far, energy. Despite recent advances in the use of wind and solar energy, the energy mix in these countries still relies heavily on the consumption of oil, gas, and coal. Thus, in these areas and globally, the burning of fossil fuels is still the major driver of global warming. The USA has emitted the most GHGs since the mid-nineteenth century, accounting for approximately 20% of the total GHGs since 1850.

Brazil has a cleaner energy mix than other countries do. More than 80% of its electricity originates from renewable sources, such as hydroelectric, solar, and wind power plants, and a significant proportion of the country's vehicles run on biofuel. Despite this fact, depending on the year and the source consulted, the country is still the fifth or sixth largest emitter at present, accounting for 2% or 3%, respectively, of the total GHG emissions. As a global leader in crop and cattle farming, the country produces a large volume of GHGs through agriculture. In Brazil, this sector plays a greater role in determining the total emissions than that in most other major economies.

Tsai noted that a significant change in a single parameter in the land-use change sector was responsible for the decrease in the total GHG emissions in the country in 2023: a significant decrease in deforestation in the Amazon, the largest tropical forest on the planet, 60% of which is located in Brazil. Approximately 4,500 square kilometers (km²) of the biome was deforested in the Brazilian territory in 2023, 62% less than in the previous

Influence of each sector

Sectors that produced the highest greenhouse gas emissions worldwide in 2023 (as a percentage of the total emissions)

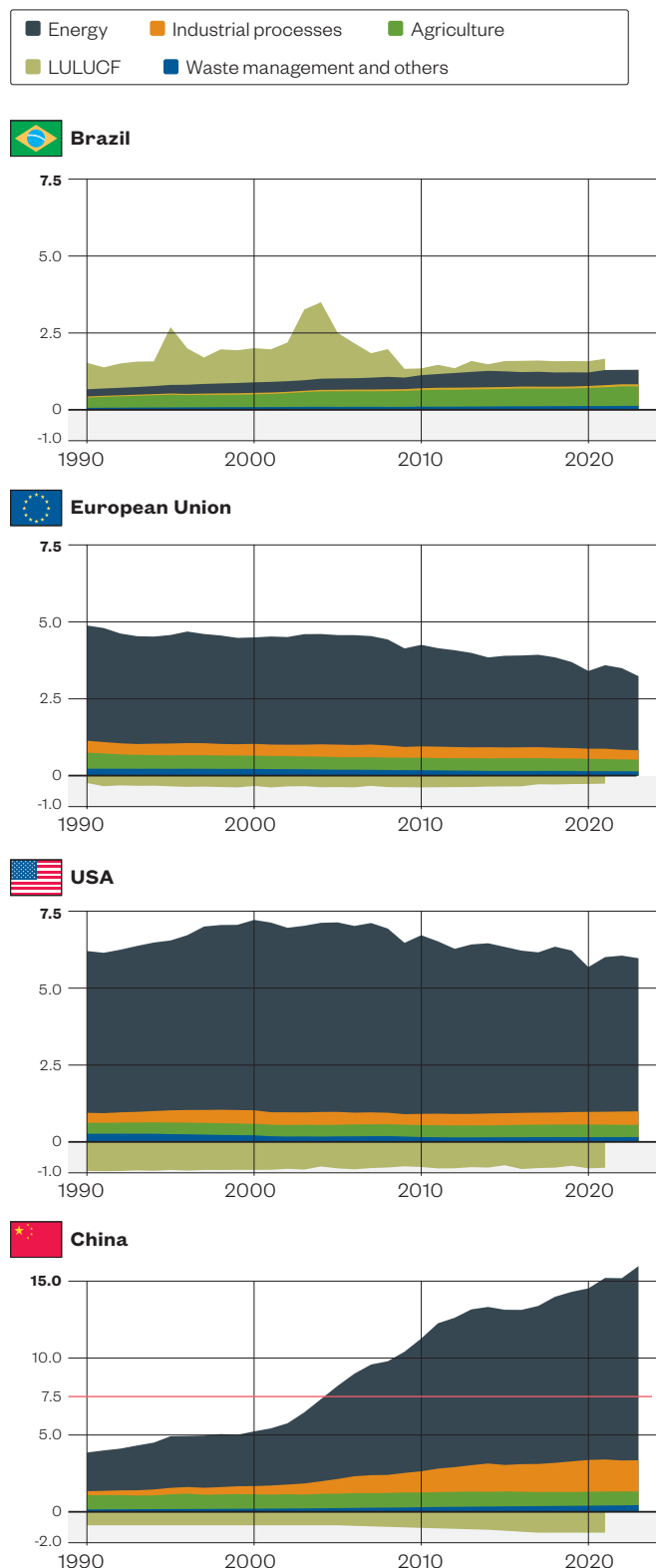


The total does not add up to 100% because not all sources of GHGs are known
SOURCE UNEP EMISSIONS GAP REPORT 2024

Emission profile by country

The energy sector is the largest producer of greenhouse gases in most major economies; in Brazil, the main producing sectors have historically been the agriculture and LULUCF sectors

IN BILLIONS OF TONS OF CO₂EQ



SOURCE UNEP EMISSIONS GAP REPORT 2024

year, according to a report issued by MapBiomass, another Climate Observatory initiative.

The official data used by the Brazilian government in international negotiations also suggest a recent and significant decrease in deforestation in the “Legal Amazon,” a political and administrative concept that encompasses almost 60% of Brazil’s territory, including the entire Amazon biome, 20% of the Cerrado (a wooded savanna biome), and a small area of the Pantanal. According to information released in early November by the Brazilian Amazon Deforestation Satellite Monitoring Program (PRODES), a project managed by INPE, 6,288 km² of the Legal Amazon was deforested in 2024, 31% less than in the previous year.

“Deforestation trends, especially in the Amazon, exert a major impact on the profile and volume of greenhouse gas emissions,” noted Rojas from the MCTI. Data from MapBiomass and PRODES generally indicate the same major trend with regard to deforestation in the Amazon, although they cannot be compared directly owing to methodological differences.

The cleaner energy mix and the notable influence of deforestation and agriculture on the total emissions make Brazil a unique country in the international landscape of greenhouse gas production. Approximately three-quarters of emissions in the world’s largest economies results from activities and processes that depend on the burning of fossil fuels. In China, the USA, and the European Union, the LULUCF sector (and even agriculture) generally exerts a lower influence on the total amount of carbon emitted into the atmosphere.

During the 2024 United Nations Climate Change Conference (COP29), held in Baku, Azerbaijan, between November 11 and 22, Brazil announced a new commitment to reduce emissions from 2030 to 2035. Referred to as the nationally determined contribution (NDC), Brazil’s target for 2035 is to reduce its net greenhouse gas emissions (considering carbon removal through forest maintenance) to between 59% and 67% of 2005 levels. In numerical terms, this would amount to a reduction in emissions in Brazil to between 850 million and 1.05 billion tons of CO₂eq per year.

The new NDC, one of the commitments required from all 196 signatory countries of the Paris Climate Agreement as part of the effort to limit global warming to 1.5 °C, was considered complacent by many environmentalists. This opinion is not shared by Roberto Schaeffer, an engineer from the Alberto Luiz Coimbra Institute



for Engineering Research and Graduate Studies at the University of Rio de Janeiro (COPPE-UFRJ). “The goal is very ambitious,” said Schaeffer, a professor in UFRJ’s energy planning program, whose team conducted the studies (not yet published) supporting the new NDC target at the request of the Brazilian government. “If we eliminate deforestation, emissions from the LULUCF sector will plummet rapidly, as will the country’s total GHG emissions. When this happens, Brazil’s emission profile will become more similar to those of other countries. From then on, we will also have to try even harder to reduce emissions from sectors other than the LULUCF sector alone while simultaneously encouraging GHG removal through the preservation and restoration of forests.”

Once this new hypothetical scenario is established, Brazil would exhibit a smaller carbon footprint, but it would also find it more difficult

to continue drastically cutting its emissions. The reason is that the four other major sectors that produce GHGs (energy, agriculture, industrial processes, and waste management) respond much more slowly to changes designed to reduce emissions. “Methane production by cattle, for example, will not decrease radically overnight, even if it is possible to partly reduce emissions resulting from enteric fermentation in livestock,” explained Schaeffer.

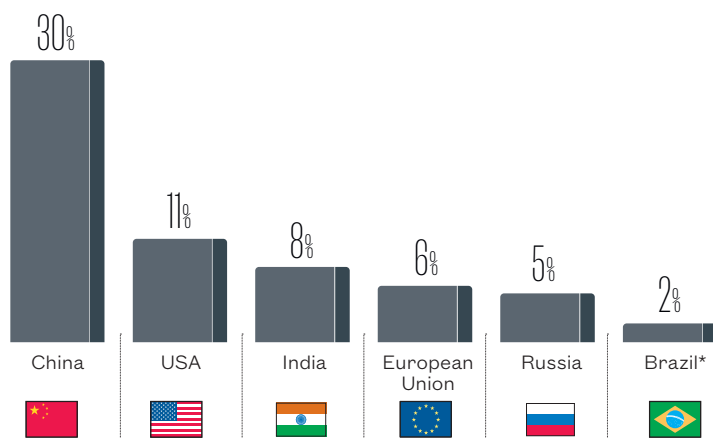
It is still too early to obtain global GHG emission data for 2024. However, the Global Carbon Budget (GCB), published annually since 2006, was released in November (not yet published in a scientific journal), providing an estimate of the year’s emissions of CO₂ alone, not including other GHGs. The figures outlined in the 2024 GCB, often employed as a reference, are cause for concern. The total carbon dioxide emissions are projected to set a new record of 41.6 gigatons by the end of December, 2.4% more than that in 2023.

Severe droughts caused by the El Niño climate phenomenon in 2023 and 2024, one of which still impacts the Amazon, have exacerbated emissions from deforestation and forest fires that cause vegetation degradation. “The impacts of climate change are becoming increasingly dramatic. However, we still see no sign that the burning of fossil fuels has peaked,” said Pierre Friedlingstein, from the University of Exeter, UK, in a press release.

In the Brazilian Amazon, deforestation continued to decrease this year. However, the number of forest fires in several biomes was very high, especially in the first half of the year, a period when few fires normally occur. Owing to this situation in Brazil, in addition to the global trend of continuously increasing emissions at a time when countries should reduce their carbon footprint—as promised in previous NDCs—optimism is currently low. However, giving up is not an option. We only have one habitable planet. ●

Largest emitters

The contribution of each country and bloc to the global greenhouse gas production in 2023



*The data are underestimated as emissions from land-use change are not accounted for
SOURCE UNEP EMISSIONS GAP REPORT 2024

Clear signs of recovery

FAPESP Annual Report shows that São Paulo's scientific community regained momentum in 2023

FABRÍCIO MARQUES

Published in September 2024

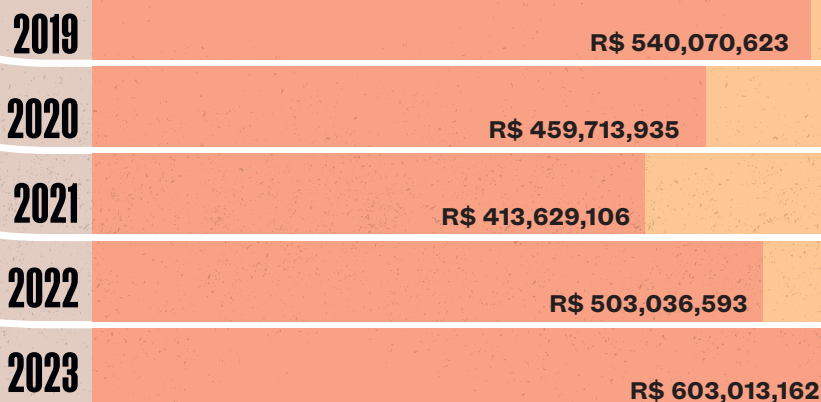
In 2023, FAPESP invested R\$1,366,291,568 in 23,029 research projects, 15.5% more than was invested in 2022. The number of projects was 11.2% greater than the previous year, although it was still less than the 24,806 projects funded in 2019, prior to the COVID-19 pandemic. One indicator that increased significantly was the number of new projects started, which, at 10,266, was 18% higher than in 2022, reversing the downward trend in the number of research proposals submitted that was caused by the global health crisis.

“After three years of decline in the number of proposals submitted to FAPESP, there were clear signs of a recovery in demand for both fellowships and research grants in 2023,” wrote the president of FAPESP’s Board of Trustees, Marco Antonio Zago, in a statement that accompanied the release of the *FAPESP Annual Report 2023* in July. “This is a result of the fact that most laboratories and postgraduate programs have returned to normal functioning, but it is also due to steps taken by FAPESP to encourage the resumption of research in São Paulo.” An overview of the measures adopted over the last year is included in the report, which is available on the foundation’s website. Annual funding data are also available for every year since 1962, when FAPESP began operating.

The impacts of the pandemic can be seen in some of the indicators, such as scientific output, which decreased for the second consecutive year in 2023. Data from Clarivate Analytics show that the number of articles published by authors from São Paulo, which reached 30,700 in 2021, fell to 26,200 in 2022 and then to 23,700 in 2023. In Brazil as a whole, 73,400 articles were published in 2021, 62,700 in 2022, and 56,300 in 2023.

The increase in demand began to become apparent in March, in an overview of “first projects” submitted to FAPESP in 2023 by researchers who had not previously applied for funding from the foundation. There were 4,483 proposals in total—26% more than the year before the

FELLOWSHIPS



pandemic. “The ability to attract new talent and ensure that their education and research are funded by FAPESP is essential to preserving the quality of São Paulo’s science, technology, and innovation system,” explained FAPESP’s scientific director, Marcio de Castro Silva Filho.

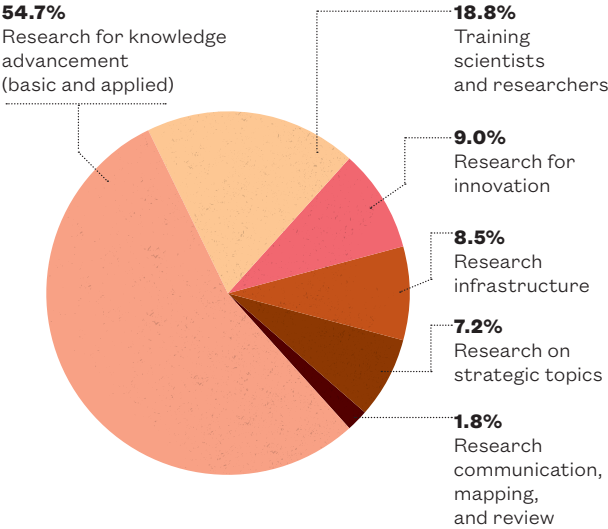
The report revealed a substantial increase in fellowships for research abroad, with 1,140 ongoing in 2023, 37% more than in 2022. The amounts invested in these fellowships, which include periods spent overseas by researchers affiliated with research institutions in São Paulo or FAPESP fellowship beneficiaries at different stages of their education from undergraduate to postdoctorate, grew by 51%. The number of fellowship beneficiaries at Brazilian institutions increased by 5.9%, and the amount funded increased by 7%. In total, R\$256.8 million was spent on 7,856 fellowships in Brazil and abroad during the year. In 2023, FAPESP’s Board of Trustees approved a 33% increase in the budget for fellowships abroad, which had been unchanged since 2012, and a 6.7% increase in fellowships in Brazil. The foundation continued to reformulate its fellowship values in 2024, with adjustments of up to 45% in some categories.

While investments in training scientists and researchers, which translated into fellowships, accounted for 18.8% of the funding allocated by FAPESP in 2023, the largest share (54.7%) was spent on research for knowledge advancement, with R\$747 million invested compared with R\$633 million in 2022. This category includes basic and applied research and covers regular grants, thematic grants, the Young Investigators at Emerging Centers program, and Research, Innovation, and Dissemination Centers (RIDCs).

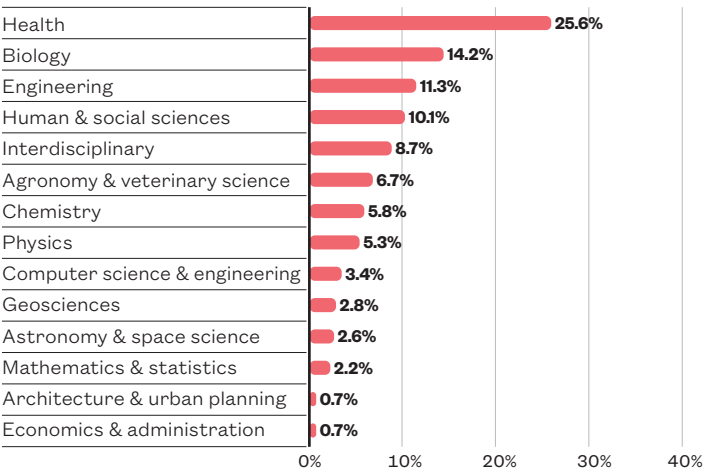
In 2023, FAPESP announced the selection of five new RIDCs in the fields of health science, biology, agronomy, and veterinary science. The Federal University of São Paulo (UNIFESP) became the host institution for an RIDC that focuses on antimicrobial resistance, whereas the Luiz de Queiroz College of Agriculture of the Uni-

Investment in 2023

BY FUNDING CATEGORY

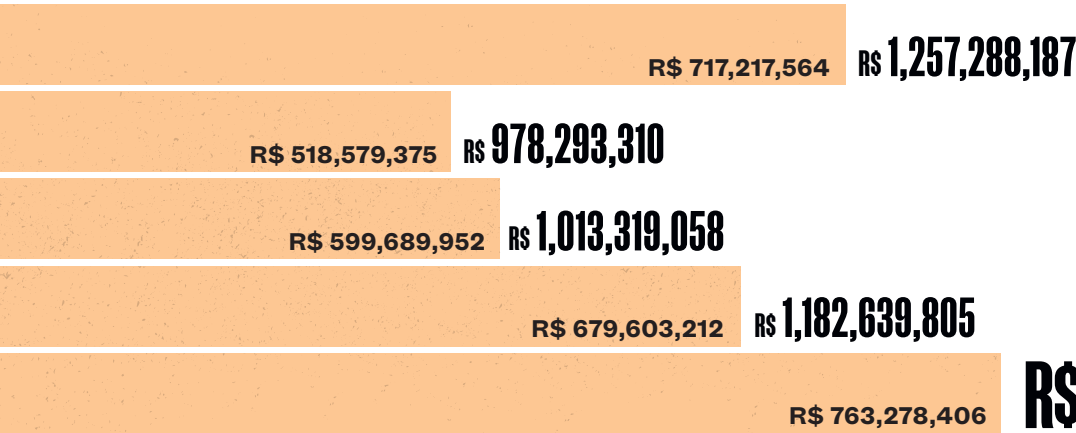


BY FIELD

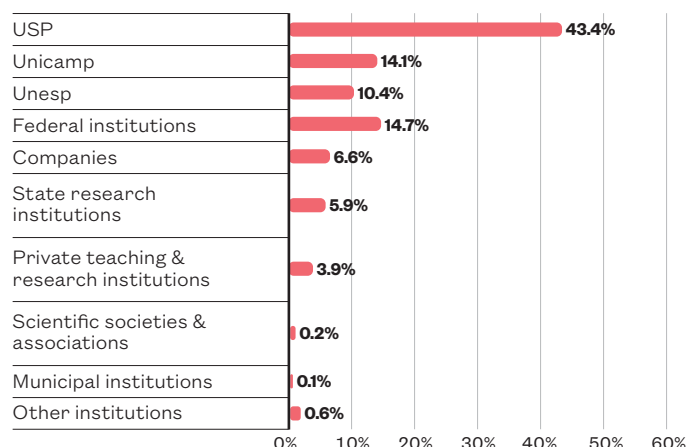


GRANTS

TOTAL



Investment in 2023 by institution



Commitments made

Funds committed to the following years for payment of approved fellowships and research grants – in R\$, as of 12/31/2023

TOTAL

R\$ 2,587,653,866

GRANTS

R\$ 1,940,630,415

FELLOWSHIPS

R\$ 647,023,451

versity of São Paulo (ESALQ-USP) was chosen to create a center for research on carbon in tropical agriculture. The Hematology and Hemotherapy Center at the University of Campinas (Hemocentro-UNICAMP) now has an RIDC that aims to innovate in theranostic medicine, which involves the use of nanotechnology to diagnose and treat cancer, while the Biosciences Institute at São Paulo State University (IB-UNESP), Rio Claro campus, founded a center to investigate the dynamics of biodiversity in the context of climate change. The Research Center for Bacteria and Bacteriophage Biology (B3), based at USP's Chemistry Institute, is studying the reproductive mechanisms and behavior of bacteria and their main predators. These research centers, which are dedicated to topics at the forefront of knowledge, will receive long-term investment for up to 11 years.

The research for innovation category received R\$122,852,931, equivalent to 9% of all FAPESP funding in 2023. A call for proposals was issued for another Engineering Research Center (CPE) to study citrus farming in partnership with the company Citrosuco. There were 18 CPEs operating in 2023 that collaborated with companies such as Shell, GSK, EMBRAPA, and Embraer in addition to groups of institutions such as USP, UNICAMP, UNESP, and Insper.

Work also began on three of the 10 Applied Research Centers (CPAs) for Artificial Intelligence that were selected through a 2021 call issued in conjunction with the Ministry of Science, Technology, and Innovation, the Ministry of Communications, and the Internet Steering Committee of Brazil (CGI.br). A survey conducted by FAPESP's Planning, Studies, and Indicators team and Research for Innovation department revealed the impact of the CPE/CPA partnership model: for every R\$1 of public funds spent, R\$4.8 was contributed by partner companies and institutions.

The Innovative Research in Small Businesses (PIPE) program established new initiatives, such as PIPE Start, which supports entrepreneurs in the initial process of validating innovative technological solutions. The foundation issued calls for the accreditation of accelerators and seed capital equity investment funds. "We are interested in hearing proposals from investment funds whose aims converge with ours, which is to fund technology companies based in the state of São Paulo," explained Carlos Américo Pacheco, chairperson of the FAPESP Executive Board, at the launch of a call that invited investment funds to submit proposals to the foundation for possible subscription of shares.

Funding for research infrastructure, a development strategy aimed at modernizing and expanding laboratories, accounted for 8.5% of total investment, with an emphasis on the Special Program to Support Research Infrastructure in the State of São Paulo. In 2023, FAPESP approved 56 proposals for the acquisition of

large equipment via three calls issued in 2022, with a total value of R\$450 million. In September 2023, another call was issued, worth R\$200 million, for the acquisition of small equipment.

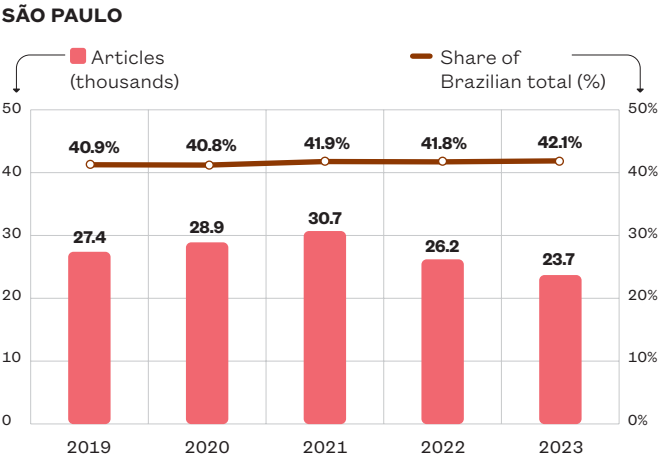
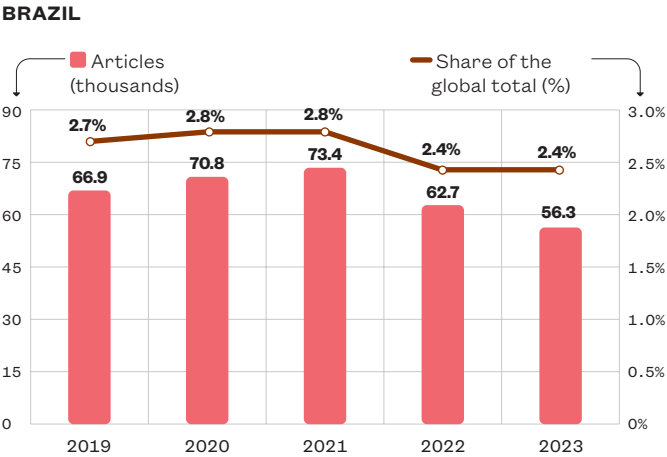
Research on strategic topics received 7.2% of the total funding to foster special programs on biodiversity, bio-energy, climate change, eScience, public policies, public education, and others. One of the highlights was the major investment in the Science Centers for Development (CCD), which received almost four times as much funding in 2023 as in 2022. Twenty-eight CCDs were created in the year that focused on fields such as health, agriculture, advanced manufacturing, smart cities, public safety, and the environment. The centers bring together researchers who seek solutions to challenges defined by São Paulo state departments. A new call for proposals for the program was issued in 2023.

Finally, the research communication, mapping, and review category, which includes science communication initiatives such as *Pesquisa FAPESP* magazine and *Agência FAPESP* as well as the production of indicators and statistical data on science, technology, and innovation in São Paulo, accounted for 1.8% of total funding.

The foundation's annual income comes from 1% of the State of São Paulo's tax revenue, which is transferred by the treasury as outlined in the São Paulo State Constitution, in addition to FAPESP's own revenue streams and joint research-funding agreements with institutions and companies. In 2023, the combination of these revenues totaled R\$2,303,470,454. The state treasury transferred R\$1,909,128,518.67, the foundation's own revenue streams provided R\$389,476,455.21, and funds from agreements amounted to R\$4,865,480.19. By the end of 2023, FAPESP had committed R\$2.6 billion in funding for the following years, R\$647,023,451.30 of which was through fellowships and R\$1,940,630,415.37 in grants, to allow ongoing projects to continue and ensure research-funding stability in the state. ●

The impact of the pandemic on the publishing of scientific articles

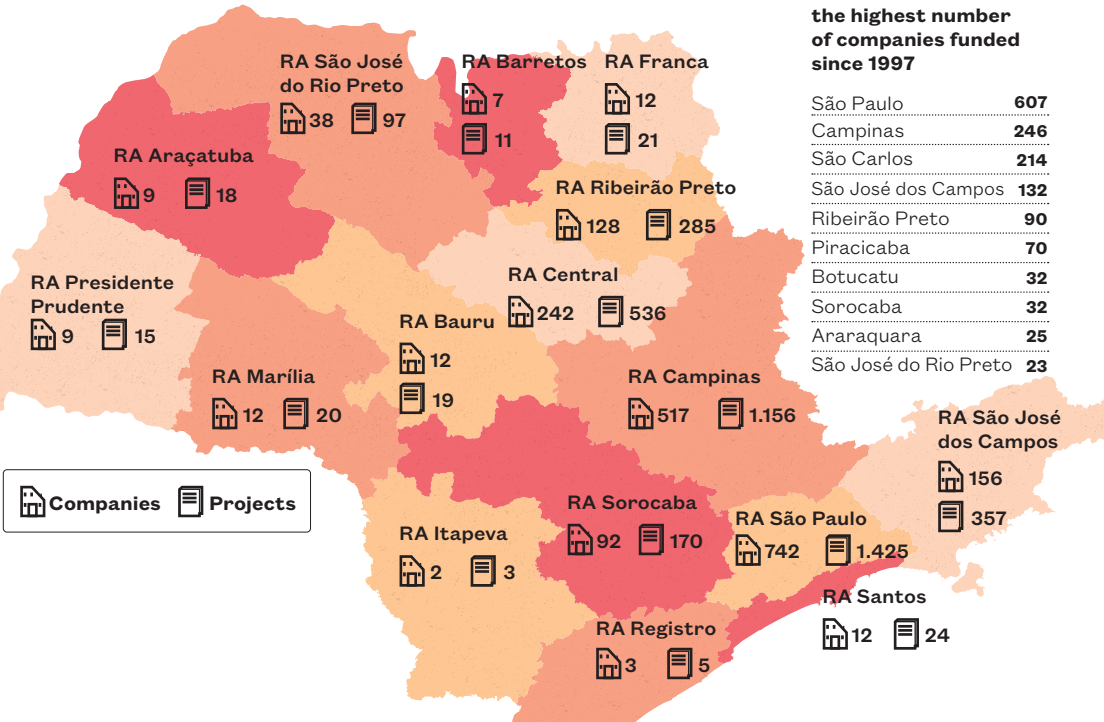
Number of articles and relative share (%)



SOURCE INCITES (CLARIVATE). DATA ACCESSED ON 07/17/2024

Geography of innovation in São Paulo

Locations of companies funded by the Innovative Research in Small Businesses (PIPE) program since 1997 by administrative region (RA)



SOURCE FAPESP ANNUAL REPORT 2023

SCIENTIFIC PRODUCTION



**For more
influential
journals**

The SciELO library is now a national initiative, reasserting Brazil's commitment to open-access academic journals

FABRÍCIO MARQUES — illustrations JULIA JABUR

Published in November 2024

The management and funding model of the electronic library SciELO Brasil, which is a groundbreaker in open access to academic journals created in the late 1990s, is being transformed with the goal of increasing the prestige and spread of scientific output in the country. Comprising 324 Brazilian journals across a range of knowledge areas and freely offering more than 500,000 scientific papers on the internet, the collection has been funded since August by a consortium of research support agencies, including the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES), the Brazilian National Council for Scientific and Technological Development (CNPq) of the federal government, and FAPESP.

The principal change is that FAPESP, which promoted the library's creation with a pilot program of 10 journals in 1997 and was almost solely responsible for its funding for over 26 years, has opted to take a small step back in the makeup of the consortium and will now cover slightly less than half (47%) of the costs, alongside the federal government through CAPES (48%) and CNPq (5%). The implications of this rearrangement go beyond the enhanced sponsorship of the collection curated by SciELO, which stands for the Scientific Electronic Library Online and sees the library transformed into a national-level initiative, with a role in Brazil's policies on open access and open science, a concept also encompassing the opening up and sharing of research data, principles, transparent practices, and solid collaboration.

A management committee has been set up with representatives of the three agencies and the library, which, in one year, will formulate new strategies and objectives. Suggestions for increasing the size of the collection and international visibility of the periodicals are on the ta-

ble. "One idea is to create quality metrics to help the journals augment the impact and spread of the articles they publish, setting awards for the best-classified titles in their knowledge areas to improve even further, and goals to raise the bar for the others," says FAPESP scientific director and geneticist Marcio de Castro Silva Filho.

The debate is still in the preliminary phase, but the proposal is to offer prestigious journals for Brazilian researchers from across different disciplines to disseminate their scientific work. "We want to strengthen the SciELO library so it has more journals and more impact," says CAPES president, physician Denise Pires de Carvalho. The collection continues to offer a digital platform for periodicals and ensures that they meet a list of quality criteria in line with international requirements related to the formatting of documents, the frequency of publication, the use of English as the language for articles, increasing the number of overseas authors, peer review, and the establishment of editorial boards.

"The aim is to promote professionalism, internationalization, and sustainability in the journals," explains Abel Packer, who created the collection in 1997 with biochemist Rogério Meneghini and is still its director. He notes, "The management transition is taking place with a minimum of impact on the library's operation". Instead of being managed by a researcher leading a project funded by FAPESP, as has been the norm since its inception, the library will now be governed by a management committee. The Federal University of São Paulo's Support Foundation (FAP-UNIFESP) will continue to lead project execution. Another change under discussion is to transform the library structure to give its journals the same kind of support as a publishing house would and engage more partners to contribute to its maintenance, such as ministries, research foundations, organizations, and companies.

According to Packer, this consortium of agencies has been possible thanks to FAPESP mobilizing to provide national scope to the initiative and the federal government being open to the idea. He explains, “Last year, CAPES began to adopt a policy for open access and open science and to formulate a wider strategy to deal with Brazilian scientific production appropriate to SciELO”.

An arm of the Ministry of Education, CAPES, is a federal government foundation responsible for funding scholarships and evaluating graduate programs in Brazil; the agency has long influenced the course of academic publications. Approximately two decades ago, CAPES adopted a scientific journal classification system known as *Qualis-periodicos*, which was used to assess output quality among students and teaching staff on Brazilian master’s and PhD pathways and define the number of scholarships for the programs. There have been recent changes in the evaluation model for use of this ranking (*see sidebar*), but retrospective analysis has shown that the CAPES classification discouraged graduate students and teaching staff from submitting manuscripts to most of the journals indexed on

SciELO because few of them were well regarded on the Qualis scale. “It’s important that more Brazilian journals become the first option for our researchers when publishing their work,” says CNPq president, physicist Ricardo Galvão.

In fact, only a small proportion of the journals in the collection have an impact comparable to that of internationally renowned titles in their areas. The impact of a journal is measured on the bibliometric indicators calculated by international platforms, which are based on the number of citations that its articles receive in other publications. One problem is that some Brazilian vehicles mostly divulge regional-level papers, which, while relevant, are rarely cited in noteworthy international journals on platforms, and there are authors who produce only incremental results, not attracting the interest of other researchers.

CAPES also deals with academic publications in another of its programs: the *Portal de Periódicos* (Periodicals Portal), which allows researchers from public institutions and universities to access content from thousands of international journals. To pay subscriptions or remunerate publishing houses that franchise their publications, the agency invested R\$546 million last year alone and has recently sought to close new types of deals with

Changes in sight

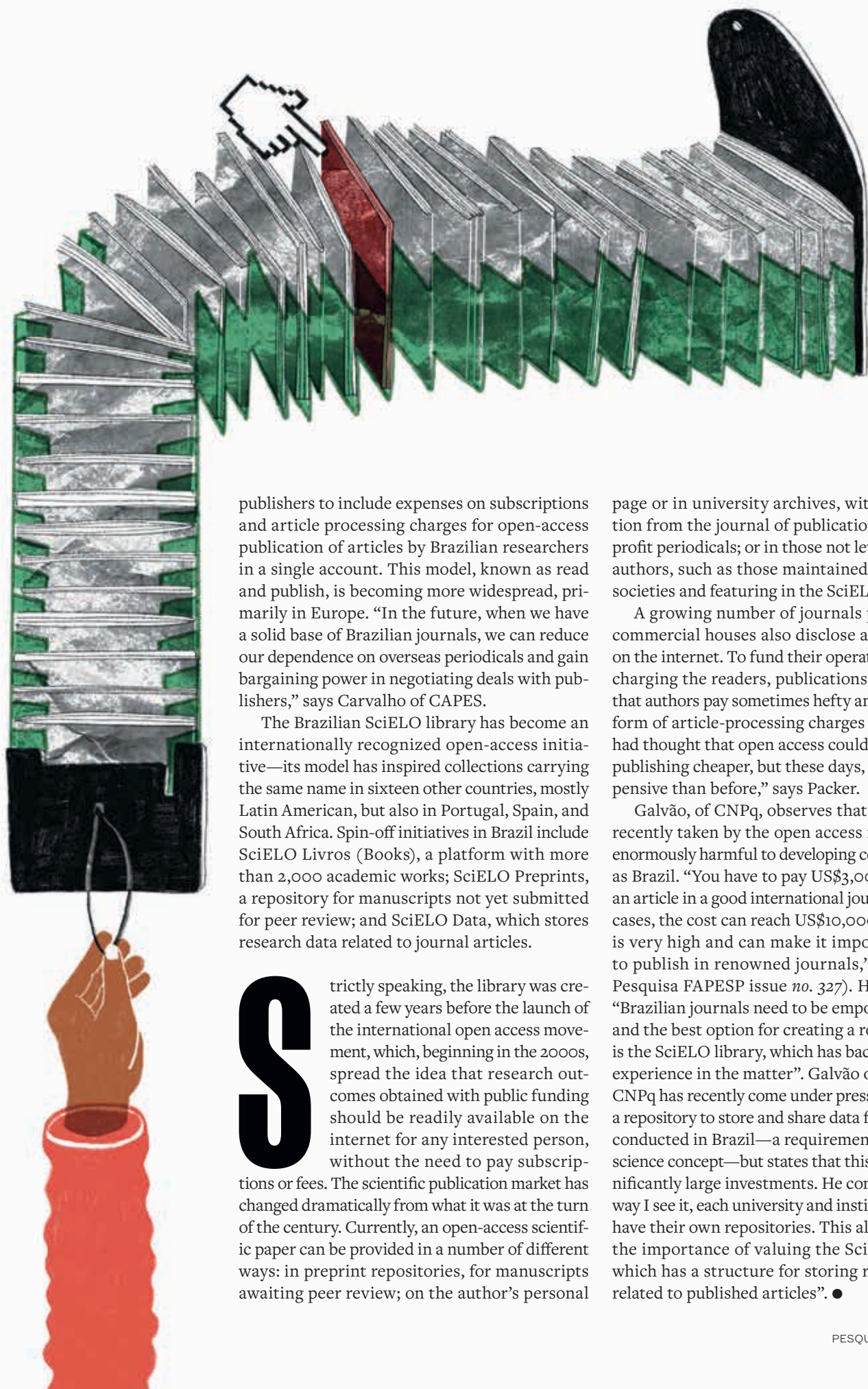
A system that ranks scientific journals will be replaced by classification with a direct focus on articles

The CAPES *Qualis-periodicos* system for classifying scientific journals will no longer be used to appraise the output of graduate students and teaching staff in Brazil during the quadrennium 2025–2028, according to the institution’s assessment director Antonio Gomes de Souza Filho. He explains, “This is a concept shift; evaluation now focuses on the quality and classification of the article, and not just the bibliometric performance of the scientific journal in which it was published”. The proposal, which was approved in early October by the CAPES Technical Scientific Higher Education Board, involves three new article classification procedures that may be combined depending on what the heads of each knowledge area define.

First, the bibliometric indicators of the journal in which the article is published, such as its citations, are taken into account. “Certain principles of Qualis continue, but we will no longer have that list of journals,” says the director. The second procedure involves combining article citation rates with their alternative indicators, or “altmetrics,” such as mentions on websites and social networks, and the number of downloads, in addition to qualitative criteria of the journal in which they are published, for example, valuing open-access journals of good quality or national relevance, per those indexed in the SciELO collection. There is no focus on metrics in the third procedure but rather on the qualitative evaluation of each

article, observing, for example, its scientific contribution and theoretical impact.

“With this widening of procedures, the new methodology makes for a more accurate appraisal of different articles published in the same journal. Instead of attributing them with the same classification on the basis of the impact of the journal, the specific contributions that each one promotes can be identified. We see this as an important development,” says Souza Filho. The methodology will be applied to the evaluation set to be completed in 2029. CAPES is expected to publish guidelines, with details of each procedure, in March 2025. SARAH SCHMIDT



publishers to include expenses on subscriptions and article processing charges for open-access publication of articles by Brazilian researchers in a single account. This model, known as read and publish, is becoming more widespread, primarily in Europe. “In the future, when we have a solid base of Brazilian journals, we can reduce our dependence on overseas periodicals and gain bargaining power in negotiating deals with publishers,” says Carvalho of CAPES.

The Brazilian SciELO library has become an internationally recognized open-access initiative—its model has inspired collections carrying the same name in sixteen other countries, mostly Latin American, but also in Portugal, Spain, and South Africa. Spin-off initiatives in Brazil include SciELO Livros (Books), a platform with more than 2,000 academic works; SciELO Preprints, a repository for manuscripts not yet submitted for peer review; and SciELO Data, which stores research data related to journal articles.

Strictly speaking, the library was created a few years before the launch of the international open access movement, which, beginning in the 2000s, spread the idea that research outcomes obtained with public funding should be readily available on the internet for any interested person, without the need to pay subscriptions or fees. The scientific publication market has changed dramatically from what it was at the turn of the century. Currently, an open-access scientific paper can be provided in a number of different ways: in preprint repositories, for manuscripts awaiting peer review; on the author’s personal

page or in university archives, with authorization from the journal of publication; in not-for-profit periodicals; or in those not levying fees on authors, such as those maintained by scientific societies and featuring in the SciELO collection.

A growing number of journals published by commercial houses also disclose articles freely on the internet. To fund their operations without charging the readers, publications now require that authors pay sometimes hefty amounts in the form of article-processing charges (APCs). “We had thought that open access could make article publishing cheaper, but these days, it is more expensive than before,” says Packer.

Galvão, of CNPq, observes that the pathway recently taken by the open access movement is enormously harmful to developing countries such as Brazil. “You have to pay US\$3,000 to publish an article in a good international journal; in some cases, the cost can reach US\$10,000. The outlay is very high and can make it impossible for us to publish in renowned journals,” he says (*see Pesquisa FAPESP issue no. 327*). He continues, “Brazilian journals need to be empowered more, and the best option for creating a robust system is the SciELO library, which has background and experience in the matter”. Galvão observes that CNPq has recently come under pressure to create a repository to store and share data from research conducted in Brazil—a requirement of the open science concept—but states that this requires significantly large investments. He concludes, “The way I see it, each university and institution should have their own repositories. This also highlights the importance of valuing the SciELO library, which has a structure for storing research data related to published articles”. ●

PHYSICS



Closer to **neutrinos**

IMAGE FERMILAB

Brazilian scholars have developed methods to purify liquid argon for the international DUNE project; the aim of this experiment is to detect the mysterious particles known as neutrinos

RENATA FONTANETTO

Published in October 2024

A Brazilian technological innovation will be used in the Deep Underground Neutrino Experiment (DUNE), which is a multibillion dollar project led by Fermilab, the leading particle physics laboratory in the United States, and is expected to be operational by the end of this decade. With the support of other research institutions and national companies, a team of physicists from the University of Campinas (UNICAMP) has developed a filtering method that removes impurities commonly found in liquid argon: nitrogen atoms.

When argon, which is a noble gas at room temperature, is maintained in chambers at -184°C , it becomes a liquid and can be used to achieve the following main objective of DUNE: to detect neutrinos, which are mysterious subatomic particles that have almost no mass, no electrical charge, and very little interaction with any material. Because of its relatively heavy atomic nucleus, argon is more likely to interact with neutrinos; these neutrinos are the second most abundant particles in the universe after photons (particles of light).

Liquid argon chambers are the most advanced way of detecting neutrinos. A larger volume correlates to a greater probability of interacting with the particles. For this reason, DUNE has four pools, each containing 17,000 tons of liquified argon. However, a number of contaminants in the tank could affect the experiment. The three most common contaminants are oxygen, water, and nitrogen. Effective molecular filters exist for the first two types of contaminants. However, filters are not available for nitrogen. Nevertheless, an invention was recently developed by a Brazilian team to address this issue.

Contaminants are generally found at levels of less than 10 parts per million (ppm); this amount correlates to very few micrograms in each gram of argon. “This level of impurity makes it impossible to carry out the experiment, and liquid argon of a higher purity is not available on the market,” explains physicist Pascoal Pagliuso, head of the

UNICAMP group that developed the new method. “DUNE requires very few molecules of impurities, in parts per trillion.”

DUNE is the largest neutrino experiment underway, with a cost of US\$3.3 billion. DUNE consists of a facility (the Long Baseline Neutrino Facility, LBNF) located at Fermilab and two detectors separated by a great distance; this facility is dedicated to producing a beam containing trillions of neutrinos. DUNE begins at Fermilab’s particle accelerator in Batavia, which is on the outskirts of Chicago, Illinois. Proton collisions produce smaller particles, which decay and create other particles. Neutrinos are among the by-products of these collisions and transformations of matter that occur in the accelerator. The LBNF is responsible for collecting the beam containing only neutrinos and sending this beam underground to the two detectors.

The first and smallest detector will be located next door, near the neutrino source at Fermilab, in a shallow cave, 60 m deep. The second, and much larger detector will be located 1,300 kilometers away inside an old abandoned mine in Lead, which is a town in the state of South Dakota. The Sanford Underground Research Facility (SURF) is currently located at this location and will house the detector in a cave that is currently being excavated 1,500 m underground. The facility is designed to prevent the neutrino beam in South Dakota from being disturbed by cosmic rays and neutrinos from space and surface disturbances. In 2020, with support from FAPESP, Brazilian researchers began developing an efficient method of purifying argon using a porous molecular sieve called a zeolite, which is based on the mineral aluminosilicate (composed of aluminum, silicon, and oxygen). The basic research that led to this technology originated from a study by Pagliuso’s team at UNICAMP that focused on the differences between nitrogen (N_2) and argon (Ar) and their response to the application of an electric field.

The practical aim of their study was to find a zeolite that could absorb (through adhesion or fix-

Liquid argon in a 35-ton capacity cryostat used at Fermilab

ation) only the nitrogen atoms without absorbing the argon atoms. Dilson Cardoso, a chemist at the Federal University of São Carlos (UFSCar) who specializes in zeolites, was essential in this pursuit. Computer simulations were carried out for materials that could be used as filters to separate nitrogen from argon. “The modeling allowed us to determine how argon circulation and purification systems behave, providing data that would help us design various parts of the system,” explains chemical engineer Dirceu Noriler, from UNICAMP. “We obtained information on the filters’ saturation time, the number of purifiers needed, and the number of cycles needed to achieve the desired purity.”

The most promising materials were then tested on a small scale in a controlled supercold environment. To this end, UNICAMP uses a liquid-argon purification test cryostat (PuLArC). This equipment was made of stainless steel, was capable of holding 90 liters of liquid to be purified and was built by the companies Equatorial Sistemas and Akaer. The team also used their experience at the cryogenic laboratory at the Brazilian Center for Research in Physics (CBPF) in Rio de Janeiro. The cryostat was similar to a double-walled thermos with a vacuum in the middle. This prevented the environment’s temperature from affecting the temperature inside the container.

According to materials engineer Fernando Ferraz, who is Akaer’s vice president of operations, the experiment enabled the creation of

3D models of the entire purification plant. “We carried out comprehensive simulations of the transport process, assembly, and installation of all necessary equipment for one of DUNE’s laboratories,” says Ferraz. “The process of controlling the purity of argon requires filtering cycles in the liquid and gaseous states, regeneration, and condensation.”

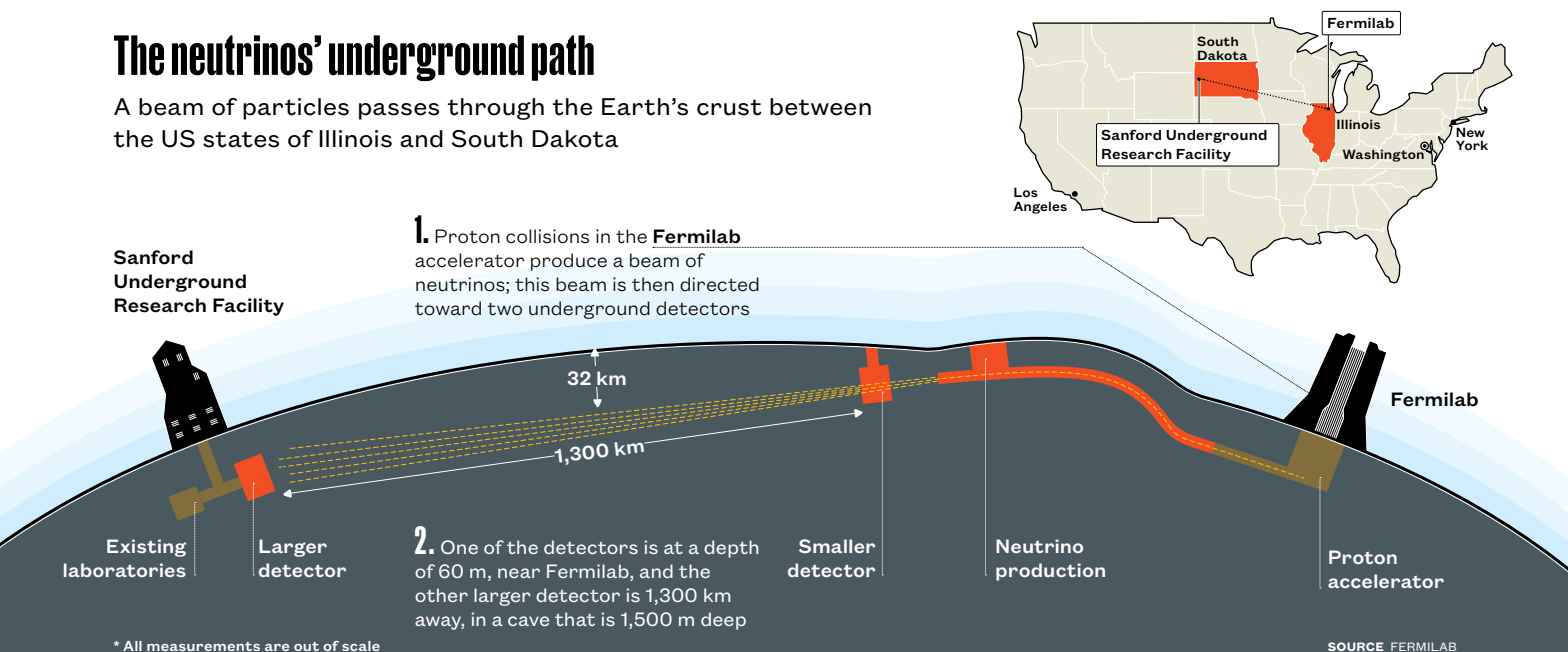
The results from the PuLArC tests were published in August 2024 in the *Journal of Instrumentation*. According to the publication, a filter made of a material known as Li-FAU, which contains lithium in addition to aluminosilicate, was the most efficient at capturing nitrogen molecules in liquid argon. With its use, the contamination in 100 liters of argon, which was initially between 20 and 50 ppm, was reduced to between 0.1 and 1 ppm in less than two hours. The filter was also tested by the DUNE team in a larger 3,000-liter tank, and the results were equally good.

The Li-FAU-based process is currently in the final stages of testing at ProtoDUNE, which is the prototype for DUNE at the European Organization for Nuclear Research (CERN), on the France-Switzerland border. At this location, the amount of liquid argon to be purified exceeds several tons. The new process has been patented and could be used for other purposes in the future. The process appears to be versatile and has the potential to be used to purify other gases, perhaps carbon dioxide, and liquids on an industrial scale.

The filter used to remove the contaminants from liquid argon is the second major contribution stemming from Brazil’s participation in DUNE, which has attracted 1,400 scientists and

The neutrinos’ underground path

A beam of particles passes through the Earth’s crust between the US states of Illinois and South Dakota





DUNE experiment cave in an old South Dakota mine where one of the neutrino detectors will be located

engineers from 200 institutions and 35 countries. The first contribution was a photon trap that captures the flashing light produced by the interaction of neutrinos with the argon atoms. Invisible to the human eye, the light has a wavelength of 127 nanometers. By storing these data, the trap enables researchers to examine the properties of neutrinos and reconstruct their trajectory in three dimensions. The device, called X-Arapuca, was created in the middle of the last decade by physicists Ettore Segreto and Ana Amélia Machado from UNICAMP. Its latest version, 2.0, is already in use in the United States.

The neutrinos generated at Fermilab will travel through the Earth's crust and reach the liquid argon tanks. The interaction with argon will release electrons and produce flickers of light. A uniform electric field will direct these electrons toward the electron detectors. The photons produced by the scintillations will then be captured by the X-Arapuca traps. "The photons produced in the scintillation allow me to calculate when the neutrinos arrived, which direction they came from, and how they interacted with the argon," explains Machado. We still do not know the mass of each of the three known types of neutrinos—muon, tau, and electron—or why they oscillate with each other as they move.

At the Sandford Research Center, where DUNE's largest detector will be located, at least two of the experiment's four modules will have X-Arapuca traps. These traps will form a photo-detection system around the liquid argon pools.

With funding from FAPESP, Brazil will be responsible for building some of the components and assembling and installing 6,000 X-Arapuca traps in one of the DUNE modules by the start of data collection, which is scheduled for 2029. "The biggest challenge will be to coordinate the process of building the traps in Brazil and receiving the rest of the components from abroad, without jeopardizing the experiment's schedule," says Segreto. "In Brazil, we will produce the mechanical parts and the optical filters, which are the most important elements for the device to function."

According to Sylvio Canuto, a physicist at the University of São Paulo (USP), investing in DUNE is important because DUNE has the potential to reveal details on neutrinos and, by extension, the formation of the universe. One of the most intriguing questions is why there are more particles than antiparticles in the cosmos. "In theory, we expected particles and antiparticles to have been created in the same proportion at the beginning of time. But, today, we see that the universe is mostly made up of particles. The origin of this mystery is attributed to the role of neutrinos, and today we are closer to unravelling it," says Canuto, who has followed Brazil's participation in DUNE since the beginning of the project and is an advisor to FAPESP's Scientific Directorate. The next step, according to the USP physicist, is to ensure Brazilian participation in the work of analyzing the data generated by DUNE to create a reference center in the country for Latin America. ●

The projects and scientific articles consulted for this report are listed in the online version.



The surprising faces of the Caatinga

The diversity of landscapes underpins the proposed new classification of semiarid environments

CARLOS FIORAVANTI

Published in October 2024

The dense, green forests surrounding the General Sampaio Mountains in Ceará resemble the lush, green landscapes of the Amazon. In the interior of Paraíba, Bahia, and Minas Gerais, imposing trees, such as the barriguda, which are so large that it takes four adults with open arms to reach around their trunks, are present. The rocky, sparsely vegetated *campos rupestres* of the Chapada Diamantina mountains resemble the Cerrado (a wooded savanna biome), although, like the other landscapes mentioned above, they are within the Caatinga (semiarid scrublands).

Covering 10 states in northeastern Brazil and reaching southeastern Brazil, the Caatinga is traditionally used to describe arid regions, but in reality, it is colorful and diverse. A proposed reclassification described in a 59-page article in the New York Botanical Garden's specialist journal *The Botanical Review* divides the Caatinga into 12 biogeographic subunits on the basis of an approach that considers the spatial distribution of



View of a forest from the top of an observation tower on the Borborema Plateau in Campina Grande, Paraíba, during the rainy season

PHOTO CARLOS ADRIAN RODRIGUES NOTA

endemic (exclusive) species, which is associated primarily with the soil type (*see map on page 44*).

“The Caatinga is actually many Caatingas,” summarizes botanist Daniela Zappi, one of the authors of the paper. Zappi has been visiting rural northeastern Brazil since 1987, mainly in search of cacti, which she studied for her master’s degree, PhD, and much of her 23-year career at Kew Gardens, UK, before she returned to Brazil to work at two research institutions in Belém and Brasília.

“The Caatinga is home to jaguars, cougars, and tapirs, amidst landscapes of stunning beauty,” adds biologist Marcelo Moro, leader of the study, who has been researching the region since his days as a biological science student at the Federal University of Ceará (UFC). He began documenting the geographic distribution of plant and animal species in the biome during his PhD and postdoctoral studies at the University of Campinas (UNICAMP), with funding from FAPESP.

In August 2016, he returned to UFC to work as a lecturer. “I realized that to map the entire region, we would need more people,” he said. He was joined by two geographers who specialize in mapping species: Rubson Maia from UFC and Luis Costa from the State University of Montes Claros (UNIMONTES) in Minas Gerais. He also onboarded four botanists: Zappi, retired botanist Nigel Taylor of the Royal Botanic Gardens, Kew, Vivian Amorim of the Federal University of Cariri, and Luciano Queiroz from the State University of Feira de Santana in Bahia. Zappi and Taylor are experts in cacti; Amorim is an expert in asteraceae, a large botanical family with 32,000 species; and Queiroz is an expert in legumes, a family of 23,000 species.

The group of botanists was tasked with delimiting the areas occupied by 328 plant species exclusive to the Caatinga. The cacti *Cereus jamacaru* and *Xiquexique gounellei* grow throughout the region but not in neighboring environments, whereas *Tacinga mirim*, another cactus, is found only in Ceará. *Borreria apodiensis*, a herb with small white flowers, is found only in Chapada do Apodi, on the border between the states of Rio Grande do Norte and Ceará, where many caves are present. A 20-centimeter spiny rat called *Proechimys yonenagae* and at least 30 lizard species are exclusive to the dunes of the São Francisco River in northeastern Bahia.

The work by Moro and his team is based on a previous classification that describes eight ecore-

gions, formulated by zoologist Agnes Velloso of the nongovernmental organization called The Nature Conservancy Brasil (TNC Brasil), forestry engineer Frans Pareyn, and agronomist Everardo Sampaio, who are all from the Northeast Plants Association (APNE); this work was published as a book by APNE in 2002.

The new division of the Caatinga used international nomenclature for delimiting areas of endemism (from largest to smallest: kingdom, region, domain, province, and district), which was made official in July 2008 by the *Journal of Biogeography* (*see detailed definitions in the online version of this report*). According to this classification, the entire Caatinga is considered a biogeographic domain. The three largest units are provinces and sub-provinces: the Chapada Diamantina Mountains and two caatinga subtypes (written here in lowercase because they are a part of the Caatinga): *stricto sensu* and sandy.

Stricto sensu caatinga, meaning “in a strict sense” in Latin, is located on land composed of crystalline (volcanic) rocks and stony and moderately fertile soil. It has three subdivisions (biogeographical districts) of its own—the North and South Sertaneja Depressions and the Borborema District—each with its own communities of animals and plants, although they are neighbors. The palm tree *Syagrus cearensis* and the lizard *Tropidurus jaguaribanus*, for example, can be found only in the North Sertaneja Depression; the shrub *Holoregmia viscida* and the legume *Tabaroa caatingicola* grow only in the South Sertaneja Depression; and the cactus *Pilosocereus chrysostele* and the lilac-flowered herb *Mimosa borboremae* live only in the Borborema District.

The second major unit of the Caatinga, the sandy caatinga, comprises a terrain of sedimentary rocks that give rise to nutrient-poor sandy soils. It is further divided into four subunits, each with its own species. The *Cearanthes fuscoviolacea* bulb is endemic to the Ibiapaba-Piauí district; the Araripe manakin (*Antilophia bokermanni*), a small and colorful bird, lives only in the rainforests of Araripe; and the *Scriptosaura catimbau* lizard is typical of the Tucano-Jatobá district and generally lives underground. The rodent *Trinomys yonenagae*, the lizards *Procellosaurinus tetradac-*



Mimosa boreboremae, found only in the forests of the Borborema plateau

Rodrigues's four-fingered teiid (*Procellosaurinus tetradactylus*), found in the São Francisco dunes

The landscapes of Brazil's semiarid region

Proposed division of the Caatinga on the basis of differences in the soil and endemism of plant and animal species

NEIGHBORING AREAS BUT WITH THEIR OWN FAUNA AND FLORA

- Caatinga coastline
- Caatinga province:
 - Stricto sensu caatinga subprovince
 - Sandy caatinga subprovince
 - Districts with many limestone outcrops
 - Chapada Diamantina province

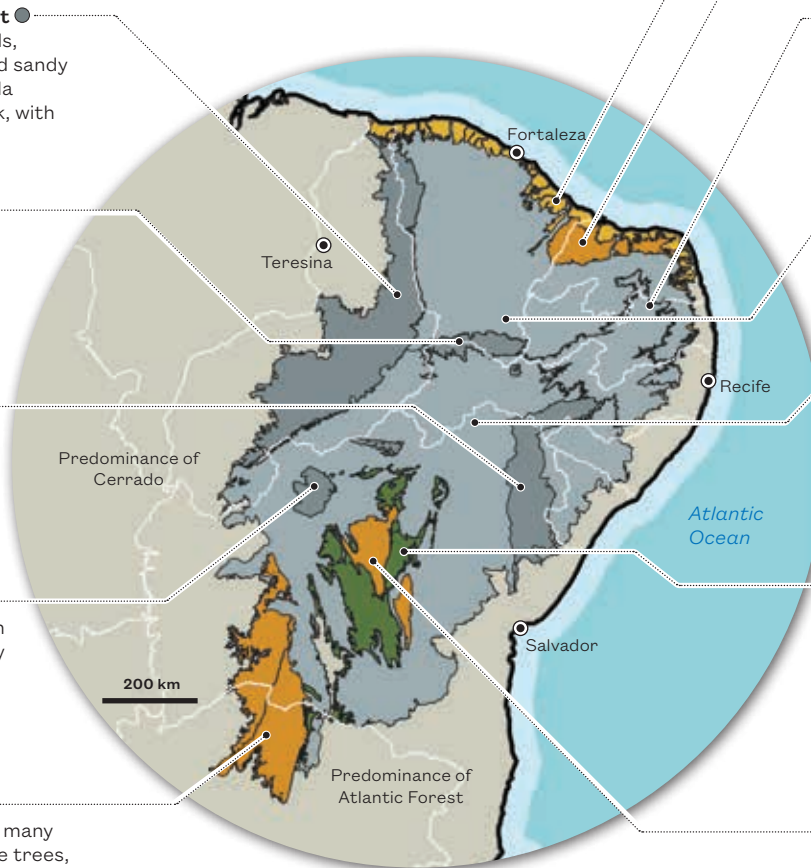
Ibiapaba-Piauí district ●
Predominantly lowlands, with some plateaus and sandy soil. Site of the Serra da Capivara National Park, with ancient cave paintings

Araípe district ●
Rich in fossils, with areas of Cerrado, rainforest, and sandy caatinga

Tucano-Jatobá district ●
One of the driest areas of the Caatinga, with deep sandy soils

São Francisco Dunes district ●
Continental dunes with endemic reptiles, many of which have adapted to live underground

Peruaçu district ●
Nutrient-rich soils and many caves occupied by large trees, such as barriguda



● **Caatinga coastline**
Driest stretch of the Brazilian coastline, with dunes, sandbanks, savannas, mangroves, and coastal forests

● **Potiguar district**
Soils originating from the decomposition of limestone, with many caves where biodiversity has yet to be studied in depth

● **Borborema district**
One of the highest-altitude areas in northeastern Brazil, with high-altitude marshes in the highest and wettest areas and Caatinga in the lowest and driest areas

● **North Sertaneja Depression district**
Typical low and flat terrain, with isolated mountains and shallow, stony soil

● **South Sertaneja Depression district**
Largest district in the Caatinga, with vast flat or undulating lowlands, mountain ranges, and shallow, rocky soil

● **Chapada Diamantina province**
Cerrado and rupestrine grasslands occupy the highest and coldest areas, whereas high-altitude marshes occupy the wettest areas and Caatinga occupies the driest areas

● **Irecê district**
Many caves. Owing to its nutrient-rich soils, much of the native vegetation has been replaced with agricultural crops

SOURCE MARCELO FREIRE MORO/UFC



Trees growing in a hole in the sedimentary terrain of Irecê, Bahia



Lear's macaw (*Anodorhynchus leari*), typical of the Brazilian semiarid Caatinga biome

3

4

Preserved forest in Itapajé, Ceará



5

tylus and *Eurolophosaurus divaricatus*, and the snakes *Typhlops yonenagae* and *T. amoipira* live only in the sands of the São Francisco dunes.

In both the *stricto sensu* and sandy caatingas, plants have adapted to the dry climate: many species lose their leaves at the beginning of the long dry season and quickly regrow them as soon as the first rains fall. They are also home to species found in the Atlantic Forest, the Cerrado, and dry areas of the Pantanal, such as the *Anadenanthera colubrina*, *Piptadenia retusa*, and *Astronium urundeuva* trees. “There are also small enclaves of dry forest in the Cerrado and the Atlantic Forest,” says Moro. According to him, dry forests in Bolivia, Venezuela, and Colombia also have species in common with the Caatinga in Brazil.

The province of Chapada Diamantina, which is part of the domain of the Caatinga, comprises high-altitude areas of Bahia, with Caatinga vegetation, tropical forests, savannas, and *campos rupestres*.

Another group of units comprising three more districts—Potiguar, Irecê, and Peruaçu—where there are many limestone outcrops (exposed rocks), cave networks, and animals about which little is known—were not distinguishable from one another on previous

maps. Some of these caves are within the Cavernas do Peruaçu National Park.

A final unit is isolated in the north, near the coast. Dubbed the Caatinga Coastline, it is home to plant species typical of the biome, as well as to the Cerrado and the Amazon, owing to higher levels of rainfall on the coast than further inland.

Moro and his team are mapping the enclaves of rainforests in highlands in the middle of the Caatinga, known as high-altitude swamps, where there are plant and animal species that are also found in the Amazon and the Atlantic Forest, as well as others that are endemic. Their plan is to finish the mapping process next year.

“Without knowing the conditions under which a species occurs in a given location, it is not possible to recover a degraded area, because the first question is ‘which species do we need to plant?’” explains UNICAMP biologist Fernando Martins, who did not participate in the research but has been studying the Caatinga for 30 years and was Moro’s doctoral and postdoctoral advisor.

“Furthermore,” he continues, “there are species able to live together and others that cannot due to competition. Species living in similar habitats can live together since competitive exclusion has already occurred. By associating species with regions of similar environments, a lot of essential information is obtained both in the theory of biology and in practice.”



1

Martins was pleased to see that the shapefiles (layers) of the map, which each identify the different types of environment within the Caatinga, were published digitally via open access, allowing any researcher to associate the data they collect with distinct areas. “This is very important to improve our understanding not only of how it was possible for such a diverse and regionalized biota to evolve in such a harsh environment but also of how to conserve this biodiversity and establish new conservation units capable of protecting the biota from climate change,” he says.

Cacti and other plants in Irecê, Bahia

Forests growing on the hillside and surrounding the inselbergs of Quixadá, Ceará

The biologist Marcela Cruz Moreira, advised by Martins during her master’s degree, compared species of angiosperms (flowering plants) from crystalline and sedimentary terrain in the Caatinga. The initial hypothesis was that sedimentary terrains, where the soil is deeper and better able to retain water, would house very different species. However, that was not the case. “Crystalline terrains, which we thought would be more selective, support a wider range of species than sedimentary ones, which might suggest the existence of highly complex evolutionary processes,” says Martins.

2



Marcelo Tabarelli, an ecologist from the Federal University of Pernambuco (UFPE), says, “The new study offers a more accurate view of the Caatinga, until now considered a single entity, although we who visit it know that it is not. This type of division, on the basis of the physical characteristics of the environment, should work well for plants, but I do not know if it will also apply to other taxonomic groups.”

Brazilian geographer José Maria Cardoso da Silva, from the University of Miami, noted, “The big question today is how much of the Caatinga’s patterns of endemism are the result of human pressure in the region.” Abandoned or current agricultural and pasture areas cover 89% of the biome—a stark contrast to what it must have been like thousands of years ago, with the same climate and soil conditions but before human occupation, according to studies led by biologist Helder Araujo of the Federal University of Paraíba (UFPB), published in *Scientific Reports* in October 2023.

“Deforestation has been widespread since the sixteenth century, especially in the east, in the North and South Depressions, and in the Borborema District,” says Araujo. “A lot of riparian forest has also been lost, and it is now rare alongside rivers like the São Francisco.” The main conservation units in the region are located in sandy caatinga, such as the Serra da Capivara National Park, the Raso da Catarina Ecological Station, and the Araripe-Apodi National Forest, which offer examples of some of the original environments of the Caatinga. ●

The research projects, scientific articles, and book consulted for this report are listed in the online version.

PHOTOS 1 DOMINGOS CARDOSO 2 MARCELO MORE

Protection against severe dengue

The candidate vaccine from Butantan reduces the risk of developing the severe form of the disease by 89%

RICARDO ZORZETTO

Published in September 2024

A technician performs a visual inspection of a batch of Butantan-DV



Compared to the control, a single dose of only 0.5 mL of the candidate vaccine against dengue from the Butantan Institute, Butantan-DV, provided lasting and elevated protection against the disease. It reduced the risk of people presenting symptoms (mild, moderate, or severe) of dengue by an average of 67.3%, even long after its administration—on average, for 3.7 years.

In an article published in August in the journal *The Lancet Infectious Diseases*, this level of protection is slightly lower than that reported in a study published in February in *The New England Journal of Medicine*. In that study, the overall decrease in symptom prevalence with the Butantan-DV vaccine was 79.6%, which was measured two years after administration. Now, after almost double the time, the immune response induced by the vaccine has decreased slightly but remains significant.

The new and most important data revealed here are that the vaccine provides increased protection in the most concerning cases. This vaccine reduced the risk of developing severe dengue or dengue with warning signs by 89% after virus exposure. Produced with an attenuated version of four varieties (serotypes) of the dengue virus, the Butantan-DV was 64.6% effective in reducing

risk in patients from 2 to 6 years of age, 70.6% effective for those 7 to 17 years of age, and 72.8% effective for those 18 to 59 years of age. It had an overall efficacy of 75.8% against dengue serotype 1 and 59.7% against serotype 2. Infections by serotypes 3 and 4 were not detected during the monitoring phase, which was concluded before the epidemic this year, and, for now, the level of protection provided by the vaccine against these two varieties of the virus is unknown.

“The peak of protection occurs during the first year of vaccination, after which a drop in the production of antibodies is normal. We will continue to monitor the data, but as of now, they suggest that it is not necessary to adopt a booster dose,” explains Fernanda Boulos, medical director of the Butantan Institute and coordinator of the clinical trials with Butantan-DV, the initial development of which was supported by funding from FAPESP.

In the tests, 10,259 people were selected to receive the vaccine, whereas 5,947 were administered an inactive compound (placebo). Neither the physicians nor the participants knew who was receiving what. The frequency of adverse events, generally local pain, fever, and red spots on the body, was greater among those who took Butantan-DV (53%) than among those who received the placebo injection (45.6%). Moreover, the rates of severe adverse events were similar in

the two groups: 6.2% in the first group and 6.6% in the second one.

“The vaccine remained highly effective and had solid safety data,” affirms physician and virologist Maurício Nogueira, of the School of Medicine of Rio Preto (FAMERP), lead author of the article in *The Lancet Infectious Diseases* and coordinator of one of the test centers. “We cannot afford to have a vaccine that is more or less safe,” he says.

According to Boulos, the new data are being submitted to the Brazilian Health Regulatory Agency (ANVISA), which is responsible for approving drugs and foods in the country, and the patent application for the vaccine has already been filed. The process of scaling up production and evaluating the quality of the vaccine is now underway. “Once this phase is complete, we will be able to calculate our production capacity better,” affirms the researcher. “If everything goes well, we hope that approval by ANVISA is granted in the first half of next year,” she says.

In January of this year, the Brazilian Ministry of Health included the first vaccine against dengue, Qdenga, in Brazil’s public health care system (SUS). Manufactured by the Japanese laboratory Takeda, the vaccine is intended for use in children aged 10 to 14 years. ●

The scientific articles consulted for this report are listed in the online version.



Port of Manaus, where Orov has been propagating

Oropouche on the prowl

New variant of virus multiplies rapidly and may facilitate disease transmission

GILBERTO STAM

Published in September 2024

A variant of the Oropouche (Orov) virus, which causes Oropouche fever, identified in January in the northern region of Brazil, may be responsible for the current spread of the disease throughout the country. As of August 19th, the Brazilian Ministry of Health registered 7,653 cases (the figure for 2023 was 831), including four cases of microcephaly and the death of two women, 21 and 24 years of age, neither of whom had any underlying conditions, with symptoms similar to those of dengue. These deaths were the first recorded globally due to this virus variant. On August 3rd, the Health Ministry confirmed the first fetal fatality from the virus, which was transmitted

from mother to son in the northeastern state of Pernambuco. Up to the 5th day of the same month, São Paulo State had confirmed five cases.

A study at the University of Campinas (UNICAMP), published in July on the medRxiv platform, illustrated that the variant known as Orov_BR-2015-2024, or new Orov, when inoculated in human cells, produces 100 times more virus in a 48-hour period than the first strain isolated in Brazil in the 1960s. When cultivated, this new variant formed pits in the cell layer that were up to 2.5 times larger than those formed by the previous strain.

“New Orov is capable of replicating more quickly and evading some of the antibodies produced by the immune system in response to previous infections,” observed virologist José Luiz Módena,

coordinator of the UNICAMP team. “As it is very quick to multiply, it can likely reach higher quantities in the blood of infected people or animals, potentially favoring infection of the transmitting insect.” The main transmitter currently is the maruim or paraensis midge (*Culicoides paraensis*), the larvae of which feed on organic material found in forests, parks, and plantations, usually on the outskirts of cities.

Módena and his team examined blood samples from residents of Manaus, Amazonas, collected in 2024. Among the 93 samples, 10 were from people with Oropouche fever. Two were sequenced and identified as new Orov, first described in January by the virologist Felipe Naveca of the Oswaldo Cruz Foundation (FIOCRUZ) Amazônia in Manaus.

The new strain was identified after sequencing 400 viruses collected during the outbreak in the Amazonian states of Rondônia, Roraima, and Acre between 2022 and 2024, as detailed in a preprint published by Naveca on medRxiv on July 24. “New Orov emerged between 2010 and 2014 after genetic rearrangement of three different viruses that circulated in Brazil, Peru, Ecuador, and Colombia,” says Naveca.

“This is a virus with a high capacity for killing the cells it infects,” says virologist Eurico Arruda, of the University of São Paulo’s Ribeirão Preto School of Medicine (FMRP-USP), where studies into Oropouche began in the 1990s. As Arruda detailed in a 2017 article in the *Journal of Medical Virology*, the virus infects leukocytes—immune system blood cells—through which it spreads throughout the organism. In a 2021 study published in *Frontiers in Neuroscience*, Arruda’s team and that of Adriano Sebollela, also of USP at Ribeirão Preto, demonstrated that Orov can multiply in sections of the human brain, causing an inflammatory response harmful to the organism.

Researchers interviewed by *Pesquisa FAPESP* agree that the new variant is not the only factor driving the Oropouche fever epidemic. Rising temperatures and shifting rainfall patterns due to climate change may have widened the maruim vector occurrence area. Moreover, deforestation in Amazonia may have driven insects into urban areas.

The intensification of diagnostic testing by the national network of the Central

Public Health Laboratories (LACENS) has also contributed to an increase in the number of recorded cases. Severe cases were diagnosed with the test developed by the FIOCRUZ Amazonia team, distributed to other countries through the Pan American Health Organization (PAHO).

“We started paying more attention to Oropouche when we found that a large proportion of outbreaks were not due to dengue, an illness with which it is easily confused,” states infectologist Julio Croda, of the Campo Grande FIOCRUZ regional office. He believes that the high numbers and geographical distribution of cases, with confirmed reports across 20 of the 27 Brazilian states, constitute an Oropouche fever epidemic in Brazil (see map). “This situation is very different from local outbreaks that occurred in North Brazil up to last year,” he comments.

The epidemic may propagate even further if Orov strains adapt to insects that are thriving in central urban areas, such as the southern house mosquito (*Culex quinquefasciatus*) and *Aedes aegypti* (transmitter of dengue). Virologist Pedro Vasconcelos of the Evandro Chagas Institute (IEC) in Belém, who coordinates the Brazilian Institute for Science and Technology for Emerging and Reemerging Viruses (INCT-VER), along with Arruda, plays down the possibility of *C. quinquefasciatus* becoming a transmitter of Orov, as laboratory experiments have demonstrated their lack of efficiency in transmitting the virus. Similar tests were not conducted with the new variant.



Maruim, transmitter of Oropouche

The risk of Orov spreading will be greater if the virus adapts to the *A. aegypti* (dengue) mosquito. “We need to monitor *A. aegypti* vector populations to see whether they are already carrying Orov,” suggests Vasconcelos. “As we know, this mosquito is difficult to tackle.”

RISK OF MICROCEPHALY

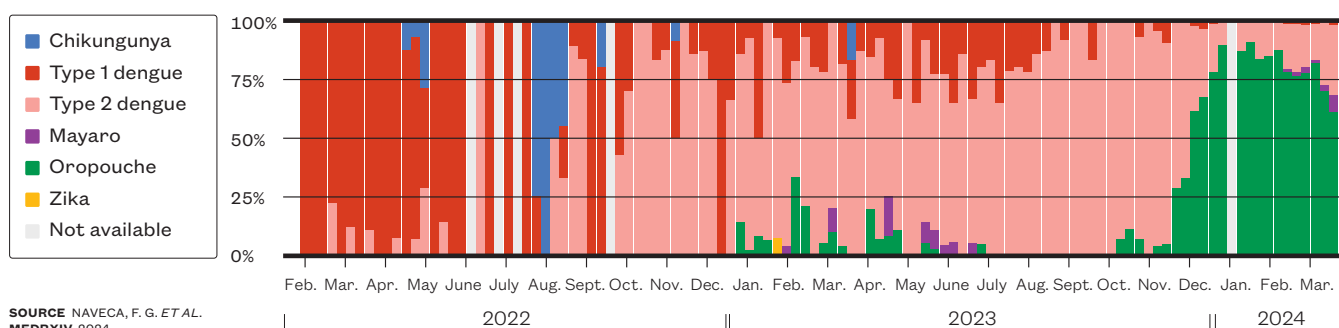
The IEC has revealed evidence of vertical transmission, where the virus is passed from mother to fetus, in four babies born with microcephaly and one stillborn baby after 30 weeks of gestation. These cases occurred in the states of Acre, Bahia, and Pernambuco.

“In mice, Orov is easily passed through the placenta and is highly capable of reaching the brain and deforming skull and fetal structures,” says Arruda. “Even from an infection in a mouse’s paw, the virus passes through the peripheral nerves and spinal cord, then arrives at the brain.” ●

The scientific projects and articles consulted for this report are listed in the online version.

Oropouche cases rising and dengue cases declining

Distribution of arbovirus cases diagnosed by molecular testing in Amazonas State between February 2022 and March 2024



SOURCE NAVECA, F. G. ET AL. MEDRXIV. 2024

A potential model of Alzheimer's disease

Brazilian researchers identify characteristic lesions of human neurodegenerative disease in the brains of capuchin monkeys

GISSELLE SOARES

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The capuchin monkeys are some of the most intelligent primates of the Americas. As they age, their brains can present the same types of lesions that characterize Alzheimer's disease. Researchers from the University of São Paulo School of Medicine (FM-USP) and the University of Brasília's (UnB) Primatology Center identified in two elderly animals—one 29 and the other 33 years of age—both beta-amyloid peptide plaques, formed by the buildup of these protein fragments around the neurons, and tau protein neurofibrillary tangles, which accumulate inside these cells and kill them. Neither plaques nor tangles were found in the brain of a nine-year-old young-adult animal. The findings were published in the journal *Scientific Reports* in March, and according to the authors, the findings may pave the way for capuchin monkeys to be adopted as a natural model to study the evolution and treatment of Alzheimer's disease, the most commonly occurring form of dementia in humans.

The idea of examining whether something similar to Alzheimer's disease also occurs in capuchin monkeys arose years ago, when the neurologist Ricardo Nitrini, FM-USP, a scholar of dementia epidemiology in Brazil and one of the coordinators of this research, met psychologist Maria Clotilde Tavares. A neuroscience and behavioral specialist, Tavares was at that time the coordinator of the UnB Primatology Center, home to the animals used in the study. "We awaited the natural death of these animals before evaluating the brain tissue," reports Nitrini.

With sizes varying from 35 to 48 centimeters (tail not measured) and weighing up to 4.8 kilograms, capuchin monkeys (*Sapajus libidinosus*) are among the most common nonhuman primates in the Americas. In Brazil, these monkeys live in practically all biomes, from the most humid, such as Amazonia and the Atlantic Forest, to the driest, such as the Cerrado (wooded savanna) and the Caatinga (semiarid scrublands). The monkeys attracted the interest of those investigating cognitive decline because, in addition



to being abundant, they have more sophisticated manual skills and behaviors than other monkeys do, such as the fabrication and use of tools to hunt or extract chestnuts. Furthermore, the encephalization quotient of these monkeys—that is, the size of their brain in relation to their body, an indicator of intelligence—is superior to that of most other nonhuman primates, and their brains are anatomically more similar to those of humans, with folds and grooves, than other monkey species, particularly those native to the continent.

“These animals have significant behavioral plasticity and adapt to different environments. I believe that, with this study, they will be more valued in the investigation of neurological illnesses,” says UnB’s Tavares. “Capuchin monkeys have a long life and can live to 40 in captivity. This will allow study into how brain degeneration affects the skills of these animals over time,” says Tiago Falótico, researcher and current president of the NGO Neotropical Primates Research Group (NeOPReGo). Falótico is exam-

ining the use of tools and cultural evolution of capuchin monkeys and was not part of the study published in *Scientific Reports*, conducted with FAPESP funding, of the Brazilian National Council for Scientific and Technological Development (CNPq), Alzheimer’s Association, and National Health Institutes (NIH) of the United States.

Until recently, neurologists and neuroscientists conjectured that Alzheimer’s disease was an exclusively human disease because there was no knowledge of other animals presenting the two typical types of lesions. This belief began to change in 2008, when Lary Walker and his team at Emory University in the U.S. reported, in an article published in *The Journal of Comparative Neurology*, the finding of beta-amyloid peptide plaques and tau protein tangles in the brain of a 41-year-old female chimpanzee.

Originating in Africa, these simians are, in evolutionary terms, the closest living primates to human beings, sharing a common ancestry from between 7 and 5 million years ago, with almost 99% identical genes. For this reason, from

Capable of making tools, capuchin monkeys may serve as a model to study cognitive decline

a biological standpoint, chimpanzees appear to be a good model for investigating the evolution and treatment of illnesses afflicting *Homo sapiens*, including Alzheimer's disease. However, maintaining a chimpanzee in the laboratory is expensive—according to some estimates, it can cost over US\$20,000 per year—and these animals are at risk of extinction (there are fewer than 300,000 in nature). Furthermore, little more than a decade ago, animal research directives became stricter. U.S. and European healthcare authorities have recommended that chimpanzees be used only to investigate human illnesses when there is no other model available or when it is not possible for ethical reasons to carry out these tests on people.

Given the impossibility of conducting certain experiments on human beings, researchers have advanced their understanding of the phenomena behind Alzheimer's disease and the quest for more effective potential treatments on the basis of initial studies with models that are not always ideal. The experiments generally begin with cell culture in the laboratory, enabling investigation of the gene activation pattern and modifications in the biochemical pathways occurring during disease, and progress to tests on rodents, almost always mice, which can indicate how the disease affects certain cognitive aspects. The variety of models used to understand how the disease takes hold and evolves is comprehensive, ranging from worms to fruit flies and from fish to other primates, such as lemurs and some monkey species. However, none of these models faithfully and completely reproduce what happens in the human brain.

Invertebrates, for example, are advantageous in certain situations because they share certain genes relevant to Alzheimer's disease and reproduce more quickly than mammals do. However, although invertebrates can be useful for learning about the biochemical pathways affected by disease, they are not ideal for studying treatments because the effects that the compounds produce in them are not always observed in animals with a more complex nervous system.

Rodents are by far the animals most commonly used in research, allowing the observation of certain behavioral effects of the disease, such as the loss of spatial memory, and certain benefits of potential therapies. However, rodent models do not enable full reproduction of the disease. "Mice and rats do not spontaneously develop beta-amyloid peptide plaques, nor tau protein tangles, although the first type of lesion occurs

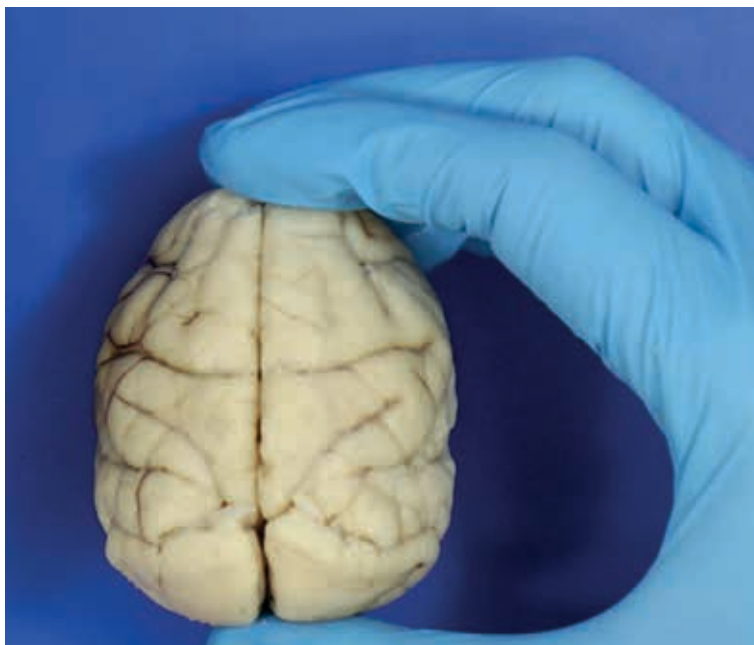
naturally in elderly specimens of a rodent known as the degus, found in Chile," says the biochemist Sergio Teixeira Ferreira of the Federal University of Rio de Janeiro (UFRJ), who investigates the causes of Alzheimer's disease.

For at least two decades, researchers have tried to address this limitation by artificially manipulating the animals. One of the strategies is to genetically alter rodents to produce beta-amyloid plaques or tau tangles. Another, developed by the UFRJ group, involves the injection of beta-amyloid peptide fragments (oligomers) directly into the mouse's brain. "This causes alterations very similar to those brought about by Alzheimer's disease, including memory loss," explains Ferreira.

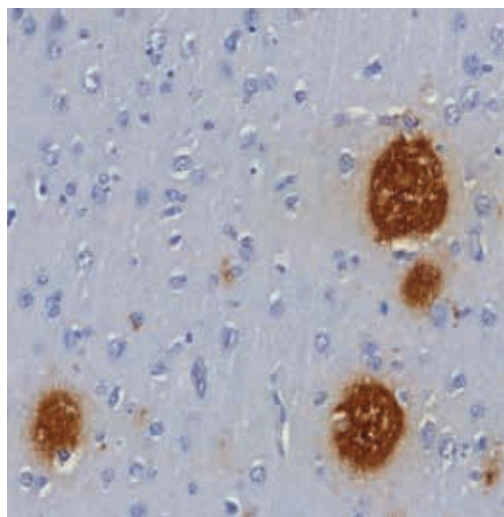
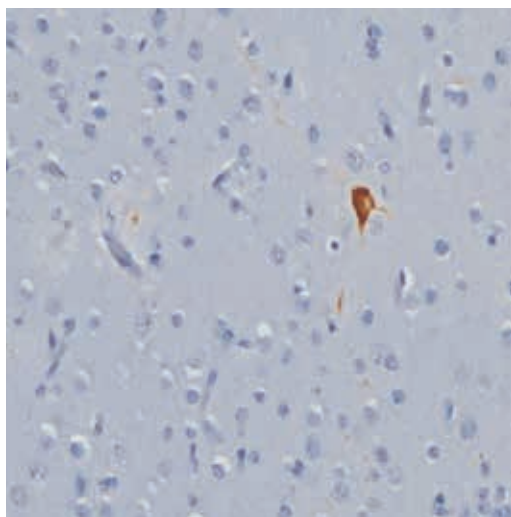
Even so, what happens with rodents can be very different from what happens in the brains of humans. For example, mice share only 85% of their genes with humans and have a much simpler brain than humans from an anatomical perspective. In rodents, the brain has a higher ratio of neurons than other cells, whereas in the human brain, the ratio is approximately one-to-one. Researchers estimate that this difference can make the disease develop in animals differently from the way it evolves in humans.

"Despite the success, the two-dimensional models of cells and animal models can capture only a fraction of the mechanisms of Alzheimer's disease because they are incapable of recapitulating the specific structure, function, and cell diversity of the human brain," wrote bioengineer Donghui Zhu and colleagues of Stony Brook University, in the U.S., in a 2022 review article published in the journal *Bioengineering and Translational Medicine*.

High encephalization quotient: capuchin monkeys' brains (*real image*) are proportionally large in relation to their bodies



PHOTOS ROBERTA DIEHL RODRIGUEZ/USP



Tau protein tangle (left) and beta-amyloid peptide plaques (right), both brown, found in the brains of capuchin monkeys

One way to close the gap between human disease and animal models is to use phylogenetically closer species that spontaneously develop the typical pathology of Alzheimer's disease. "Working with natural models allows observation of a more realistic condition, more similar to what happens in humans," says Analía Arévalo, a neuroscientist specializing in language, and a researcher at the Experimental Surgery Research Laboratory at FM-USP, who did not participate in the *Scientific Reports* study.

Even among primates, which have more complex cerebral architecture than rodents do and are evolutionarily closer to humans, the perfect model has yet to be identified. Beta-amyloid peptide plaques have been detected in rhesus monkeys (*Macaca mulatta*), cynomolgus macaques (*Macaca fascicularis*), white-tufted marmosets (*Callithrix jacchus*), and gray mouse lemurs (*Microcebus murinus*), but these plaques do not always occur simultaneously with tau protein tangles, although the animals may present cognitive deficiencies. Another difference is observed in the brain regions where these plaques and tangles form. In humans, plaques and tangles occur more frequently in the hippocampus, the area associated with memory acquisition and consolidation, whereas in marmosets and rhesus monkeys, these structures are more common in areas associated with emotions (limbic system) or hearing (temporal cortex).

In these two aspects, capuchin monkeys may provide a closer model of human disease: the monkeys present beta amyloid plaques and tau protein tangles, and these lesions affect both the cortex and the hippocampus, with researchers also identifying signs of neuroinflammation,

which also occurs in humans. "No other New-World primate used in the studies is as intelligent as the capuchin monkey, which makes its own tools and can remain in a biped position for quite some time," says neuroscientist Roberta Diehl Rodriguez, lead author of the *Scientific Reports* study. "Moreover, the New-World primate presents more similar neuropathological alterations to those of human beings," she states.

For capuchin monkeys to effectively become model animals for Alzheimer's disease, however, researchers need to confirm the occurrence of lesions in a greater number of animals and characterize how these lesions affect behavior. "This will be the most interesting aspect to compare with the disease profile in humans," says Arévalo.

Even if it works, there is a limitation. The disease in these animals may take decades to develop. To overcome this issue, the neuroscientist Fernanda De Felice's group at the UFRJ is seeking an artificial Alzheimer's disease model in young primates. Ten years ago, she and colleagues from Queen's University in Canada successfully reproduced in cynomolgus macaques—currently endangered—the damage that Alzheimer's disease causes in humans through the injection of beta-amyloid oligomers into the animals' brains. These oligomers accumulate in the frontal cortex, the hippocampus, and other areas associated with memory and cognitive aspects. More recently, the group induced lesions in young rhesus monkeys between 3 and 5 years of age to avoid waiting for the natural evolution of Alzheimer's disease. "If we can reproduce the disease in young animals," says Ferreira, of UFRJ, and husband and collaborator of De Felice, "it would make the work much easier." ●

The scientific project and articles consulted for this report are listed in the online version.

Stings neutralized

Close-up of an
Africanized bee
hive at a UNESP
research center
in Botucatu

Scientists developed a serum for the stings of Africanized bees, which are responsible for 30,000 accidents per year in Brazil

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In Vitória da Conquista, Bahia, a 55-year-old man died after suffering more than 100 bee stings. A similar case was reported in Santa Cruz do Rio Pardo, in the interior of São Paulo State. The victim, 84, was also stung more than 100 times. In Bertioga, on the coast of São Paulo, a 58-year-old postman on his rounds was attacked by a swarm of bees and later died. All of these fatal cases occurred within just a few days of each other in February and March of this year.

“In Brazil, there are approximately 30,000 accidents involving Africanized bees every year, resulting in approximately 150 deaths,” says veterinarian Rui Seabra Ferreira Júnior, director of the Research Center for Poisons and Venomous Animals (CEVAP) at São Paulo State University (UNESP), Botucatu campus, citing data from the Brazilian Ministry of Health. He adds that official figures are likely underestimated. “Patients are often admitted to intensive care with acute renal failure due to the venom, and the cause of death, which usually occurs days later, is not recorded as an accident caused by bees,” he explains.

Ferreira is the author of a patent for a new anti-bee sting serum, which, according to clinical studies, could reduce the number of such deaths. Granted by Brazil’s National Institute of Industrial Property (INPI) in November 2023, the patent is the result of research conducted by CEVAP, the Butantan Institute in São Paulo, and Vital Brazil in Niterói, Rio de Janeiro. The INPI’s report attested to the originality, inventiveness, and industrial applicability of the technology.

Phase 1 and 2 clinical trials were carried out on 20 adult patients who suffered between seven and 2,000 bee stings. This stage of testing took three years, from 2016 to 2018, and was performed at Botucatu Hospital in São Paulo and Nossa Senhora da Conceição Hospital in Tubarão, Santa Catarina.

“Like other antivenom serums, ours is administered by an intravenous drip. We created

a protocol on the basis of the number of stings the patient suffered,” says Ferreira. He explained that because the venom enters the body acutely, the medication must be administered as quickly as possible to prevent damage.

The results of the clinical trials, led by the CEVAP researcher and coauthor of the patent Dr. Benedito Barraviera, were published in the journal *Frontiers in Immunology* in 2021, indicating that the serum is safe and effective. All patients improved after receiving the inoculation. Only two patients experienced mild adverse effects, such as skin irritation. Next, the team will test a larger number of patients to statistically confirm its initial observations.

“We are going to carry out the phase 3 clinical trial on a more representative sample of the Brazilian population, with approximately 400 participants, all of whom will have been stung by Africanized bees,” says Ferreira. “The project is ready and awaiting funding from the federal government, as there are no private pharmaceutical companies producing antivenoms in Brazil.” After this stage, which is expected to last approximately two years, if the results are positive, the researchers will be able to request approval of the serum from the Brazilian Health Regulatory Agency (ANVISA).

FATAL VENOM

Two decades of study resulted in a serum that could be the world’s first antidote specifically for stings. Ferreira began researching serotherapy in 2002, during his master’s degree in tropical diseases at UNESP’s School of Medicine and at CEVAP, under the supervision of Barraviera.

His PhD focused on the same topic and was also supervised by Barraviera, who today heads the Center for Translational Science and Biopharmaceutical Development at CEVAP. Funded by FAPESP through the Science for Development Centers (CCD) program, it supports anti-apitoxin serum studies.

“It was in 2006, during my postdoctorate in immunochemistry at Butantan, that I began studies to create the serum,” says Ferreira. Africanized bees are the result of crossbreeding between the European honey bee (*Apis mellifera*) and the African subspecies *Apis mellifera scutellata*, which was introduced in Brazil in 1956 because they are more productive and resistant to diseases. In 1957, approximately 25 queen bees escaped from a quarantined apiary in a eucalyptus forest at the Rio Claro School of Philosophy, Sciences, Languages, and Literature in São Paulo, which later became part of UNESP in the 1970s. The escapees crossbred with European subspecies, resulting in an Africanized polyhybrid bee characterized by a strong defensive instinct. Reports of swarm attacks in Brazil and other countries on the American continent came soon after.

According to Ferreira, there are two distinct types of bee-sting accidents. The most common accident involves only a few stings. In these cases, in individuals who are not allergic, the result is a local inflammatory reaction that resolves itself without the need for medical intervention. People sensitive to the venom, however, can experience a severe allergic reaction, with a risk of anaphylactic shock, requiring immediate treatment with allergy medications.

The second type involves attacks en masse and results in many stings, which can be fatal. “In such large quantities, the venom can cause acute respiratory and renal failure,” explains Ferreira. The damage is caused by two components of the venom, a peptide called melittin and an enzyme called phospholipase A2 (PLA2), which have both a cytotoxic effect (damaging cells) and a hemolytic effect (destroying red blood cells).

To date, the effects of these substances have traditionally been treated with antihistamines and anti-inflammatories, which can reduce symptoms but may not be enough to prevent death. The new serum, which must be stored at a temperature of 2–8 degrees Celsius, is designed to address the root cause of the problem, neutralizing the venom.

To produce serum, scientists have had to overcome several biotechnological hurdles. One is the need to obtain a high quantity of bee venom of standardized quality. To achieve this, they installed devices in hives consisting of copper wires connected to small glass plates. When bees touched the wires, they were subjected to a small electrical shock—not enough to harm them but enough to cause them to deposit a drop of venom on the plate. The study was carried

Effectiveness against necrosis

Study confirms that serum for recluse spider bites reduces risk of skin damage

The Butantan Institute recently concluded an observational study on the effectiveness of a serum designed to prevent tissue necrosis caused by recluse spider (*Loxosceles* spp.) bites. For decades, Butantan has manufactured trivalent antiarachnid serum, which is also indicated for accidents involving bites by Brazilian wandering spiders (*Phoneutria* spp.) and scorpion (*Tityus* spp.) stings. However, no scientific study has proven its effectiveness at reducing the risk of skin necrosis caused by recluse spider venom. Bites by Brazilian wandering spiders and scorpion stings do not generate necrosis. A recent study published in the journal *PLOS Neglected Tropical Diseases* in 2022 filled this knowledge gap.

“Since the 1970s, experimental studies with animals have shown that of the treatments available, the one that best prevented necrosis was a serum specifically made to target recluse spider venom,” says Dr. Ceila Malaque, a researcher at Hospital Vital Brazil and coordinator of the scientific study. “However, there was previously no research on humans like the study that was carried out at Butantan.”

Over the course of six years, 146 patients treated at Vital Brazil were evaluated, with 74 patients receiving serum while the remaining patients not receiving serum. The results showed that the antivenom had a protective effect against necrosis, especially when it was administered within the first 48 hours after the bite.



The recluse spider, whose bite can kill the skin

“We wanted to do the same analysis with patients admitted up to 36 hours after the accident, but unfortunately, it was not possible to study this cutoff. Victims of spider bites are often unaware that they were bitten and seek medical care too late, more than two days after the accident,” laments Malaque



A trap created by CEVAP researchers to collect bee venom (above) and a vial containing the developed serum



out with another patent author, biologist Ricardo Orsi of UNESP's School of Veterinary Medicine and Animal Science.

The next challenge was to standardize the purification and isolation process of the venom's main components—the compounds that cause the death of people and animals who suffer multiple stings. Daniel Pimenta, a biomedical scientist from Butantan, took part in this stage. “The technological secret behind the serum is the fact that it is made only with antibodies to neutralize the destructive action of melittin and phospholipase A2,” says Ferreira. “All the other components, which can cause pain and allergies, are removed.”

This approach resulted in greater well-being and safety for horses inoculated against the venom so that they would produce antibodies for the serum, thus eliminating the risk of allergic shock. The serum was made at the Vital Brazil Institute in conjunction with veterinarian Luís Eduardo da Cunha Ribeiro, coauthor of the patent, by giving horses three or four purified doses of the venom toxins in small concentrations, which triggered an immunological response. A sample of the animals' blood was taken to separate the part containing the antibodies, which were then isolated and concentrated to form the antivenom.

The UNESP scientist does not yet know how much each dose will ultimately cost. “Manufacturing antivenom serums is expensive because the process includes caring for the animals that produce the venom and for the horses that will be immunized, on top of the cost of the biotechnological production process,” he explains. “Our hope is that the Ministry of Health will negotiate with public laboratories that produce serums so that it can be distributed free of charge through the national health system.”

In parallel with the development of serum, another project involving UNESP scientists is

attempting to quickly classify the clinical condition of sting victims by severity. The diagnostic kit for beekeeping accidents, a novel concept, is being developed by the startup Triad for Life, with funding from FAPESP's Innovative Research in Small Businesses program (PIPE).

The biologist Bruna Cavecci Mendonça, who is part of the Triad for Life team, explained that the standard procedure consists of counting the stingers present in the victim's skin, performing clinical observations of the patient, and performing nonspecific biochemical tests. “These are currently the only sources of information to assess the degree to which a person has been stung. In addition to being a time-consuming process, the amount of venom injected can vary from one bee to the next. Some stings can even be empty, meaning they inject no venom.”

Using a drop of the patient's blood, the new kit measures the volume of phospholipase A2 toxin, which is part of the bee venom. The analysis is based on an immunoenzymatic test (a lateral flow immunochromatographic assay) that uses venom antibodies as a reagent. “A result is provided by a color change within 10 minutes, a little like a pregnancy test,” says the researcher.

Because the test measures the concentration of phospholipase in the bloodstream, it can also be used to monitor treatment and assess whether a given approach is working. A patent was filed in 2022. The company is currently producing more antibodies in order to manufacture the first batch of kits, which will be tested in hospitals. ●

The Amazon revealed

Researchers meet with people from the rainforest to discuss how laser scanning can provide information about the region's past and contribute to its future

MARIA GUIMARÃES, reporting from Manaus

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“Indigenous knowledge is like archaeology: the more you dig, the more you find,” historian Soleane Manchineri, ombudsman at the Acre State Public Defender’s Office, told an auditorium full of researchers from across Brazil, relatives (as Indigenous people refer to each other), and representatives of other traditional Amazonian communities (*quilombolas* and *beiradeiros*). The phrase was emblematic of the meeting, which was held at Museu da Amazônia (MUSA) in Manaus from October 18 to 21.

The idea was to share the preliminary results of the Amazon Revealed project, which is led by archaeologist Eduardo Góes Neves of the Museum of Archaeology and Ethnology at the University of

Lidar virtually removes trees, as if with an X-ray vision, revealing “honeycomb” structures in Terra do Meio, Pará

São Paulo (MAE-USP) and involves using a remote sensing technology called Lidar (light detection and ranging) to map the ground by bombarding it with thousands of laser beams. Funded by the National Geographic Society and with authorization from local communities, flyovers in areas impacted by deforestation and infrastructure were conducted for this study.

Lidar can be used to create a detailed three-dimensional image of a forest’s structure, with its trunks, branches, and leaves, as well as showing what is below that structure. This is what interests Neves, who wants to highlight the importance of the Amazon as a type of historical and biocultural heritage formed by the peoples of the rainforest over the last 13,000 years.

This researcher has worked in the region for almost 40 years and has witnessed deforestation and destruction on a major scale. She has also helped educate archaeologists, many originally from the Amazon region and several now working at universities and research centers in Brazil’s northern states. The project began in five areas where researchers with ties to Neves were already carrying out research in partnership with local communities, who agreed to join the initiative: Acre/Southern Amazonas, Middle Guaporé, Tapajós, Terra do Meio, and Marajó. Neves runs the project together with Brazilian archaeologists Bruna Rocha of the Federal University of Western Pará (UFOPA) in Santarém, Cristiana Barreto of the Emílio Goeldi Museum of Pará (MPEG) in Belém, Carlos Augusto da Silva of the Federal University of Amazonas (UFAM), Italian director of MUSA Filippo Stamparoni, and Morgan Schmidt, an American researcher currently doing a postdoctorate at the Federal University of Santa Catarina (UFSC).

The project is based at MUSA, which was founded by physicist Ennio Candotti and since 2011 has been situated in a 100-hectare area of the Adolpho Ducke Forest Reserve, just outside the capital of Amazonas. With spaces integrated into the forest, the museum presents aspects of the region’s flora, fauna, and human population. It was thanks to the Amazon Revealed project that the auditorium where the meeting took place was built. The space includes a display on Amazonian archaeology and another showing the early results of the project, as well as information about a technical reserve for storing archaeological, ethnographic, and fossil artifacts. “This has helped MUSA become a hub for archaeological research,” says Stamparoni.

The goal is to conduct collaborative, co-designed, and coproduced science with local communities. “The project is not ours; the demand for demarcation studies is theirs,” says Francisco Pugliese, an archaeologist from the University of Brasília (UnB). “We are just the instruments.”

The informed consent essential to carrying out the research in each area comes from long and detailed conversations between archaeologists and inhabitants. Indigenous peoples’ knowledge also guides researchers to locations rich in history and helps them interpret their findings, an uncommon practice in academia.

LASER VISION

In Acre, the use of Lidar to view the ground beneath the forest has increased the number of known geoglyphs—enormous geometric figures that ancient peoples marked on the ground using ditches and walls, often interconnected by ancient roads. Flyovers have been conducted in the area, revealing that these archaeological sites, which are well documented in the southern part of the state, also exist north of the Purus River, including in the state of Amazonas. One of the newly documented geoglyphs is a square large enough to encompass the Maracanã stadium, with roads spreading out of two sides, as shown by Portuguese topographer and geometer Hugo Pires of the University of Porto, Portugal.

Pires joined the project recently, after hearing about it on an episode of the podcast *Rádio Novo Apresenta* hosted by Letícia Leite, who is responsible for communication for Amazon Revealed. He works with documentation of archaeological heritage in several places around the world and has developed a method for processing Lidar data called the morphological residual model (MRM). With this technique, depressions and elevations captured in the microrelief by Lidar are colored, generating an image that reveals the complexity of the terrain with greater contrast, thus highlighting archaeological details.

The first person to spot geoglyphs in the Brazilian Amazon was paleontologist Alceu Ranzi, now retired from the Federal University of Acre, when flying into Rio Branco on a commercial flight in 1986. It took him almost 20 years to begin studying them. “In 2000, I realized that archaeologists were not working on this,” he says, and he began flying over the area to look for them. “Then came Google Earth. I spent hours on the computer looking for geoglyphs.” He was approached by Francisco Nakahara, who did not know him but had seen a documentary on the subject and wanted to look for the designs. Ranzi taught him how to find them, and Nakahara began sending him coordinates. “He is an 84-year-old man, and he has identified more than 300 geoglyphs,” says the paleontologist. Approximately one thousand geoglyphs have been recorded in deforested areas in the state.

A more surprising discovery was made in the municipality of Costa Marques, Rondônia, on the border with Bolivia. The region is home to In-

digenous people and people of African origin in the *quilombola* community of Príncipe da Beira, descendants of slaves taken to build a fortress to defend against Spanish invasion at the end of the eighteenth century. The importance of the fortress declined over the nineteenth century and was eventually abandoned. According to Carlos Augusto Zimpel, an archaeologist from the Federal University of Rondônia (UNIR), the ruins contained European objects, such as crockery and cutlery. The building was listed by the National Institute for Historical and Artistic Heritage (IPHAN) in 1950. Lidar revealed the remains of a nearby Portuguese village, which was named Bragança on an eighteenth-century map, but the location of which was previously unknown. “I have walked by without noticing the village,” Zimpel said. Images of the terrain’s relief were used to reconstruct the layout of streets, identifying geoglyphs and ditches near the village that indicate a much older occupation, with remnants of ceramics near patches of *terra preta* (dark earth

originating from indigenous soil management practices). “The Amazon Revealed project could stimulate archaeological tourism,” noted Santiago Cayaduro Pessoa, who lives in the community and works as a guide at the fort.

The Kuikuro of the Upper Xingu are partners in the archaeological study, but at first, they did not accept the airplane flyovers because they did not want data about their sacred sites to be made public. Instead, they have been collecting images in specific locations using a drone equipped with Lidar, which was piloted masterfully by the technical geographer Kumessi Kuikuro. “The Kuikuro have a glowing reputation in the Xingu Indigenous Reserve in terms of mapping, and they are often sought out by other ethnic groups,” says MPEG archaeologist Helena Lima. Under the agreement, the data collected belong to Indigenous people, who grant varying levels of access to the researchers.

One archaeological site near the village features mounds, ditches, squares, and roads. The ditches run to the river and connect all the sites in Upper Xingu, according to Schmidt, who has been working in the Amazon since 1998. Owing to the presence of *terra preta*, the intentional creation of which he recently described in coauthorship with Kuikuro Indigenous people, he believes that the mounds arranged in a circle were trash piles behind each of the houses. The houses, which were made of clay and wood, were unable to withstand the test time. However, the compost heaps were.

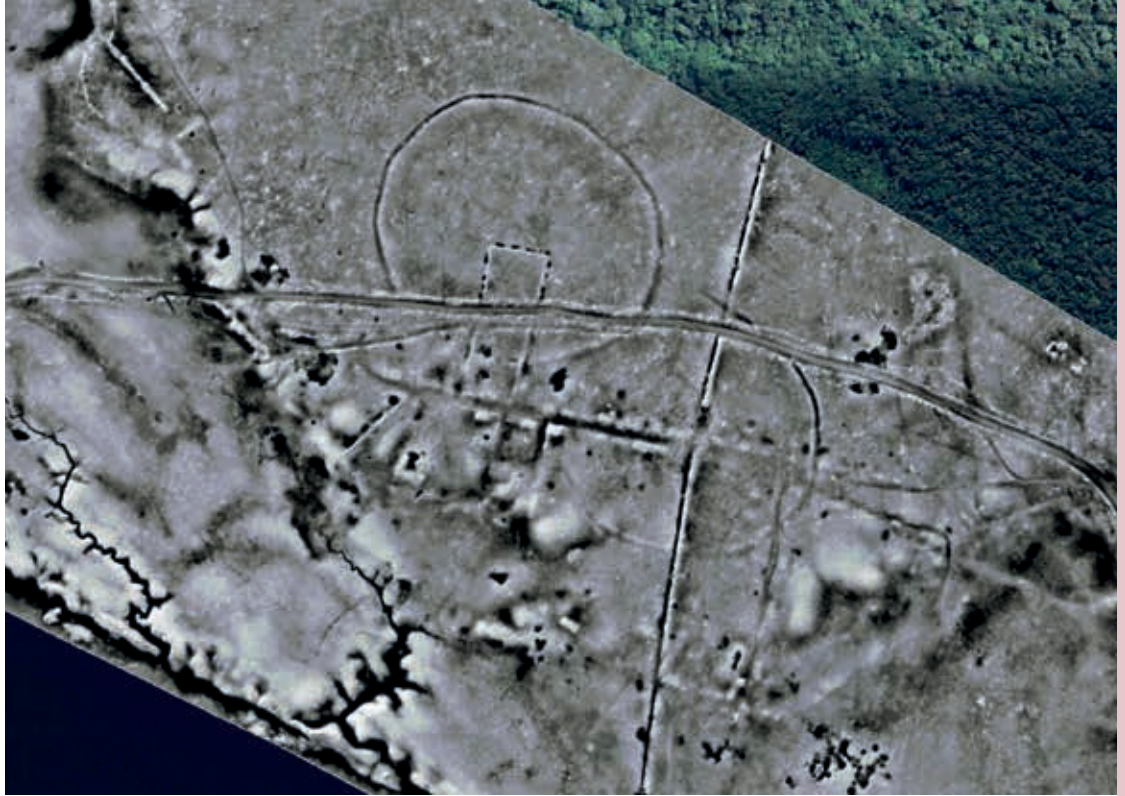
In the spirit of joint research between archaeologists and Indigenous groups and in support of decolonialism, all material excavated on Tupari land is being kept in the village of Palhal, Rondônia, where there are plans to create a museum. Three-dimensional scanning will be used to make replicas for researchers. One of the struggles faced by the inhabitants of Palhal is the demarcation of their land since the village is not within the contiguous Rio Branco Indigenous Reserve. “Our ancestors are buried there,” explains Adilson Tupari.

The findings may lead to meaningful approaches for protecting the rainforest and improving the lives of those who reside there, since archaeological sites are protected by the Brazilian constitution. “We gave IPHAN a good problem to solve,” jokes Neves, from the MAE-USP. The dilemma is that there is no mechanism to register archaeological sites on the basis solely of lidar images, and the technology has already begun to reveal more areas of interest than can feasibly be visited and excavated. The rules and regulations for registration need to be adapted and expanded, and even then, the problems will not be

Tupari and Jupaú delegations at the meeting, held at MUSA, and a community meeting with the village of Alto Jaru, Rondônia, as part of the project



Between two circular geoglyphs, straight lines and slight reliefs are remnants of the village of Bragança on the banks of the Guaporé River



overcome. “Regulatory protection does not necessarily mean physical protection,” says archaeologist Thiago Berlanga Trindade, head of IPHAN’s Data Registration Service. The community and society need to be involved in oversight.

People living in rainforests—whether Indigenous, quilombola, or riverside communities—are facing urgent, violent threats. There have been reports of genocide, rape, deadly epidemics, roads being built through protected lands, river pollution, destruction of sacred sites, illegal farming (with monocultures of soy, maize, or rice), land grabs, logging, mining, and droughts resulting from climate change and hydroelectric dams. Climate change has been a more unexpected blow, in addition to the succession of violence experienced since Europeans arrived in the region. “We are experiencing a drought that my grandparents never thought they would see,” says Marquinho Castro dos Santos of the Mayoruna people. Santos teaches at the school in his village of Marajaí, which is located on the banks of the Solimões River in the municipality of Alvarães. Through this erosion of basic rights, they also lose access to their heritage. The *beiradeira* community—resulting from marriages between Indigenous people, descendants of enslaved people from Africa, and riverside people—from Terra do Meio, in southern Pará, is losing its history, with little access to education and no acknowledgment of the local culture. There is also a *bei-*

radeira community living on the banks of the Tapajós River in Montanha and Mongabal, as well as a representative of the Munduruku Indigenous people. The archaeologist Vinicius Honorato of the UFOPA has highlighted that archaeology helps strengthen traditional knowledge.

Antônio Enésio Tenharin, a municipal secretary for Indigenous Peoples in Humaitá, south of Amazonas, says that in the quest to recover and preserve their heritage, his people filed a civil suit in 2014, demanding the creation of a heritage center and the publication of educational material on the impacts that construction of the Trans-Amazonian highway had on the Tenharin and Jiahui Indigenous peoples.

The meeting in Manaus brought all of these groups together and reinforced archaeology’s position as an ally. “We are in this battle together,” said Vilson Tenharin, from the village of Marmelos in southern Amazonas. The four-day event was crucial to the formation of a network that the leaders intended to strengthen by promoting further meetings. They say that archaeological work needs to come from the peoples of the forest, including through the training of archaeologists of Indigenous, quilombola, and *beiradeira* origin.

Seen as a science that focuses on the past, archaeology has now presented itself as a window for thinking about (and safeguarding) the future. For researchers and people who live in the rainforest, the Amazon is not revealed; it is revealing itself. ●

The journalist traveled at the invitation of the Amazon Revealed project.



Disputed territories

Mineral extraction for energy transition aggravates land possession and water access conflicts in Brazil

CHRISTINA QUEIROZ

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The race for the exploration of minerals that have been dubbed critical for the energy transition is exacerbating existing socioenvironmental conflicts in the Brazilian mining and metals sector. These natural elements are needed to develop a low-carbon economy and to produce components used in the manufacture of batteries, electric vehicles, solar panels, wind turbines, and others. They are also largely used in activities not related to the energy transition. A total of 101,000 people across 15 states were impacted by transition mineral extraction, which led to 380 confrontations in the country between 2020 and 2023. The Amazonia Legal region, a collective of nine Brazilian states, had the most disputes, with 46.3% of incidents. Individual analysis by state revealed that Pará and Minas Gerais accounted for 66.7% of the clashes. The data were collated in a study published in August by the Observatory of Mining Conflicts in Brazil, an initiative by



Bento Rodrigues, in the Mariana region (MG), in 2016: the subdistrict was badly affected by the Samarco dam collapse

researchers from institutions across the country, social movements, and nongovernment organizations (NGOs).

Another survey conducted by the same observatory in 2023 indicated that since 2020, legal and illegal extraction throughout the mineral sector has led to between 850 and 950 conflicts and affected approximately 1 million people per year. The document also shows that in 2022, the states of Minas Gerais (37.5%), Pará (12%), and Alagoas (10.1%) reported the highest proportion of people affected by the disputes.

One of the research authors, geographer Luiz Jardim Wanderley of Fluminense Federal University (UFF), stated that conflicts are considered the reactions of those affected by social and environmental impacts and by situations of violence, including working under slave-like conditions, rapes, accidents, threats, attempted murders, and deaths. Wanderley states, “During the pandemic, the mineral sector registered countless labor violations for not having adopted efficient policies to safeguard the health of workers”. The “Annual Report of the International Council on Mining and Metals” indicates that in Brazil, 43 employees of companies associated with the entity died as a result of workplace accidents in 2021. The figures for 2019 and 2020 were 287 and 44, respectively.

Wanderley explains that to be included in the mapping, the conflict must have given rise to reactions among the population, including legal proceedings, protests, letters of repudiation, or grievances published in newspapers. He specifies that “Confrontations not causing this type of response are not counted in our figures”. In the survey studies, data from the Pastoral Land Commission (CPT), which has been recording agrarian conflicts since 1985, and the Indigenist Missionary Council (CIMI), both entities of the Catholic Church, were analyzed. Data on this type of incident that were recorded in documents produced by NGOs, grievances manifested by social movements, press news, and other means were also used.

The study of minerals needed for energy transition covered conflicts involving 31 elements, including aluminum, barium, boron, cadmium, cobalt, copper, lithium, manganese, niobium, and nickel. According to information from the Brazilian National Mining Agency (ANM), the extraction value of these minerals between 2013 and 2022 rose from R\$27.7 billion to R\$38.6 billion, resulting in real-term (inflation-deducted) growth of 39%. In the same period, the mineral sector numbers as a whole increased from R\$243 billion to R\$266 billion in deflated values—a 9.3% rise.

The conflicts that have been identified in this survey may overlap: the most prevalent type

covers land-use disputes, which are involved in 59.2% of incidents, followed by conflicts over water access (39.4%), health issues (16.4%) and labor disputes (12.4%), which explains Wanderley. Energy transition minerals copper and bauxite were the most significant causes, accounting for 25.3% of the incidents each. Moreover, the market value of these elements escalated between 2020 and 2023. “The data suggest that there is a correlation between the intensity of mineral extraction, its sale value, and the incidence of conflicts,” he says.

Barcarena (PA), Canaã dos Carajás (PA), and Craíbas (AL) occupy the top three spots on the list of towns and cities with the highest number of disputes involving the mining of important elements for the energy transition. “The overall trend is a rise in per capita revenues across municipalities hosting mining activity.

However, social development and a reduction in inequalities have not gone hand-in-hand with these increases,” says João Marcio Palheta of the Federal University of Pará (UFPA), who did not participate in the study.

Predominant in Barcarena is the extraction and processing of bauxite, which is used in the production of aluminum. In 2018, local people complained of tailings (mining waste) leaking from a dam, which contaminated rivers and igarapés (tropical creeks). The primary mining activity in Canaã dos Carajás is iron and copper ore extraction, which has displaced local communities. “This situation generates conflicts over land losses and impacts lifestyles among communities, primarily indigenous and riverside dwellers,” says Palheta. The municipality is also a focal point for labor disputes with mining companies; the region is home to the largest iron-ore extraction projects in the history of Brazilian-founded multinational giant Vale, with an output capacity of 120 million tons per year.

Palheta studies four municipalities hosting mining projects in Pará State: Barcarena, Parauapebas, and Paragominas, as well as Canaã dos Carajás. He states that the municipalities with the highest per capita gross domestic product (GDP) in Brazil frequently cover locations with large-scale industrial or extractive projects, such as those in Parauapebas. Palheta reports, “Nevertheless, as occurs across other towns and cities with these characteristics, Parauapebas is blighted by poverty and lacks basic sanitation”.

He believes this to be due to a lack of transparency in the use of funds from the Financial Compensation for Mineral Exploration (CFEM),

which is levied on mining profits. “CFEM resources can only be invested in healthcare and education, but there is a lack of control mechanisms to identify where the money is in fact spent,” states the geographer. On the basis of reports published by the Observatory of Mining Conflicts in Brazil, the Municipal Human Development Index (IDH-M) falls short of the national average in 27 of the 50 municipal areas most mined in Brazil. With respect to the Gini index, which measures inequalities, 34 of these 50 municipalities have worse indicators than the world’s 14th most unequal country, the Republic of the Congo.

According to the organization, the groups that are most affected by energy-transition mineral exploration are small rural landowners (involved in 23.9% of occurrences), mining company workers (12.1%), and indigenous peoples (9.8%), whereas international mining corporations (46.3%) and medium-sized national companies (33.6%) predominated among organizations implicated in conflicts. “The rising value of energy-transition minerals increasingly attracts smaller mining operations to locations with little background of mining exploration, further complicating the situation,” says UFF’s Wanderley.

His observation is backed by economist Beatriz Macchione Saes of the Federal University of São Paulo (UNIFESP). On the basis of research into the relationships among economic development, mining, and conflicts triggered by the activity, she provides an example of the situation in the Jequitinhonha Valley, Minas Gerais State. Since

1991, the region has received projects for the exploration of lithium, a metal used, among other applications, in electric car batteries; however, an increasing number of mining companies are interested in taking action. She notes, “Four companies are currently seeking approval for lithium exploration initiatives in the region, and their possible installation may worsen conflicts with local communities”.

The production engineer Bruno Milanez of the Federal University of Juiz de Fora (UFJF) and a specialist in mineral sector corporations explained that after the 1990s, these companies began to adopt practices to mitigate socioenvironmental impacts. The researcher provides the example that, up to 1989, mining companies operating in Oriximiná, state of Pará, discharged their extraction waste directly into the rivers in a procedure accepted in those days by the Brazilian State. He notes, “Those companies are still trying to remedy the damage resulting from this activity to the present day”. In the 2000s, mining corporations installed dams to contain tailings; these days, this waste can be dry-stacked after passing through filtration systems. “However, even with reduced impacts, the negative socio-environmental effects cannot be escaped,” he states. Milanez reports that some companies recognize the issue and no longer use the term ‘sustainable mining,’ noting that “the most common concept currently used by the sector is ‘responsible mining.’ Companies acknowledge that negative impacts are inherent in their activities, but maintain that damage reduction strategies can be adopted”.

In a statement issued by email, the aluminum multinational Hydro Group noted that operations carried out by companies receiving their investments in the country are monitored and audited, with the commitment “to being good neighbors to communities.” One of these operations is Mineração Paragominas in Pará, which has adopted a technique for returning inert bauxite mining tailings to brownfield areas. The company states that this method enables reconstruction of the original land topography and reduction of erosion risk, minimizing environmental impacts. Multinational Anglo American, which extracts diamonds, mercury, copper, and nickel, explained via email that, in 2019, it created a plan to improve education and health care systems among host communities in Brazil.

Saes, of UNIFESP, says that the commodity boom between 2020 and 2014 was marked by a worsening of the incidence of this type of con-

Residents of Barcarena (PA) protesting in 2018 against process waste discharge into the local river by an aluminum refinery





A copper mine in Canaã dos Carajás (PA), one of the municipalities with the highest number of conflicts associated with energy-transition minerals

flict in the country. During that period, Brazil recorded a considerable increase in the demand for primary goods and raw materials, including minerals. “Iron ore was one of the most in-demand commodities in the international market, with exports soaring from 100 million tons in 2000 to 300 million tons in 2015,” she adds, going on to say that the rise in conflicts is proportional to the expansion of mining activities.

In the first decades of the twenty-first century, two of Brazil’s largest environmental disasters, caused by iron ore extraction, took place. In 2015, a dam collapse at the mining complex of Samarco (controlled by Vale and Anglo-Australian giant BHP Billiton) in the region of Mariana (MG) killed 19 people and spilled 39 million m³ of toxic sludge, affecting the Doce River and several communities across the states of Minas Gerais and Espírito Santo over more than 600 kilometers (km). According to the Atlas of the Brazilian mineral problem (*Atlas do problema mineral brasileiro*), published in 2023, the triumvirate formed by Samarco, Vale, and BHP Billiton was responsible for the greatest number of conflicts between 2004 and 2020, with a total of 462 conflicts occurring during that period.

In 2019, the collapse of a Vale dam in Brumadinho (MG) killed 270 people and contaminated the Paraopeba River basin, which is 510 km long. In an emailed communication, Vale stated that R\$37.7 billion was earmarked for remediation of the damage caused by the disaster, with 70% of this total applied to date. The company further states that mechanisms have been in place since 2023 to hear about the needs of affected populations.

In Mariana, the reparation process undertaken by Samarco allocated R\$37 billion for reparation and compensation of damage arising from the disaster, of which R\$17.48 billion has been paid out in indemnities and emergency financial aid. In a statement sent by email, the company affirmed that the resettlement of impacted communities was 85% complete. Despite these agreements, victims are seeking recourse under the UK legal system, as BHP, one of Samarco’s controllers, is Anglo-Australian in origin. In 2023, a London law firm filed a damage indemnity claim to the value of R\$230 billion for 700,000 victims of the disaster.

A researcher examining the development of these reparation efforts, sociologist Raquel Oliveira, of the Study Group into Environmental Matters at the Federal University of Minas Gerais (UFMG), notes that the process has led to inter-

nal tensions between the affected communities. Oliveira explained that prior to the disaster, many families shared their lands with their relatives. Grandparents, parents, and children, for example, would build their houses on the same smallholding, maintained as inheritance land. She adds, “Nonetheless, these reparation measures do not fully take into account the complexity and dynamics of these land arrangements, leading to revision of domestic agreements and hampering the recognition of new family units”.

Anthropologist Gabriela de Paula Marcurio, who is conducting doctoral research at UNIFESP with a fellowship from FAPESP, highlights another issue—the mining companies implicated in these disasters not considering relevant losses by the afflicted communities when they cataloged the harm caused by their activities: forced changes in lifestyle and the time spent managing problems caused by the dam collapse, such as attending meetings. As part of her doctoral work, Marcurio is researching the influx of companies looking to exploit iron ore, copper, and phosphate from the region of Juazeiro, in the *sertão* (badlands) of Bahia State, an area in which the mineral frontier is expanding. She states that the people of the area start to feel the effects even before the formal installation of a mining company. “Small-scale farmers have complained about the presence of drones, and

outsiders walking around their properties without consulting them,” she says.

Milanez, of the UFJF, emphasizes that the Brazilian subsoil is a federal government asset; thus, people’s houses may be expropriated to enable projects in the sector to progress. Furthermore, according to ANM, those who obtain authorization to install a mine in a certain location will hold exclusive rights to exploit the land in question. This engineer states that “In many instances, these factors will put conflicts in a situation characterized by an imbalance of power”.

With an end to articulating and disseminating strategies to constrain or prohibit mining in certain areas, a group of researchers, social movements, local communities, and NGOs created the platform *Territórios Livres de Mineração* – TLM (Mining-Free Lands) in 2022. This repository carries information on steps taken in line with municipal legislation, plebiscites, and public consultations that were successful in putting the brakes on undesirable projects in vulnerable areas, exemplified by the town of Muriaé (MG), whose residents thwarted the installation of a bauxite exploration project in the district of Belisário in the surrounding area of Serra do Brigadeiro State Park. “Public pressure caused local councilors to approve of Law Bill 192, classifying the region as water heritage, and impeding mining activity in the location,” Milanez concludes. ●

The project, scientific articles, reports, and book consulted for this report are listed in the online version.



Photo from 2019 showing the destruction caused by the Vale dam collapse in Brumadinho (MG)



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